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DOSIMETRIC ASSESSMENT AND BIOHEAT ANALYSIS OF ELECTROMAGNETIC EXPOSURE IN PEDIATRIC TISSUES

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Abstract- Widespread deployment of Wi-Fi and cellular networks has significantly increased human-made electromagnetic (EM) pollution, disrupting natural background levels and spurring debate over the long-term health risks of continuous high-frequency exposure. Quantifying how radiofrequency radiation interacts with biological tissue is complex and frequency-dependent, making accurate assessment essential for public health and biomedical engineering. This research presents a numerical analysis of thermal effects across relevant communication bands using a child anatomical model, reflecting the heightened vulnerability of developing systems and higher tissue water content in children. Simulations carried out in FDTDLab using the finite-difference time-domain (FDTD) method modeled wave propagation and dielectric heating based on real-world field measurements. We quantified energy deposition using whole-body and localized (1g and 10g) Specific Absorption Rates (SAR), alongside thermal modeling for localized hotspots and systemic stress. Comparing these results with IEEE and ICNIRP guidelines offers crucial evidence regarding EM safety in pediatric populations.

Keywords: FDTD simulation, Pennes' bio-heat equation, Heterogeneous anatomical model, Numerical dosimetry, Maxwell's equations

INTRODUCTION

The rapid proliferation of wireless communication infrastructure over recent decades has drastically altered modern urban environments, giving rise to continuous, human-made radiofrequency electromagnetic field (RF-EMF) exposure. The dense deployment of cellular base stations accelerated by fourth- and fifth-generation (4G/5G) systems alongside household Wi-Fi technology has significantly elevated background electromagnetic radiation in populated areas [1]-[4]. Because higher frequencies, multi-antenna configurations, and denser networks modify energy deposition patterns, public and scientific concern regarding the long-term biological consequences of chronic RF exposure has intensified [5]-[9].

Electromagnetic radiation interacts with biological systems through both thermal and non-thermal pathways. Thermal effects stem from dielectric energy absorption causing tissue temperature elevation, whereas non-thermal mechanisms involve potential physiological or cellular alterations (e.g., oxidative stress, shifts in cell membrane permeability, or altered intracellular signaling) occurring without significant heating. Because these mechanisms can take place concurrently, isolating their distinct biological impact remains challenging. To evaluate energy absorption quantitatively, the Specific Absorption Rate (SAR), measured in W/kg, serves as the primary dosimetric metric [10]-[15].

Exposure assessment relies on a combination of empirical field measurements, analytical techniques, and computational electromagnetic simulations [13]-[17]. Numerical modeling, such as the finite-difference time-domain (FDTD) method, is particularly valuable for mapping wave propagation and energy deposition across complex biological geometries. International health and regulatory organizations, including the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and the Institute of Electrical and Electronics Engineers (IEEE) have established guidelines defining basic restrictions and reference levels to protect against established thermal hazards [18]-[21]. Additionally, the International Agency for Research on Cancer (IARC) designated RF-EMFs as "possibly carcinogenic to humans" (Group 2B) [22].

Pediatric populations represent a critical focus in dosimetric research due to their ongoing physiological development, thinner cranial bones, higher tissue hydration levels, and longer cumulative lifetime exposure [23]-[24]. While several dosimetric studies report higher SAR values in child models compared to adults under equivalent exposure conditions [25]-[26], [12], others note variations based on anatomical parameters and frequency bands [12]. Furthermore, current regulatory standards are largely human-centric, leaving potential impacts on wildlife and broader ecosystems insufficiently addressed, while long-term non-thermal effects remain scientifically inconclusive.

To address these ongoing uncertainties, this study utilizes numerical computational modeling to perform a rigorous assessment of EM wave propagation, SAR distribution, and induced thermal responses within a heterogeneous pediatric anatomical model subjected to common communication and Wi-Fi frequency bands.

RESEARCH DESIGN AND METHODS

Numerical simulations were conducted using the high-resolution "Thelonious" child anatomical model from the IT'IS Foundation Virtual Population dataset [27]. Representing a six-year-old male, the model incorporates approximately 80 segmented tissue classifications including detailed neural, visceral, cutaneous, and osseous tissues. Children exhibit distinct radiofrequency (RF) absorption characteristics compared to adults due to elevated tissue hydration, thinner anatomical shielding, and a developing central nervous system [23]-[28]. Frequency-dependent electrical conductivity, relative permittivity, density, and thermal parameters were drawn directly from the IT'IS tissue property repository [29].

Given the complex geometry and tissue heterogeneity of the human body, analytical solutions for electromagnetic wave propagation are intractable [12], [30]. We employed the finite-difference time-domain (FDTD) technique via the FDTDLab software suite developed at the Laboratory of Applied Electrodynamics and Radio Engineering (LAE) of Ivane Javakhishvili Tbilisi State University to model electromagnetic wave propagation and dielectric heating [13]-[17]. Maxwell's curl equations were discretized using Yee's finite-difference scheme in both spatial and temporal domains [31]-[32].

A uniform spatial grid resolution of 2 mm was selected to resolve fine anatomical structures while maintaining computational stability. Incident RF exposure was modeled as continuous sinusoidal plane waves across key communication and Wi-Fi frequency bands. Wave orientations spanned three incident directions (frontal, rear, and lateral) under two orthogonal electric field polarizations.

The rate of absorbed electromagnetic energy per unit mass was quantified using the Specific Absorption Rate (SAR), which evaluates internal electric field intensity relative to tissue electrical conductivity and mass density.

To evaluate localized temperature elevation, the computed SAR distribution was coupled as an external heat source into Pennes' bio-heat transfer equation [33]. This formulation models

dynamic heat transfer across living tissues by accounting for metabolic heat production, tissue thermal conduction, and blood perfusion.
Thermal boundary conditions were established with an initial baseline tissue temperature of 37°C and an ambient air temperature of 22°C. Convective surface heat dissipation at the skin-air interface was governed by a convective heat transfer coefficient of 8 W/m²K.
The temperature elevation induced by RF absorption was evaluated relative to the unexposed baseline state. Temperature increases exceeding 1.0°C were marked as biologically critical. Localized SAR values were benchmarked against basic restrictions defined by ICNIRP (2.0 W/kg averaged over 10g mass) and the FCC (1.6 W/kg averaged over 1g mass) [34].

NUMERICAL SIMULATION RESULTS AND DISCUSSION

Electromagnetic Dosimetric Assessment

To systematically evaluate the spatial dependence of wave coupling within pediatric anatomy, full-wave electromagnetic computations were carried out on the child model across three operating frequencies (2.1 GHz, 5 GHz, and 6 GHz) under six orthogonal plane wave polarizations. These polarization scenarios were designed to characterize how the directional alignment of incoming wave propagation and electric field vectors influences energy absorption throughout the child's body.
The physical and structural parameters of the six-year-old child model reflect representative pediatric dimensions, including body height, mass, body mass index, and average cranial skull thickness [35]. The model incorporates dozens of anatomically differentiated tissue types discretized on a fine isotropic grid, enabling high-resolution dosimetric and thermal evaluation [27].
EM energy deposition was quantified using 1g-averaged SAR, 10g-averaged SAR, and whole-body averaged Specific Absorption Rate (WBA-SAR). These dosimetric quantities were computed directly from internal electric field distributions based on tissue electrical conductivity, root-mean-square electric field intensity, and tissue mass density [12]. All absorption metrics were normalized to a standardized incident power density.
A clear frequency-dependent transition in wave penetration behavior occurs across the evaluated spectrum. At lower frequencies around 2.1 GHz, the incident field exhibits deeper penetration into internal anatomical structures. This behavior is governed by the longer free-space wavelength, which closely matches characteristic physical dimensions of the pediatric frame. This alignment enhances resonant coupling mechanisms, promoting deeper volumetric energy absorption throughout internal organs and tissues.
Conversely, at higher frequencies (5 GHz and 6 GHz), wave penetration depth decreases substantially. Higher-frequency fields encounter elevated tissue conductivity and dielectric losses, causing rapid attenuation near the body boundary. As a result, energy deposition shifts outward toward superficial layers, producing localized absorption maxima within the skin, scalp, facial tissues, and extremities. This transition from deep volumetric absorption to surface-dominated deposition aligns with classical skin-depth behavior in lossy biological media, effectively shielding inner visceral organs from direct core field exposure.
Tissue specific comparisons of peak localized energy deposition across the whole body, head, and brain indicate that localized absorption remains highest in peripheral boundaries, muscles, and cranial surfaces rather than central neural structures. Nevertheless, 2.1 GHz exposure induces notable electromagnetic energy coupling within peripheral brain tissues.
This elevated neural absorption in pediatric models stems from key physiological characteristics: Thinner skull structures in young children afford less attenuation prior to wave entry into neural tissue. Higher water content in pediatric neural tissue increases dielectric permittivity and electrical conductivity [36], enhancing local electromagnetic field interaction.

Consequently, peak localized brain SAR at 2.1 GHz remains noticeably higher than at 5 GHz or 6 GHz. At higher frequencies, superficial tissue layers absorb the majority of incident power before it can propagate into deeper cranial regions. While this protects deep cerebral structures, it simultaneously amplifies energy deposition within surface tissues. Under high incident power flux conditions, localized peak SAR values in the skin and extremities can exceed internationally recommended public exposure limits across several polarization states [12], [37].

The cumulative exposure burden was further evaluated through whole-body averaged SAR. Due to the smaller overall volume and lower body mass of the pediatric frame, simulated whole-body SAR values regularly approach or exceed established public basic restriction thresholds under high exposure conditions.

Furthermore, whole-body absorption exhibits a strong dependence on wave orientation. Exposure configurations where the electric field vector aligns parallel to the major longitudinal axis of the body produce substantially stronger coupling than orthogonal orientations. In these vertical alignments, the child's body acts as a more efficient receiving structure, maximizing overall absorbed power and elevating whole-body SAR metrics.

Bio-Heat Transfer Analysis

Thermal distribution profiles resulting from absorbed electromagnetic energy were evaluated using steady-state bio-heat transfer modeling, which accounts for tissue thermal conduction, metabolic heat generation, and capillary blood perfusion relative to core arterial temperature [33]. The calculated thermal distributions closely mirror the absorption patterns observed in the electromagnetic simulations. The most pronounced thermal stress occurs within shallow tissues primarily the skin, scalp, hands, and facial regions. At 5 GHz and 6 GHz, rapid field attenuation near the boundary concentrates dielectric heating within outer layers [37]. Under elevated exposure scenarios, localized temperature increases in these surface layers frequently exceed the standard 1.0°C thermal safety reference threshold, as local surface blood perfusion and convective cooling cannot fully dissipate the rapid heat input.

Current international exposure standards are largely derived from adult anatomical data designed to prevent acute thermal injury. They do not fully incorporate pediatric anatomical variations, developmental tissue composition, or age-dependent dielectric properties. Because children feature thinner cranial structures, smaller anatomical dimensions, developing neural networks, and higher tissue hydration, these heterogeneous simulations demonstrate that pediatric subjects can experience heightened localized energy absorption and steeper thermal gradients under equivalent external exposure conditions. These findings underscore the importance of conservative safety approaches when evaluating wireless technologies in environments frequented by children.

CONCLUSION

This study presented a detailed numerical investigation into the dosimetric and thermal impacts of radiofrequency EM fields across communication and Wi-Fi frequency bands on a heterogeneous child anatomical model. By coupling full-wave finite-difference time-domain (FDTD) electromagnetic simulations with Pennes' bio-heat transfer modeling, we characterized energy deposition and localized temperature distributions across multiple incident wave orientations and polarization configurations.

Thermal evaluations indicate that while deep cerebral structures are protected from direct heating at higher frequencies due to shallow field attenuation and strong vascular perfusion, peripheral tissues experience substantial thermal loading. Under elevated incident exposure conditions, localized temperature increases and mass-averaged SAR metrics in surface tissues and along

cranial interfaces frequently approach or exceed international safety thresholds established by ICNIRP and the FCC.

Given the rapid evolution of wireless technologies and the increasing presence of electromagnetic fields (EMFs) in everyday environments, current safety standards, which are primarily based on short-term exposure assessments using human models, may not fully reflect the complexity of real-world exposure scenarios. It is important to emphasize that electromagnetic fields interact not only with humans but also with living organisms across a wide range of biological systems. Therefore, our recent research, together with findings reported in [39]-[42], highlights the need for continued investigation of both thermal and potential non-thermal effects of electromagnetic field exposure. Such research is essential for developing evidence-based safety recommendations that provide comprehensive protection of public health and, more broadly, the health of living organisms and ecosystems.

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Pedagogical Sciences

Оқу сапасын деректер негізінде басқарудағы директордың оқу жұмысы жөніндегі орынбасарының рөлі

Смаилова Гульмира Тулебековна
«Абай атындағы №31 жалпы білім беретін мектеп» КММ, директордың оқу жұмысы жөніндегі орынбасары

Аннотация. Мақалада мектепішілік бағалау деректерін оқытуды жетілдіруге пайдаланудағы директордың оқу жұмысы жөніндегі орынбасарының рөлі қарастырылады. Оқу мақсаттары бойынша қиындықтарды анықтау, бағалау өлшемдерін келісу, педагогтерге әдістемелік қолдау көрсету және қабылданған шешімнің нәтижесін қайта тексеру жолдары ұсынылады. Деректі талдауды сабақтағы нақты әрекетпен байланыстыратын басқару моделі мен сегіз апталық сынақ жоспары берілген. Ұсыныстар мұғалімнің есептік жүктемесін көбейтпей, оқушының ілгерілеуін байқауға және мектепішілік кәсіби ынтымақтастықты нығайтуға бағытталған.

Кілт сөздер: оқу сапасы, мектепішілік бағалау, деректер негізінде басқару, оқу олқылықтары, әдістемелік қолдау, қалыптастырушы бағалау, педагогикалық көшбасшылық.

Оқу сапасын басқарудың өзекті міндеті

Директордың оқу жұмысы жөніндегі орынбасары үшін оқу сапасын басқарудың негізгі міндеті — бағалау нәтижесінен нақты педагогикалық шешімге өту. Тоқсандық үлгерім, бөлім бойынша жиынтық бағалау және сабақтағы күнделікті жұмыстар оқушының оқу жағдайын әр қырынан көрсетеді. Оларды бірлесе талдау қай оқу мақсатына қайта оралу керектігін, қандай әдісті өзгерту қажеттігін және кімге қосымша қолдау ұсынуға болатынын анықтауға көмектеседі. Осы байланысты ұйымдастыру мектеп басшылығының күнделікті жұмысына айналуы қажет.

Мәселенің өзектілігін халықаралық зерттеу деректері де айқындайды. Экономикалық ынтымақтастық және даму ұйымының Қазақстан бойынша PISA 2022 есебінде 15 жастағы оқушылардың 36 пайызы оқу сауаттылығынан кемінде екінші деңгейге жеткені көрсетілген [1]. Бұл көрсеткішті жекелеген мектептің нәтижесімен теңестіруге болмайды. Дегенмен ол мәтінді түсіну, ақпаратты іріктеу және білімді қолдану дағдыларына мектепішілік талдауда арнайы назар аудару қажеттігін көрсетеді. Ұлттық деңгейдегі мәлімет мектептің өз жағдайын зерттеуіне негіз болатын сұрақ ұсынады.

Мақаланың мақсаты — директор орынбасарының бағалау деректерін талдау, педагогтердің бірлескен жұмысын үйлестіру және оқу қиындықтарына жауап беру әрекеттерін байланыстыратын практикалық модель ұсыну. Талдау нысаны ретінде оқушының оқу мақсатына қатысты орындаған жұмысы алынады. Әдістемелік негізі — деректерді қолдану және кері байланыс жөніндегі нұсқаулықтарды талдау, оларды мектепішілік басқару міндеттеріне бейімдеу. Ұсынылған модельді енгізу нәтижесі нақты мектеп жағдайында қайта бағалауды қажет етеді.

Талдауға жарамды деректерді іріктеу

Hamilton және әріптестерінің нұсқаулығында бағалау деректерін оқытуды жетілдірудің үздіксіз цикліне енгізу және мектепте оларды қолданудың ортақ бағытын қалыптастыру ұсынылады [2]. Мұндай жұмысты ұйымдастыруда дерек жинаудың мақсаты педагогтерге түсінікті болуы қажет. Әр көрсеткішке «Осы ақпаратқа сүйеніп қандай шешім қабылдаймыз?» деген сұрақ қойылады. Егер оған нақты жауап болмаса, көрсеткішті тұрақты есепке қосудың қажеттілігі қайта қаралады.

Талдау үшін тапсырманың оқу мақсатына сәйкестігі, бағалау өлшемдерінің түсініктілігі және жұмыстардың салыстыруға келетіндігі тексеріледі. Бір сыныпта негізінен есте сақтауды, екінші сыныпта күрделі дәлелдеуді талап еткен жұмыстардың орташа балдарын тікелей салыстыру дұрыс қорытынды бермейді. Мұғалімдер оқушының аты-жөні көрсетілмеген бірнеше жұмысты бір өлшеммен бағалап, пікір айырмашылығының себебін талқылай алады. Бағалау келісілгеннен кейін ғана нәтижелерді жинақтау орынды.

Бір көрсеткішке сүйеніп оқушыға немесе педагогке қорытынды баға беруден сақтанған жөн. Төмен нәтиже тапсырма тілінің күрделілігімен, алдыңғы тақырыптағы олқылықпен немесе сабаққа қатыспаумен байланысты болуы мүмкін. Мұндай болжам жұмыс үлгісімен, сабақтағы бақылаумен және оқушымен қысқа әңгімемен нақтыланады. 1-кестеде деректерді педагогикалық шешіммен байланыстырудың үлгісі ұсынылған.

1-кесте. Бағалау деректерінен педагогикалық шешімге өту

Байқалған белгі	Нақтылау тәсілі	Ықтимал әрекет
Бір оқу мақсаты бойынша қате жиі қайталанады	Қате жауаптарды түріне қарай топтау	Қиындыққа сәйкес қысқа қайта оқыту
Жауап дұрыс, түсіндірме жеткіліксіз	Оқушының шешу жолын тыңдау	Дәлелдеу үлгісін талдау және қолдану
Сыныптар нәтижесі алшақ	Тапсырма мен бағалау өлшемдерін салыстыру	Өлшемдерді келісу, ортақ үлгілерді қарау
Қолдаудан кейін де ілгерілеу байқалмайды	Қатысуды және қолдау мазмұнын тексеру	Қиындықты қайта анықтап, тәсілді өзгерту

Директор орынбасары үйлестіретін жұмыс циклі

Мектепішілік жұмысты бес өзара байланысты қадаммен ұйымдастыруға болады. Бірінші қадамда нақты мәселе таңдалады. «Білім сапасын көтеру» сияқты кең міндеттің орнына «оқушылардың мәтіннен өз тұжырымына сәйкес дәлел таңдау дағдысын жетілдіру» тәрізді бақыланатын мақсат белгіленеді. Бір кезеңде бір немесе екі басымдықпен жұмыс істеу талдауды тереңдетуге мүмкіндік береді. Таңдалған басымдық мектептің даму жоспары мен пәндік қажеттіліктеріне сай болуы тиіс.

Екінші қадамда бастапқы жағдай анықталады. Мұғалім сол дағдыны тексеретін шағын тапсырма ұсынады және жауаптарды алдын ала келісілген өлшемдермен қарайды. Әдістемелік бірлестік жетекшісі жиі кездесетін қиындықтарды жинақтайды. Директор орынбасары қорытындының нақты жұмыс үлгілеріне сүйенуін қадағалайды. Диагностикаға қатыспаған оқушының нәтижесі нөлмен алмастырылмайды; оның қатыспағаны бөлек белгіленіп, кейін тексеру мүмкіндігі қарастырылады.

Үшінші қадамда қолдау тәсілі жоспарланады. Мұғалім мақсатқа сәйкес түсіндіруді, шағын топтағы жұмысты немесе деңгейленген тірек тапсырмаларды таңдайды. Директор орынбасары бұл жұмысқа уақыт бөлуге, тәжірибелі әріптестің көмегін ұйымдастыруға және қажет материалды қолжетімді етуге қатысады. Жоспарда әрекет, жауапты адам, орындалу мерзімі және нәтиже қалай тексерілетіні қысқа көрсетіледі. Көп тармақты есептің орнына кейін қайта қарауға болатын түсінікті шешім қажет.

Төртінші қадамда жоспарланған тәсіл сабаққа енгізіліп, оның орындалуы бақыланады. Мұнда тек тапсырманың берілгені жеткіліксіз: оқушының қандай тірек алғаны, оны қалай пайдаланғаны және қай тұста әлі қиналғаны қаралады. Сабаққа қатысу кезінде алдын ала келісілген бір мәселеге назар аударуға болады. Мәселен, оқушылар мұғалімнің түсіндірмесінен кейін өз жауабын түзете алды ма, әлде сол қатені қайталады ма? Бақылау жазбасы осы сұраққа жауап беретін нақты мысалдарды қамтиды.

Бесінші қадамда ілгерілеу тексеріліп, келесі шешім қабылданады. Қайта тапсырма бастапқы оқу мақсаты мен талап деңгейін сақтайды, бірақ бұрынғы жауапты жатқа қайталауға мүмкіндік бермейтіндей өзгертіледі. Нәтиже жақсарса, тәсілді жалғастыру немесе басқа топта сынау қарастырылады. Өзгеріс болмаса, қиындық туралы бастапқы болжам, қолдау мазмұны және оның орындалу жағдайы қайта талданады. Циклдің аяқталуы жаңа оқу міндетін анықтауға негіз болады.

Педагогтердің бірлескен жұмысын ұйымдастыру

Бұл модельде директор орынбасары ортақ мақсат пен жұмыс ырғағын үйлестіреді, ал пән мұғалімі тапсырманың мазмұны мен оқыту тәсіліне жауап береді. Әдістемелік бірлестік жетекшісі бағалау өлшемдерін келісуге және тәжірибе алмасуға көмектеседі. Қажет болған жағдайда сынып жетекшісі оқушының сабаққа қатысуына қатысты мәліметті нақтылайды. Міндеттер осылай бөлінсе, әр қызметкер өз құзыретіне сай әрекет етеді және бір ақпаратты бірнеше рет жинау азаяды.

Әдістемелік отырыста кестелерді кезекпен оқудың орнына алдын ала таңдалған оқу мәселесін талқылауды ұсынамыз. Мысалы, отыз минуттық кездесудің алғашқы бөлігінде бірнеше оқушы жұмысы қаралады, кейін қателердің ықтимал себептері салыстырылады, соңында бір ортақ әрекет пен қайта тексеру күні келісіледі. Талқылаудағы пікір оқушының жұмысына немесе сабақтағы нақты бақылауға сүйенеді. Қорытындыда кімнің не істейтіні анық жазылады.

Оқу сауаттылығына қатысты қолдану үлгісі

Модельді түсіндіру үшін мәтіндегі тұжырымды дәлелдеу дағдысын жетілдіру жағдайын қарастырайық. Оқушыларға қысқа мәтін және автордың негізгі ойын түсіндіріп, оны мәтіннен алынған дәлелмен негіздеу тапсырмасы беріледі. Бағалау кезінде тұжырымның дұрыстығы, дәлелдің сәйкестігі және екеуінің байланысын түсіндіру қаралады. Қателерді осы өлшемдер бойынша бөлу мұғалімге қандай әрекетке көбірек уақыт қажет екенін анықтауға көмектеседі.

Егер оқушы мәтіннің мазмұнын қайталап, өз тұжырымына дәлел келтіре алмаса, мұғалім дайын жауаптың құрылымын бірге талдауды ұсына алады. Одан кейін оқушылар берілген бірнеше үзіндінің ішінен тұжырымға сәйкес келетінін таңдап, таңдауын түсіндіреді. Келесі тапсырмада тірек біртіндеп азайтылып, дәлелді өздігінен табу талап етіледі. Дағдыны меңгерген оқушыларға екі ықтимал дәлелдің қайсысы сенімдірек екенін салыстыру тапсырмасы беріледі.

Кері байланыс оқушының келесі әрекетін көрсетуі тиіс. Education Endowment Foundation (EEF) қорының нұсқаулығы кері байланыстың жазбаша немесе ауызша берілуінен бұрын, оның оқуға қалай көмектесетініне назар аударады [3]. Осы үлгіде «дәлелің жеткіліксіз» деген белгілеуді «тұжырымыңды растайтын сөйлемді тап және оның байланысын түсіндір» деген нұсқаумен нақтылауға болады. Сабақта жауапты түзетуге уақыт беріледі. Кейін мұғалім оқушының түзетуді түсініп орындағанын жаңа мәтін арқылы тексереді.

Директор орынбасары аталған жұмысты қазақ тілі, тарих немесе жаратылыстану пәндерінің әдістемелік бірлестіктерімен келісіп ұйымдастыра алады. Ортақ назар дәлелді жауап құруға бағытталғанымен, әр пәндегі дәлелдің сипаты сақталады. Тарихта дереккөзге,

жаратылыстануда бақылау мен мәліметке сүйену талап етілуі мүмкін. Сондықтан ортақ дағды үшін барлық пәнге бірдей тапсырма енгізу міндетті емес.

Модельді кезеңмен енгізу және нәтижені бағалау

Жұмысты бірден барлық сыныпқа таратуға асықпай, шағын топта сынақтан өткізу орынды. EEF-тің енгізу жөніндегі нұсқаулығы мәселені зерттеу, дайындалу, іске асыру және жұмысты жалғастыру кезеңдерін ажыратады [4]. Осы қағидаға сүйене отырып, бір әдістемелік бірлестікке немесе сыныптар тобына арналған сегіз апталық жоспар ұсынамыз. Оның мерзімін мектептің оқу кестесіне және таңдалған дағдының күрделілігіне қарай өзгертуге болады.

2-кесте. Сегіз апталық сынақ жұмысының ұсынылатын жоспары

Мерзім	Негізгі жұмыс	Үйлестіру	Қаралатын нәтиже
1–2-апта	Мәселені таңдау, өлшемдерді келісу, бастапқы тексеру	Орынбасар және бірлестік жетекшісі	Бастапқы жұмыстар мен қиындықтар тізімі
3–4-апта	Қолдау тәсілін сабаққа енгізу	Пән мұғалімдері	Оқушы жауаптары және қолданылған тіректер
5–6-апта	Аралық талқылау, тәсілді нақтылау	Бірлестік жетекшісі	Түзетілген жұмыстар және келесі әрекет
7–8-апта	Қайта тексеру, нәтижені салыстыру	Мұғалімдер және орынбасар	Ілгерілеу туралы қорытынды және шешім

Нәтижені бағалауда бірнеше көрсеткіш жеткілікті: келісілген өлшемге жеткен оқушылар саны, бастапқыда қиналған оқушылардың ілгерілеуі және үйренген тәсілді жаңа тапсырмада қолдануы. Әр көрсеткіштің қалай есептелетіні алдын ала анықталады. Мысалы, пайыздық үлес өлшемді орындаған оқушылар санын жұмысты орындаған оқушылар санына бөліп, жүзге көбейту арқылы табылады. Салыстырылатын екі тексеруде қатысушылар құрамы өзгерсе, ортақ қатысқан оқушылардың нәтижесі бөлек қаралады.

Жалпы сынып көрсеткішімен қатар жеке ілгерілеуді қарау маңызды. Сыныптың орташа нәтижесі артқанымен, бастапқыда көмек қажет болған оқушыларда өзгеріс болмауы мүмкін. Сондықтан қолдау алған топтың жұмыс үлгілері қайта қаралып, кімнің қандай өлшемде алға жылжығаны белгіленеді. Оқу мақсаты сақталған жағдайда ерекше білім беру қажеттіліктеріне байланысты қолданылған қолдау мен орындау шарттары да тіркеледі. Бұл нәтижелерді түсіндіруде жағдай айырмашылығын ескеруге мүмкіндік береді.

Бастапқы және кейінгі нәтиженің айырмасын толығымен бір әдістің әсері деп түсіндіруге болмайды. Оған тақырыптың қайталануы, тапсырмамен таныстық немесе сабаққа қатысудағы өзгеріс те ықпал етуі мүмкін. Сондықтан қорытындыда «осы тәсілді қолдану кезеңінде ілгерілеу байқалды» деген тұжырым нақты жұмыс үлгілерімен негізделеді. Тұрақты шешім қабылдау үшін дағдының кейінгі сабақтарда сақталуы және жаңа жағдайда қолданылуы тексеріледі.

Деректермен жұмыс істеудің кәсіби мәдениеті

Ұсынылған жұмыстың тұрақтылығы педагогтердің сеніміне байланысты. Жалпы талқылауға оқушы аты-жөні көрсетілмеген жұмыс үлгілерін қолдануды, ал жеке қолдау туралы мәліметке тек жұмысқа қатысатын қызметкерлердің қол жеткізуін ұсынамыз. Сыныптар мен мұғалімдердің ашық рейтингін жасау талдаудың мақсатына айналмауы тиіс. Негізгі назар анықталған қиындыққа және оны шешуге бағытталған әрекетке аударылады.

Электрондық кестені пайдаланғанда оған тек шешім қабылдауға қажетті өрістер енгізілгені жөн: оқу мақсаты, бағалау өлшемі, қате түрі, қолдау әрекеті және қайта тексеру нәтижесі. Дайын журналдағы ақпаратты жаңа есепке қолмен көшіру қажеттілігі бар-жоғы

алдын ала қаралады. Автоматты есептеу педагогикалық түсіндіруді алмастырмайды. Мысалы, пайыз дұрыс есептелгенімен, тапсырма оқу мақсатын дәл өлшемесе, басқарушылық қорытынды да жаңсақ болуы мүмкін.

Оқушы мен ата-анаға берілетін ақпарат та түсінікті әрекетке жетелеуі керек. Оқушы өзінің қай өлшемді орындағанын және келесі жолы нені түзететінін біледі. Ата-анаға баланың нәтижесін сыныптастарымен салыстырудан гөрі, үйде қандай қолдау қажет екені түсіндіріледі. Мектеп пен отбасы келісетін әрекет нақты әрі орындалатындай болғаны жөн: мысалы, оқушының қысқа мәтін бойынша өз пікірін дәлелдеп айтуын тыңдау.

Қорытынды

Оқу сапасын деректер негізінде басқаруда директордың оқу жұмысы жөніндегі орынбасары бағалау мен әдістемелік қолдаудың арасын байланыстырады. Оның ұйымдастырушылық шешімі нақты оқу мәселесін таңдаудан басталып, мұғалімдердің бірлескен талдауымен, қолдау әрекетімен және нәтижені қайта тексерумен жалғасады. Мұндай жұмыстың мәні жинақталған есептің көлемімен емес, оқушыға ұсынылған көмектің қаншалықты орынды болғанымен және келесі шешімнің қандай дәлелге сүйенгенімен айқындалады.

Мектеп деңгейінде алғашқы қадам ретінде бір оқу дағдысын таңдап, ортақ бағалау өлшемдерін келісіп, сегіз апталық сынақ жұмысын ұйымдастыруға болады. Оның қорытындысы бойынша тиімді болған әрекеттер сақталып, орындалуы қиын немесе пайдасы байқалмаған тәсілдер қайта қаралады. Осылайша мектепішілік бағалау педагогтердің күнделікті шешім қабылдауына қызмет етіп, әр оқушының оқуына дер кезінде қолдау көрсетуге негіз болады.

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МЕКТЕПТЕГІ БІЛІМ САПАСЫН БАСҚАРУДАҒЫ ДЕРЕКТЕРГЕ НЕГІЗДЕЛГЕН ӘДІСТЕМЕЛІК ҚОЛДАУ

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«Абай атындағы №31 жалпы білім беретін мектеп» КММ, директордың оқу жұмысы жөніндегі орынбасары

Аннотация. Мақалада директордың оқу жұмысы жөніндегі орынбасарының білім сапасын басқарудағы қызметі қарастырылады. Оқу нәтижелерін талдау, мұғалімнің кәсіби дамуын ұйымдастыру және қабылданған шешімнің орындалуын бағалау өзара байланысты үдеріс ретінде ұсынылады. Бағалау деректерін сабақтағы бақылаумен және оқушының жұмысымен ұштастырудың жолдары көрсетіледі. Мектеп тәжірибесіне бейімдеуге арналған талдау кестесі мен алты апталық әдістемелік жұмыс үлгісі берілген. Негізгі тұжырым: мониторингтің құндылығы жиналған ақпараттың көлемімен емес, сол ақпаратқа сүйеніп оқытуға енгізілген өзгерістің негізділігімен анықталады.
Кілт сөздер: білім сапасы, мектепішілік басқару, деректерді талдау, әдістемелік қолдау, қалыптастырушы бағалау, педагогикалық көшбасшылық.

Білім сапасын басқарудың педагогикалық бағыты

Мектептегі білім сапасын арттыру үшін директордың оқу жұмысы жөніндегі орынбасары оқу нәтижесі туралы ақпаратты мұғалімнің күнделікті тәжірибесімен байланыстыра білуі қажет. Тоқсандық баға оқушы жетістігінің жалпы көрінісін береді. Алайда келесі сабақты қалай өзгерту керектігін анықтау үшін оқушының қай тапсырмада қиналғанын, қандай тәсілді қолданғанын және қателесу себебін қарастыру керек. Осы талдаудан кейін ғана қайта түсіндіру, қосымша жаттығу немесе оқыту тәсілін өзгерту туралы негізді шешім қабылдауға болады.

Мақаланың мақсаты — оқу нәтижелеріне сүйенетін әдістемелік қолдауды мектеп ішінде ұйымдастырудың ықшам үлгісін ұсыну. Материал халықаралық әдістемелік еңбектерді талдауға және сол идеяларды жалпы білім беретін мектептің жұмысына бейімдеуге негізделген. Ұсынылған кесте мен жұмыс реті әдістемелік модель болып табылады; олардың тиімділігін нақты мектепте қолдану барысында тексеру қажет.

ЮНЕСКО-ның 2024/5 жылғы білім беру мониторингі жөніндегі баяндамасында көшбасшылықтың төрт бағыты аталады: күтілетін нәтижелерді белгілеу, оқуға назар аудару, ынтымақтастықты дамыту және адамдардың кәсіби өсуіне жағдай жасау [1]. Бұл бағдарларды оқу жұмысына қолданғанда директор орынбасарының негізгі міндеті айқындалады: педагогтерге ортақ оқу мәселесін анықтауға, оны шешудің тәсілін таңдауға және нәтижесін бірге бағалауға жағдай жасау.

Осы мақсатта мектепішілік бақылау жоспарына нақты зерттеу сұрағын енгізуге болады. Мысалы, «оқушылардың оқу сауаттылығы қандай?» деген ауқымды сұрақты «оқушылар мәтіндегі тұжырымға сәйкес дәлелді қалай таңдайды?» деп нақтылау талдауды жеңілдетеді. Мұндай сұрақ мұғалімнің қай әрекетін бақылау керектігін және оқушы жұмысынан қандай белгі ізделетінін көрсетеді. Жоспардағы әр бағыт үшін шешім қабылдайтын мерзім мен жауапты педагогтер алдын ала келісіледі.

Оқу деректерін түсіндіру және сенімді қорытынды жасау

Деректерге негізделген басқаруды тек пайыздармен жұмыс істеу деп түсінуге болмайды. Оқушының жазбаша жауабы, есеп шығару жолы, ауызша түсіндіруі және кері байланыстан кейінгі түзетуі де шешімге негіз болатын ақпарат береді. Бағалар білімдегі өзгерісті байқатса, осы жұмыс үлгілері оның мазмұнын ашады. АҚШ Білім ғылымдары институтының әдістемелік нұсқаулығы деректерді оқытуды жетілдірудің тұрақты цикліне енгізуді және оқушыны өз нәтижесіне сүйеніп мақсат қоюға үйретуді ұсынады [2].

Алдымен бағалау құралының сапасын тексеру қажет. Тапсырма таңдалған оқу мақсатына сәйкес келе ме, нұсқауы түсінікті ме, бағалау өлшемдері бірізді қолданыла ма? Егер оқушылардың басым бөлігі бір тапсырмадан қателессе, оның себебі тақырыпты меңгермеумен қатар тапсырманың тұжырымында да болуы мүмкін. Бірнеше мұғалімнің бірдей жұмыс үлгілерін ортақ өлшем бойынша талқылауы бағалаудағы айырмашылықтарды анықтауға көмектеседі.

Салыстыру кезінде тапсырманың күрделілігін, орындау уақытын және қатысқан оқушылар құрамын ескерген жөн. Қатыспаған оқушының нәтижесін автоматты түрде нөл деп белгілеу сынып көрсеткішін бұрмалайды. Шағын топта бір оқушының нәтижесі пайыздық мәнді едәуір өзгертуі мүмкін, сондықтан пайызбен бірге оқушылар саны да көрсетіледі. Әртүрлі дағдыны өлшейтін екі жұмыстың орташа балын тікелей салыстыру оқу ілгерілеуін дәл сипаттай бермейді.

Талдаудағы келесі қадам — бастапқы болжамды қосымша дерекпен тексеру. Оқушы мәтінге сүйеніп жауап бермесе, оған сөздік қор, тапсырманы түсіну немесе дәлел таңдаудың тәсілі қиын болуы мүмкін. Қысқа әңгімелесу мен жұмыс үлгісін қарау осы себептерді ажыратуға мүмкіндік береді. Нәтижесінде әдістемелік бірлестік жалпы «сапаны көтеру» тапсырмасының орнына орындалатын нақты әрекетті келіседі. 1-кестеде осындай шешімдердің ықтимал нұсқалары берілген.

1-кесте. Оқу деректерін әдістемелік шешіммен байланыстыру үлгісі

Байқалған қиындық	Тексерілетін дерек	Қолдау әрекеті	Қайта бағалау белгісі
Жауапта дәлел жеткіліксіз	Жазбаша жауап және ауызша түсіндіру	Дәлел таңдауды үлгілеу, жауапты бірге талдау	Жаңа тапсырмада тұжырымға сәйкес дәлел келтіру
Есептің шешу жолы түсіндірілмейді	Аралық қадамдар және оқушы түсіндірмесі	Шешу қадамдарын дауыстап түсіндіру үлгісі	Ұқсас есепте амал таңдауын негіздеу
Кері байланыстан кейін қате қайталанады	Алғашқы және түзетілген жұмыс	Түзетуге уақыт беру, бір нақты қадам ұсыну	Қатесін түсіндіріп, өздігінен түзету
Топтық жұмыста қатысу біркелкі емес	Бақылау жазбасы және жеке жауап	Рөлдерді алмастыру, әр оқушыға жеке тапсырма беру	Әр оқушының жеке жауабының болуы

Ескерту. Кесте нақты мектептің нәтижелерін емес, дерекке сүйеніп шешім қабылдаудың авторлық әдістемелік үлгісін көрсетеді.

Мұғалімге қолдау көрсетудің мазмұны

Әдістемелік қолдау талдау барысында анықталған сұраққа жауап беруі тиіс. Егер қиындық оқушының өз жауабын дәлелдеуіне қатысты болса, жалпы тақырыптағы семинармен шектелу жеткіліксіз. Мұғалімдерге нақты тапсырма құрастыру, жауап үлгілерін

салыстыру және сабақта қолданатын сұрақтарды талқылау пайдалырақ. Директор орынбасары мұндай жұмыстың уақытын келісіп, қажетті материалға қолжетімділікті қамтамасыз етеді және аралық талқылауды ұйымдастырады.

Қолдаудың ықшам форматы ретінде бірлескен жоспарлауды ұсынуға болады. Пән мұғалімдері бір оқу мақсатын, сол мақсатқа сәйкес тапсырманы және жетістікті көрсететін белгілерді таңдайды. Әр педагог тапсырманы өз сыныбына бейімдеп қолданады, келесі кездесуге бірнеше анонимдендірілген жұмыс үлгісін әкеледі. Талқылауда қай түсіндіру тәсілі оқушыға көмектескені және қай жерде қосымша қолдау қажет болғаны қарастырылады. Осылайша әдістемелік отырыс нақты сабақтың мазмұнымен байланысады.

Сабақты бақылау да алдын ала келісілген сұраққа құрылуы орынды. Мысалы, бақылаушы оқушылардың қаншасы жауап бергенін ғана емес, олардың дәлелді қайдан алғанын және мұғалімнің нақтылау сұрағына қалай жауап бергенін тіркей алады. Сабақтан кейінгі әңгімеде алдымен байқалған әрекет сипатталады, содан соң мұғалімнің түсіндірмесі тыңдалады. Бірлескен шешім келесі сабақта сынауға болатын шағын өзгеріспен аяқталады.

Оқушыға берілетін кері байланыстың мазмұнына да назар аудару қажет. EEF нұсқаулығында кері байланыстың тиімділігі оның жазбаша не ауызша берілуінен гөрі оқуды жақсартуға қалай көмектесетінімен байланыстырылады [3]. Сондықтан «толықтыр» деген жалпы ескертудің орнына «тұжырымыңды растайтын бір деректі таңда және оның сәйкестігін түсіндір» деген нұсқау ұсынуға болады. Оқушыға осы әрекетті орындауға уақыт беріліп, кейін оның түзетілген жауабы қаралады.

Қолдау форматын таңдағанда педагогтің қажеттілігі ескеріледі. Жас маманға тапсырма мен бағалау өлшемін бірге дайындау қажет болуы мүмкін; тәжірибелі мұғалімге оқушылардың күрделі жауаптарын әріптесімен талқылау пайдалы. Кәсіби дамуды өткізілген іс-шара санымен ғана есептеу жеткіліксіз. Оның мазмұнын мұғалім қолданған жаңа әрекет пен оқушы жұмысында байқалған өзгеріс арқылы талқылаған жөн.

Алты апталық әдістемелік жұмысты ұйымдастыру үлгісі

Өзгерісті енгізу үшін оның көлемі мен мерзімін мектептің мүмкіндігіне сәйкестендіру қажет. EEF-тің енгізу жөніндегі нұсқаулығында мәселені зерттеу, дайындалу, іске асыру және орнықтыру кезеңдері ұсынылған [4]. Осы логиканы ескере отырып, бір әдістемелік бірлестікке арналған алты апталық бастапқы жұмыс үлгісін ұсынамыз. Бұл мерзім — ұйымдастыру нұсқасы; оқу нәтижесінің тұрақтылығын кейін де бақылау қажет.

Бірінші аптада мәселе нақтыланады. Педагогтер бір дағдыны таңдап, оқушылардың бастапқы жұмысын қарастырады. Мысалы, зерттеу сұрағы «оқушы мәтіндегі тұжырымын сәйкес дәлелмен негіздей ала ма?» деп қойылады. Орынбасар таңдалған мәселенің мектеп жоспарына сәйкестігін және мұғалімдердің осы жұмысқа бөлетін уақытын келіседі.

Екінші аптада ортақ құрал дайындалады. Мұғалімдер қысқа тапсырма мен түсінікті бағалау өлшемдерін жасайды, бірнеше жұмыс үлгісін бірге бағалайды. Бақылау үшін тұжырымның анықтығы, дәлелдің сәйкестігі және олардың байланысын түсіндіру сияқты белгілер таңдалуы мүмкін. Әр белгі бойынша бастапқы жағдай тіркеліп, қандай өзгеріс күтілетіні алдын ала жазылады.

Үшінші және төртінші апталарда келісілген тәсіл сабақта қолданылады. Мұғалім дәлел таңдау жолын үлгілеп көрсетеді, оқушыларға жаттығу мен жауапты түзетуге мүмкіндік береді. Әріптестік бақылау кезінде осы әрекеттің орындалуы қаралады. Қажеттілік туындаса, әдістемелік бірлестік тапсырманың тілін немесе тірек үлгісін өзгертеді; жасалған өзгерістің себебі қысқаша тіркеледі.

Бесінші аптада аралық талдау жүргізіледі. Педагогтер қай оқушылардың дербес орындауға көшкенін және кімге қолдау әлі қажет екенін анықтайды. Егер қиындық сақталса, оның себебі тәсілдің орындалуында ма, тапсырманың деңгейінде ме, әлде бастапқы

болжамда ма деген сұрақ қаралады. Оқушыға қатысты қорытынды оның бірнеше жұмысымен және түсіндірмесімен тексеріледі.

Алтыншы аптада бастапқы мақсатқа сай, бірақ мазмұны жаңа тапсырма орындалады. Нәтижелер бірдей өлшемдермен салыстырылады. Әдістемелік бірлестік тәсілді жалғастыру, бейімдеу немесе тоқтату жөнінде шешім ұсынады. Орынбасар осы шешімге қажетті уақыт пен ресурсты нақтылап, келесі тексеру мерзімін белгілейді. Жұмыс нәтижесін бір бетке ықшамдап рәсімдеуге болады: мәселе, қолданылған әрекет, байқалған өзгеріс және келесі қадам.

Жұмысты бүкіл мектепке тарату туралы шешім алғашқы жағымды нәтижеге ғана сүйенбеуі керек. Тәсілдің басқа сыныпта орындалу мүмкіндігі, педагогке түсіретін жүктемесі және қосымша материалдың қажеттілігі қарастырылады. Егер әдіс белгілі бір жағдайға тәуелді болса, сол жағдайды да сипаттау қажет. Бұл өзге мұғалімге дайын әрекетті механикалық көшіруден гөрі оны өз сыныбына саналы бейімдеуге көмектеседі.

Нәтижені бағалау және жұмыс жүктемесін реттеу

Әдістемелік жұмысты бағалауда екі түрлі сұрақты ажыратқан жөн. Біріншісі — келісілген әрекет орындалды ма? Оған сабақтағы бақылау, мұғалімнің қысқа жазбасы және ұсынылған тапсырма жауап береді. Екіншісі — оқушының оқуында қандай өзгеріс байқалды? Оны жаңа тапсырмадағы дербес жауап, қатесін түзетуі және түсіндіруінің сапасы көрсетеді. Іс-шараның өткізілуі мен оқу нәтижесінің жақсаруы бір көрсеткіш ретінде есептелмеуі тиіс.

Нәтижені түсіндіру кезінде себеп пен қатар байқалған өзгерісті шатастырмау маңызды. Бастапқы және кейінгі жұмыстың айырмашылығына қосымша дайындық, сабаққа қатысу немесе тапсырманың жеңілдігі әсер етуі мүмкін. Сондықтан шағын мектепішілік сынақтан кейін «әдіс тиімділігі дәлелденді» деген тұжырымның орнына қандай өзгеріс, кімдерде және қандай жағдайда байқалғанын көрсету дәлірек. Кейінгі тексеру сол өзгерістің сақталғанын бағалауға мүмкіндік береді.

Орташа нәтиже өскенімен, кейбір оқушылардың қиындықтары сақталуы ықтимал. Сол себепті жалпы көрсеткішпен қатар бастапқыда көбірек қолдау қажет болған оқушылардың ілгерілеуі қарастырылады. Қолжетімділік үшін мәтінді құрылымдау, нұсқауды кезеңге бөлу немесе жауапты түсіндірудің балама тәсілін ұсынуға болады. Мұндай бейімдеу бағаланатын негізгі дағдыны сақтауы керек; оны анықтау пән мұғалімі мен тиісті мамандардың бірлескен жұмысына сүйенеді.

Деректермен жұмыс мұғалімнің уақытын да ескеруі қажет. Электрондық журналда бар мәліметті бірнеше есепке қайта көшірудің орнына, тек шешім қабылдауға қажет өрістерді қалдырған орынды. Мектепке қолжетімді электрондық кестеде оқу мақсаты, тапсырма, байқалған қиындық, қолдау әрекеті және қайта қарау мерзімі көрсетілсе жеткілікті. Пайдаланылмайтын көрсеткіштерді көбейту талдаудың мазмұнын жақсартпайды.

Оқушының аты-жөні мен жеке нәтижесіне қолжетімділік жұмысқа қатысатын жауапты қызметкерлермен шектелгені жөн. Әдістемелік талқылауға ұсынылатын жұмыс үлгілері анонимдендіріледі. Мұғалімдерді бір ғана сыныптың орташа балы бойынша жария салыстырудан сақтану қажет: сынып құрамы мен бастапқы деңгейі әртүрлі болуы мүмкін. Кәсіби талқылау сенімге сүйенгенде педагог қиындықты жасырмай, оны шешуге қатысты көмек сұрай алады.

Қорытынды

Директордың оқу жұмысы жөніндегі орынбасары деректерді жинау, әдістемелік қолдау және нәтижені қайта бағалау арасындағы байланысты ұйымдастырады. Бұл жұмыстың бастапқы нүктесі — нақты оқу мәселесі. Мұғаліммен бірге таңдалған әрекет сабақта тексеріліп, оқушы жұмысындағы өзгеріс арқылы талқыланғанда басқарушылық шешімнің педагогикалық мазмұны айқындалады.

Мектеп үшін қолайлы алғашқы қадам — бір әдістемелік бірлестікте бір дағдыға қатысты жұмысты бастау. Ортақ өлшемді келісу, қолдауды жоспарлау және нәтижені қайта қарау мерзімін белгілеу осы қадамды орындалатын міндетке айналдырады. Жинақталған тәжірибе кейінгі шешімдерді нақтылауға негіз болады. Білім сапасын басқарудың мәні де осында: әрбір талдау оқушыға қажет қолдауды анықтап, мұғалімнің келесі әрекетін негіздеуі тиіс.

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Көркем еңбек сабағында этнодизайн арқылы экологиялық мәдениетті қалыптастыру

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Аннотация. Мақалада көркем еңбек сабағында ұлттық қолөнер элементтерін материалды қайта пайдаланумен ұштастырудың әдістемелік мүмкіндіктері қарастырылады. Этнодизайнға негізделген шағын жоба арқылы оқушының көркемдік шешімін, материал таңдауын және бұйымның қолданылуын өзара байланыстыру жолдары ұсынылады. Мата қиындысынан қалташалы панно жасау мысалында зерттеу, эскиз әзірлеу, дайындау, сынау және рефлексия кезеңдері сипатталады. Жұмысқа қолжетімділік пен қалыптастырушы бағалауға арналған өлшемдер беріледі. Ұсынылған үлгі мұғалімнің сынып жағдайына бейімдеуіне арналған.

Кілт сөздер: көркем еңбек, этнодизайн, ұлттық қолөнер, экологиялық мәдениет, материалды қайта пайдалану, жобалық жұмыс.

Көркемдік шешім мен жауапты тұтынудың байланысы

Көркем еңбек сабағындағы бұйымның құндылығы оның сыртқы көрінісімен бірге қандай қажеттілікті өтейтініне, қалай жасалғанына және қанша уақыт қолданылатынына байланысты. Оқушы әдемі жұмыс дайындауға ұмтылғанда материалдың қасиетін, қалдықтың мөлшерін және бұйымды жөндеу мүмкіндігін де ойластыруы қажет. Осы байланыс сабақтағы шығармашылық әрекетті күнделікті өмірдегі саналы таңдаумен ұштастыруға мүмкіндік береді. Сондықтан этнодизайнға негізделген жобаны экологиялық мәдениетті қалыптастырудың практикалық бағыты ретінде қарастыруға болады.

ЮНЕСКО-ның 2024 жылы қабылданған мәдениет пен өнер саласындағы білім беру жөніндегі негіздемесі жергілікті мәдениет пен мұраға сабақта көбірек орын беруді ұсынады [1]. Бұл ұстанымды көркем еңбекке бейімдеу ұлттық бұйымның пішіні мен өрнегін зерттеуден, оны қазіргі қолдану жағдайымен байланыстырудан көрінеді. Ал БҰҰ-ның Тұрақты даму мақсаттарындағы 12.5-міндет қалдықтың пайда болуын болдырмау, азайту, қайта өңдеу және қайта пайдалану бағыттарын қамтиды [2]. Мектеп жобасында осы бағыттардың ішінде оқушы өзі орындай алатын әрекетті таңдау маңызды.

Мақаланың мақсаты – этнодизайн мен материалды қайта пайдалануды біріктіретін, көркем еңбек сабағында қолдануға болатын әдістемелік үлгі ұсыну. Негізгі тұжырым мынадай: экологиялық мазмұн бұйымға берілетін атауда ғана қалмай, материалды іріктеуде, пішімді жоспарлауда, бөлшектерді біріктіруде және дайын жұмысты пайдалануда көрінуі тиіс. Мәтінде ұсынылған жоба тәжірибелік зерттеу нәтижесі емес, сыныпта бейімдеп қолдануға арналған әдістемелік шешім ретінде берілді.

Этнодизайнды сабақ мазмұнына енгізу

Осы мақалада этнодизайн ұғымы дәстүрлі қолөнердегі пішін, өрнек, түс үйлесімі мен жасау тәсілдерін қазіргі бұйымның қызметіне сай қолдану мағынасында пайдаланылады. Оқушы ұлттық нақышты дайын бейне ретінде көшіріп алумен шектелмей, таңдалған элементтің композициядағы орнын түсіндіреді. Мәселен, өрнек қалтаның жиегін айқындай

ма, бөліктердің қайталануын ұйымдастыра ма, әлде бұйымның орталығына назар аударта ма деген сұрақтар көркемдік шешімді нақтылауға көмектеседі.

Зерттеуге музей коллекциясындағы бұйымның фотосуретін, өнер туралы басылымдағы үлгіні немесе жергілікті шебердің рұқсатымен алынған материалды пайдалануға болады. Мұғалім дереккөздегі бұйым атауын, материалы мен жасалу тәсілін алдын ала тексереді. Оқушылар екі үлгіні салыстырып, олардың пішінін, түстерін, өрнек ырғағын және қызметін сипаттайды. Өрнектің мағынасы дереккөзде көрсетілмесе, оны ойдан толықтырмай, көзге көрінетін композициялық ерекшелікті талдаған дұрыс.

Мата қиындысын біріктіру тапсырмасы түстердің үйлесімін, бөлшектердің мөлшерін және материалды үнемді орналастыруды қатар қарастыруға ыңғайлы. Бір оқушы контраст түстерді, екіншісі бір түстің реңктерін таңдауы мүмкін. Мұғалім шешімнің бір ғана нұсқасын ұсынбай, таңдау себебін сұрайды. Мысалы, оқушы ұсақ өрнекті бөлшектерді тым көп орналастырғанда композицияның қабылдануын өз эскизі арқылы тексеріп, кейбірін алып тастауға немесе ірілендіруге шешім қабылдай алады.

Экологиялық мәдениетті бағалау үшін «табиғатты қорғау керек» деген жалпы пікір жеткіліксіз. Оқушы материалдың қайдан алынғанын, неге жарамды екенін, кесуден қалған бөліктерді қалай пайдаланатынын түсіндіруі қажет. ЮНЕСКО-ның тұрақты даму мақсаттары жөніндегі оқу нұсқаулығында танымдық, әлеуметтік-эмоциялық және мінез-құлықтық оқу нәтижелері ажыратылады [3]. Осы жіктеуді сабаққа бейімдегенде материал туралы білу, ортақ ресурсқа жауапкершілікпен қарау және үнемді әрекет ету өзара байланыста қарастырылады.

Қалташалы панно жобасын ұйымдастыру

Ұсынылатын жоба – оқу құралдарын сақтауға арналған ұлттық нақыштағы қалташалы панно. Оны 5–7-сынып оқушыларының дайындығына қарай бейімдеуге болады. Мұғалім жобаны сыныпта меңгерілетін нақты оқу мақсатына сәйкестендіріп, күрделілік деңгейін таңдайды. Жобаға екі немесе үш сабақ бөлу – жұмыс көлеміне, құралдардың қолжетімділігіне және оқушылардың тігу дағдысына байланысты әдістемелік ұсыныс. Жаңа тігіс түрін меңгеру қажет болса, оған бөлек жаттығу уақыты қарастырылады.

Оқушыға мынадай жобалық тапсырма беріледі: «Қолда бар таза мата қиындысын пайдаланып, өзіңе қажетті оқу құралдарына арналған қалташалы панно жаса. Ұлттық қолөнер үлгісінен таңдаған көркемдік элементті композицияға енгіз. Материалды, өлшемді және бекіту тәсілін неге таңдағаныңды түсіндір. Дайын бұйымды қауіпсіз жағдайда сынап, қажет болса жетілдір». Жобаның адресаты нақты болғаны дұрыс: оқушы өз жұмыс орнын немесе сыныптағы шағын шығармашылық бұрышты негізге ала алады.

Негіз ретінде пішінін сақтайтын таза мата, қалталарға өлшемі жеткілікті қиынды, жіп, ине, қайшы, сызғыш және бор қолданылады. Тым жұқа негіз қалтаға салынған заттың салмағынан созылуы мүмкін, сондықтан материал таңдауы шағын сынақпен тексеріледі. Пайдалануға жарамды киімді тек жоба үшін қию ұсынылмайды; тігіннен қалған немесе бастапқы қызметіне жарамайтын, бірақ таза әрі берік бөлшектерді алған жөн. Сыныпта ортақ материал қорының болуы оқушылардың мүмкіндіктерін теңестіруге көмектеседі.

1-кесте. Жоба кезеңдері және оқудың көрінетін дәлелі

Кезең	Оқушының әрекеті	Ұсынылатын дәлел
Қажеттілікті анықтау	Сақталатын заттарды және бұйымның орнын анықтайды.	Қысқа сипаттама және қажетті өлшемдер.
Үлгіні зерттеу	Екі қолөнер үлгісін салыстырып, бір көркемдік элементті таңдайды.	Дереккөз атауы және таңдау түсіндірмесі.
Жобалау	Екі эскиз жасап, қалта мен өрнектің орналасуын салыстырады.	Таңдалған эскиз, пішім және материал тізімі.
Дайындау	Бөлшектерді үнемді орналастырып, қауіпсіз біріктіреді.	Пішімнің орналасуы және дайын бұйым.
Сынау және жетілдіру	Өзі жоспарлаған жеңіл заттармен тексеріп, қажет тұсын түзетеді.	Сынақ жазбасы және енгізілген өзгеріс.

Бірінші сабақта қажеттілік талқыланып, үлгілер зерттеледі және эскиз дайындалады. Мұғалім екі эскизді салыстыру кезінде «Қай нұсқада материал аз қиылады?», «Қалтаның өлшемі салынатын затқа сай ма?», «Өрнек бұйымды пайдалануға кедергі келтірмей ме?» деген сұрақтарды қолдана алады. Оқушы негізгі матаны қимас бұрын қағаз пішімді үстіне орналастырып көреді. Бұл кезеңдегі өзгеріс материалдың артық жұмсалуын азайтуға бағытталады.

Келесі сабақта оқушылар бөлшектерді дайындап, бұрын меңгерген қол тігісімен біріктіреді. Мұғалім тексеруді дайын бұйыммен шектемей, қалтаны орналастыру және бекіту кезінде қысқа кері байланыс береді. Мысалы, қалта аузы тым тар болса, оны тікпей тұрып жоспарланған затпен салыстыруға болады. Жұмыс күрделі болған жағдайда үшінші сабақ сынау, түзету және таныстыруға арналады. Жоба кезеңдерінің осылай бөлінуі ұқыптылықты сақтап, асығыс аяқтау қажеттілігін төмендетеді.

Сынау үшін панно алдымен үстелге қойылып, қалтаға жоспарланған жеңіл оқу құралдары салынады. Оқушы заттың сыйымдылығын, тігістің беріктігін және бұйымнан зат алудың ыңғайлылығын бақылайды. Іліп тексеру қажет болса, бекіту орнын мұғалім ұйымдастырады. Байқалған кемшілік қысқа жазылады: мысалы, қалта салбыраса, оның өлшемін кішірейту немесе бекітуін күшейту ұсынылады. Бағалауда осындай саналы түзету оқушының жобалау әрекетінің маңызды бөлігі ретінде ескеріледі.

Қауіпсіздік және оқушылардың қатысуына жағдай жасау

Жұмысқа таза, құрғақ, жағымсыз иісі жоқ материал қабылданады. Ластанған, көгерген немесе бұрын химиялық зат сақтауға қолданылған қаптама пайдаланылмайды. Қайшы жабық күйде сабымен ұсынылады, ине арнайы қорапта не инеқапта сақталып, жұмыс соңында түгелденеді. Мұғалім құралдарды қолдану тәсілін көрсетіп, жұмыс орнын реттеуді бақылайды. Осы үлгідегі жобаға ыстық желім, өткір пышақ немесе күрделі электр жабдығы қажет емес; қол тігісі жеткілікті.

Тапсырманың күрделілігін бөлшек саны мен композиция арқылы өзгертуге болады. Қолдауды қажет ететін оқушы бір қалта мен ірі өрнек элементін қолданады; тәжірибесі жеткілікті оқушы бірнеше қалтаның үйлесімін және алынбалы сәндік бөлшекті жобалайды. Қағаз пішім, әрекеттердің қысқа реттілігі, контраст түсті жіп немесе мұғалімнің қайталап көрсетуі жұмысты қолжетімді етеді. Тігу әрекетін орындауға кедергі бар жағдайда оқушы композиция мен пішімді әзірлеп, біріктіруді қолдаумен орындай алады; оның дербес шешімі бөлек тіркеледі.

Топтық жұмыста міндеттерді оқушылардың қызығушылығы мен қажетті қолдауына қарай бөліп, әрқайсысына жобалық шешім қабылдауға мүмкіндік берген жөн. Бір оқушының

тек материал тасып, екіншісінің барлық көркемдік шешімді қабылдауы оқу мүмкіндігін тең бөлмейді. Сондықтан әр қатысушы кемінде бір эскиз нұсқасын немесе материалды үнемдеуге қатысты ұсынысын түсіндіреді. Таныстыруды қысқа жазба, ауызша түсіндіру не фотосуретке берілген түсініктеме түрінде ұйымдастыруға болады.

Үдерісті бағалау және кері байланыс

Бағалау өлшемдері жұмыс басталғанда түсіндіріліп, сабақ бойы қайта қолданылады. Көркем еңбек нәтижесін тек безендірудің күрделілігімен бағалау материалды ұқыпты таңдауды, сәтті өзгерісті және бұйымның қызметін назардан тыс қалдыруы мүмкін. Сондықтан ұсынылған өлшемдер дайын өнімді де, оны жасау барысындағы шешімдерді де қамтиды. Бұл кесте қалыптастырушы бағалауға арналған; оны міндетті балдық шкала немесе ресми бағалау нормасы ретінде қарастыруға болмайды.

2-кесте. Қалыптастырушы бағалауға арналған өлшемдер

Өлшем	Бақыланатын әрекет	Кері байланыс сұрағы
Көркемдік шешім	Таңдалған элементті бұйымның пішінімен және түсімен үйлестіреді.	Қай элемент композицияны тұтастырып тұр?
Материалды ұқыпты пайдалану	Қолда бар материалды таңдап, пішімді үнемді орналастырады.	Қай қиындыны келесі жұмысқа сақтай аласың?
Қызметі мен сапасы	Қалта өлшемін тексереді, бөлшектерді берік біріктіреді.	Қай бөлікті өзгерту қолдануды жеңілдетеді?
Қауіпсіз жұмыс	Құралды дұрыс пайдаланып, жұмыс орнын реттейді.	Келесі әрекетке дейін нені тексеру қажет?
Шешімді түсіндіру	Таңдауын негіздеп, сынаудан кейінгі өзгерісті сипаттайды.	Алғашқы эскизден не өзгерді және неліктен?

Кері байланыс нақты әрекетке сүйенгенде оқушы келесі қадамын түсінеді. «Жұмысыңды әдеміле» деген нұсқаудың орнына «Қалта жиегіндегі өрнек зат алуға кедергі келтіріп тұр; оның орнын өзгертіп көр» деуге болады. Құрдастардың пікірінде де бір байқалған ерекшелік пен бір сұрақ жеткілікті. Соңғы шешімді автордың өзі қабылдап, қандай ұсынысты не үшін қолданғанын түсіндіреді.

Рефлексияда оқушы материалды таңдаудағы бір шешімін, жұмыс барысында түзеткен бір тұсын және бұйымды әрі қарай қалай қолданатынын жазады. Мұғалім эскизді, дайын өнімді және түсіндірмені салыстыру арқылы оқу барысын бақылай алады. Алайда бір жобадағы ұқыпты әрекет оқушының экологиялық мәдениеті толық қалыптасты деген қорытындыға негіз болмайды. Тұрақты әдетті бағалау үшін келесі жұмыстардағы материал таңдауы мен әрекетін қайта бақылау қажет.

Қорытынды

Этнодизайнға негізделген жоба көркем еңбек сабағында ұлттық қолөнерді зерттеуді, функционалды бұйым жасауды және материалға жауапкершілікпен қарауды бір тапсырмада байланыстырады. Мұғалім үшін шешуші әдістемелік қадам – оқушының таңдауы мен оны негіздеуін көрінетін ету. Қажеттілікті анықтау, екі нұсқаны салыстыру, пішімді алдын ала орналастыру және бұйымды сынау осы мақсатқа қызмет етеді.

Ұсынылған қалташалы панно жобасының құндылығы қымбат материалға немесе күрделі жабдыққа тәуелді емес. Оның мазмұны қолда бар ресурспен ойластырылған шешім жасауға негізделеді. Оқушы ұлттық нақышты орынды қолданып, жарамды материалды сақтап, бұйымын күнделікті пайдалануға бейімдесе, сабақтың көркемдік және тәрбиелік

міндеттері нақты әрекет арқылы байланысады. Ал мұғалімнің жүйелі бақылауы бұл әрекеттерді кейінгі жобаларда дамытуға бағыт береді.

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Technical Sciences

A NETWORK-LAYER PROTECTION METHODOLOGY FOR MULTISERVICE COMMUNICATION NETWORKS BASED ON OUT-OF-BAND ANOMALY DETECTION

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Abstract

The convergence of voice, video and data services onto a single packet-switched infrastructure has turned the network layer of multiservice communication networks into a single point of failure: a successful attack on Layer 3 degrades every converged service simultaneously. This paper proposes a protection methodology built on the explicit separation of the data plane from the security plane. Transit traffic remains untouched on the hardware forwarding path, while a mirrored copy delivered through a SPAN port is examined by an out-of-band software sensor, so that analysis latency cannot propagate into transit latency by construction. The methodology covers four threat vectors specific to converged environments — source address spoofing, overlapping-fragment attacks, volumetric Layer 3 floods, and manipulation of Differentiated Services markings — the last of which receives comparatively little attention in the literature despite being characteristic of multiservice networks. A prototype sensor was implemented in Go and evaluated on a virtual testbed. Benchmarking places per-packet processing cost between 34.6 ns and 1850 ns depending on detector complexity, three to four orders of magnitude below the end-to-end delay budget for voice traffic defined by ITU-T G.114. Functional testing against a synthetic traffic capture confirmed correct classification of all four attack classes with no false positives on legitimate traffic.

Keywords: multiservice communication network, network-layer security, anomaly detection, quality of service protection, next generation networks, out-of-band monitoring

Xülasə

Səs rabitəsi, video yayımı və məlumat ötürülməsinin vahid paket şəbəkəsində birləşdirilməsi multiservisli rabitə şəbəkələrinin şəbəkə səviyyəsini kritik zəiflik nöqtəsinə çevirir: bu səviyyəyə edilən uğurlu hücum bütün konvergentləşdirilmiş xidmətlərin eyni vaxtda pozulmasına səbəb olur. Məqalədə məlumat ötürmə müstəvisinin təhlükəsizlik müstəvisindən ayrılmasına əsaslanan mühafizə metodologiyası təklif edilir. Tranzit trafik aparat səviyyəsində toxunulmaz qalır, SPAN portu vasitəsilə əldə edilən güzgülənmiş nüsxə isə xarici proqram sensoru tərəfindən təhlil olunur; beləliklə, təhlil gecikməsi tranzit gecikməsinə struktur olaraq təsir edə bilmir. Metodologiya dörd hücum vektorunu əhatə edir: ünvan saxtakarlığı, fraqmentlərin üst-üstə düşməsi hücumları, həcmli şəbəkə səviyyəsi daşqınları və xidmət keyfiyyəti nişanlarının manipulyasiyası. Go dilində hazırlanmış prototip sensorun benchmark nəticələri paket emalının detektordan asılı olaraq 34,6 ns ilə 1850 ns arasında olduğunu göstərir ki, bu da ITU-T G.114 tövsiyəsində səs trafiki üçün müəyyən edilmiş gecikmə həddindən üç-dörd tərtib aşağıdır.

Açar sözlər: multiservisli rabitə şəbəkəsi, şəbəkə təhlükəsizliyi, anomaliyaların aşkarlanması, xidmət keyfiyyətinin mühafizəsi, növbəti nəsil şəbəkələr

Аннотация

Конвергенция голосового трафика, видеопотоков и передачи данных в единой пакетной инфраструктуре превращает сетевой уровень мультисервисных сетей связи в критическую точку отказа: успешная атака на уровень L3 одновременно выводит из строя все конвергированные сервисы. В статье предлагается методология защиты, построенная на разделении плоскости передачи данных и плоскости анализа безопасности. Транзитный трафик проходит по аппаратному тракту без программного вмешательства, а его зеркальная копия, полученная через SPAN-порт, анализируется внешним программным сенсором в режиме Out-of-Band, вследствие чего задержка анализа конструктивно не способна повлиять на задержку передачи. Методология охватывает четыре вектора угроз, включая манипуляцию метками DiffServ — вектор, специфичный для мультисервисной среды и сравнительно редко рассматриваемый в литературе. Прототип сенсора реализован на языке Go; время обработки пакета составляет от 34,6 нс до 1850 нс в зависимости от сложности детектора, что на три-четыре порядка ниже нормативной задержки для голосового трафика по ITU-T G.114.

Ключевые слова: мультисервисная сеть связи, сетевая безопасность, обнаружение аномалий, защита качества обслуживания, сети следующего поколения

1. Introduction

Modern telecommunication networks are increasingly built on the principle of convergence: voice traffic, video streams and data transfer are consolidated within a single IP infrastructure. This approach, which underpins the Next Generation Networks (NGN) concept formalised in ITU-T Recommendations Y.2001 and Y.2011, allows operators to reduce operating expenditure substantially and to scale services with considerable flexibility. At the same time, the consolidation of heterogeneous services introduces a structurally new problem. All critical data flows now traverse a single point — the network layer of the TCP/IP stack — which means that compromising this layer alone causes degradation or complete failure across the entire set of delivered services.

The conventional arsenal of network security instruments — IPsec, VPN tunnelling and access control lists — was designed for homogeneous networks with a predictable traffic profile. Transplanted into a multiservice environment, these tools reveal a common limitation: each addresses a local task without forming a coherent system of protection. Composite attacks such as source address spoofing, interference with dynamic routing protocols, or distributed denial of service require a coordinated response combining cryptographic protection with real-time behavioural analysis of packets. Existing studies generally treat these aspects in isolation and do not offer a unified methodological basis for high-load converged networks.

The objective of this work is to develop a coherent methodology for protecting information at the network layer of multiservice communication networks and to implement a software prototype capable of detecting network anomalies without compromising quality of service (QoS). The study is deliberately confined to Layer 3 of the OSI reference model; the data link and application layers are addressed only insofar as they influence processes occurring at L3. Experimental verification was carried out in a software-emulated network environment, without carrier-class hardware.

The contribution of the paper is twofold. First, it formulates an adaptive protection methodology founded on the separation of the data plane from the security plane, which resolves the structural conflict between analytical depth and forwarding latency. Second, it presents and evaluates a working prototype that implements this methodology as four specialised detectors,

including one targeting DiffServ marking abuse — a vector specific to multiservice environments that has received limited attention in the existing literature.

2. Network-layer threats in multiservice environments

The architectural origin of network-layer vulnerabilities lies in the design of the IP protocol itself. When IP was specified, routing resilience was prioritised while verification of the packet source was deliberately omitted (Postel, 1981). In homogeneous corporate networks this limitation was compensated for by perimeter defences. In a multiservice environment the same property acquires a qualitatively different dimension: a single transport plane means that a threat realised at L3 automatically affects every converged service at once.

From a practical standpoint, network-layer threats can be classified according to the resource they target rather than the mechanism by which they are delivered. Table 1 presents this classification.

Table 1. Classification of network-layer threats by targeted resource

Threat	Underlying weakness	Consequence for the multiservice network	Targeted resource
IP spoofing	No source verification in IP	ACL bypass, concealment of DDoS sources	Filtering policies
Teardrop / fragmentation flood	Defects in fragment reassembly logic	Buffer exhaustion, failure of QoS queues	Router memory
ICMP/UDP flood, Smurf	Stateless nature of IP, broadcast amplification	Exhaustion of CPU and link capacity	Computational resources
DSCP abuse	No verification of priority markings	Voice and video degradation, loss of legitimate packets	Prioritisation mechanisms

The fourth row merits particular attention. Unlike the classical threats aimed at disrupting availability, DSCP abuse is specific to multiservice networks. An adversary positioned inside the network perimeter can mark its own packets with the Expedited Forwarding class reserved for voice traffic (Jacobson et al., 2002), thereby occupying the high-priority queue and displacing legitimate VoIP flows. The consequence is degradation of call quality with none of the signatures of a conventional attack: there is no traffic surge and no anomaly in the routing tables. The analysis leads to a central observation — threats at L3 in a multiservice environment differ not only in their delivery mechanism but in the resource they consume, and a methodology oriented exclusively towards address-space filtering leaves attacks on routing and prioritisation mechanisms entirely uncontrolled.

3. Limitations of established protection technologies

Existing protection technologies are best assessed not in terms of their general capabilities but against the two constraints specific to multiservice networks: strict latency requirements for real-time traffic, and the need to counter the threats enumerated in Section 2.

Access control lists exhibit the best latency characteristics, since hardware implementation on TCAM matrices permits processing at line rate. Their stateless nature, however, makes an ACL effective precisely to the extent that the administrator can anticipate the shape of the threat at the moment the rules are written. IP spoofing, in which malicious traffic carries a formally admissible source address, is invisible to an ACL. DSCP manipulation, which uses legitimate addresses and ports, passes equally unnoticed.

IPsec and VPN tunnelling address confidentiality and integrity (Kent & Seo, 2005), but introduce into multiservice traffic exactly those characteristics that are most critical to it. Encapsulation and cryptographic transformation increase both packet size — an overhead of 20 to 60 bytes in tunnel mode — and processing delay. For VoIP, where the permissible end-to-end delay does not exceed 150 ms under ITU-T G.114, additional delay from a software cryptographic implementation may become critical on loaded nodes. A more fundamental limitation is that IPsec offers no protection against volumetric denial-of-service attacks: the border router will expend computational resources decrypting junk traffic on equal terms with legitimate traffic.

The contradiction can therefore be stated succinctly: instruments with zero latency cost (ACL) possess no analytical capability, while instruments with analytical capability (stateful firewalls, inline IPS) impose delay that a multiservice network cannot absorb.

4. Proposed methodology

The proposed methodology removes the cause of the contradiction rather than attempting to balance its terms. Its founding principle is the separation of the data plane from the security plane. All transit traffic continues to pass through the hardware interfaces of the router without any software intervention. A copy of that traffic, obtained through port mirroring (SPAN), is directed to an external software sensor operating out-of-band. Analysis latency is thereby rendered structurally incapable of influencing forwarding latency — not reduced to an acceptable level, but excluded by construction.

The functional architecture comprises four sequential stages.

At the first stage the sensor performs selective parsing of the headers of incoming mirrored traffic. The fields subject to analysis are those of the IPv4/IPv6 header — addresses, DSCP/ToS, fragmentation flags and offset — together with ICMP and UDP headers and packet arrival timestamps used to compute flow intensity. Deep packet inspection of the payload is deliberately excluded, which preserves sensor throughput on high-load interfaces.

At the second stage the extracted metadata enters an analytical core implementing four detection modules, each corresponding to one of the threats classified in Section 2. The RPF verification module reproduces the logic of Unicast Reverse Path Forwarding in software (Baker & Savola, 2004), identifying packets whose source addresses are incompatible with the receiving interface. The fragmentation control module verifies the mathematical consistency of fragment offset fields, detecting overlapping fragments before they reach their destination. The flow statistics module tracks per-source packet rates and signals when thresholds characteristic of volumetric flooding are exceeded. The DSCP audit module analyses the correspondence between the priority marking, the packet size and the transport protocol, exposing illegitimate assignment of the EF class.

At the third stage, once an anomaly is confirmed, the sensor issues a control action to the router: it dynamically installs a deny rule in the hardware ACL, or initiates Remote Triggered Black Hole filtering to isolate the source. Because the command travels over a separate management channel, it does not compete with transit traffic for computational resources.

At the fourth stage, after a configured blocking timeout expires, the sensor automatically withdraws the restrictive rule and returns the router to its standard mode. This prevents the accumulation of stale rules and the long-term degradation of ACL table capacity.

The methodology does not claim to replace existing protection mechanisms; ACL and IPsec retain their functions within the baseline security tier. Its value lies in filling the analytical gap — behavioural monitoring of threats that static mechanisms are structurally incapable of detecting, without compromising the QoS requirements of the multiservice environment.

5. Prototype implementation

The prototype sensor was implemented in Go. The choice of technology stack was governed by three concrete requirements: minimisation of deployment dependencies, since the

resulting statically linked binary requires no runtime environment on the monitoring host; high concurrent throughput, provided by the goroutine scheduling model; and resilience of the defensive code itself to the classes of attack it processes, since automatic bounds checking eliminates the buffer overflow conditions that malformed fragments are designed to trigger. Packet capture is performed through libpcap bindings, with capture filters applied at kernel level so that irrelevant traffic is discarded before it reaches user space.

The analytical core comprises four detectors sharing a unified packet metadata abstraction and a common alert channel with deduplication. Each detector corresponds to one row of the threat classification in Table 1. Table 2 summarises their operating principles: the header fields each module reads, the rule by which it reaches a verdict, and the state it retains between packets.

Table 2. Operating principles of the four detection modules

Detector	Header fields inspected	Decision rule	Retained state
SpoofingDetector	Source address; interface role	Source address belongs to a trusted internal prefix yet arrived on an external interface (uRPF strict mode)	Static set of trusted prefixes
FloodDetector	Source address; arrival timestamp	Instantaneous rate exceeds the pps threshold, or the smoothed EWMA rate exceeds the threshold scaled by an alert factor	Per-source counter and EWMA value, reset each second
QoSDetector	DSCP/ToS; total length; IP version	Packet marked EF or AF41 exceeds the size envelope admissible for the corresponding codec class	None; stateless O(1) evaluation
TeardropDetector	Fragment identifier, offset, flags, length	Arriving fragment overlaps arithmetically with a fragment already recorded for the same datagram	Per-datagram fragment map with timeout eviction

Two of these modules warrant closer examination in code, for different reasons. The flood detector illustrates the concurrency discipline that governs the entire core and explains the timing results reported in Section 6. The QoS detector implements the DSCP abuse check, which constitutes the principal novel element of this work and cannot be conveyed adequately in prose. The remaining two modules — spoofing and fragmentation — follow directly from the rules stated in Table 2 and reproduce well-documented algorithms, so their source is omitted here for reasons of space.

Listing 1 shows the essential structure of the flood detector, which maintains per-source state and applies an exponentially weighted moving average to distinguish sustained pressure from transient bursts.

Listing 1. Core state and inspection path of the EWMA-based flood detector

```
type ipState struct {
   packets  uint64  // packet counter for the current second
   ewmaRate float64 // exponentially weighted moving average, pps
}

type FloodDetector struct {
   mu            sync.Mutex
   states        map[string]*ipState
   threshold     uint64  // instantaneous pps threshold
   ewmaAlpha     float64 // smoothing coefficient alpha
   ewmaAlertFactor float64 // threshold multiplier for EWMA
   rawAlerts     chan<- *Alert
}

// Inspect stays on the hot path: it only increments a counter.
// Alert generation is deferred to the asynchronous tick loop.
func (fd *FloodDetector) Inspect(pkt *PacketInfo) *Alert {
   key := pkt.SrcIP.String()
   fd.mu.Lock()
   s, ok := fd.states[key]
   if !ok {
      s = &ipState{}
      fd.states[key] = s
   }
   s.packets++
   fd.mu.Unlock()
   return nil
}
```

The design principle visible in Listing 1 applies throughout the core: the per-packet path performs the minimum work required to record an observation, while statistical evaluation, threshold comparison and alert emission are relegated to a once-per-second tick executed on a separate goroutine. This is what keeps the inspection cost of the simpler detectors within tens of nanoseconds, as Section 6 shows.

Listing 2 presents the behavioural analysis of DiffServ fields. The check rests on an observation that requires no payload inspection: a legitimate voice frame carrying the EF marking is bounded in size by the codec that produced it — a G.711 frame at 20 ms packetisation amounts to roughly 200 bytes — whereas an adversary seeking to occupy the priority queue has every incentive to mark large payload-bearing packets. A mismatch between the declared service class and the observed packet size is therefore sufficient evidence of marking abuse.

Listing 2. Behavioural analysis of DiffServ markings in the QoS detector

```
// Inspect correlates the DSCP class against the observed packet size.
func (q *QoSDetector) Inspect(pkt *PacketInfo) *Alert {
   switch pkt.DSCP {

   case q.dscpEF: // voice class: reject oversized EF-marked packets
      if pkt.TotalLen > q.maxVoiceSize {
         return &Alert{
            Type:     AlertTypeQoS,
            SourceIP: pkt.SrcIP.String(),
            Detail: fmt.Sprintf(
               "QoS manipulation [EF/voice]: IPv%d packet with "+
                  "DSCP=%d exceeds the admissible size: %d > %d bytes.",
               pkt.Version, pkt.DSCP, pkt.TotalLen, q.maxVoiceSize,
            ),
            Timestamp: time.Now(),
         }
      }

   case q.dscpAF41: // video class: reject packets above the MTU envelope
      if pkt.TotalLen > q.maxStreamSize {
         return &Alert{
            Type:     AlertTypeQoS,
            SourceIP: pkt.SrcIP.String(),
            Detail: fmt.Sprintf(
               "QoS manipulation [AF41/video]: IPv%d packet with "+
                  "DSCP=%d exceeds the admissible size: %d > %d bytes.",
               pkt.Version, pkt.DSCP, pkt.TotalLen, q.maxStreamSize,
            ),
            Timestamp: time.Now(),
         }
      }
   }
   return nil
}
```

The algorithmic complexity of this method is O(1), since the switch statement compiles to a jump table; the detector holds no state between packets, which accounts for its modest allocation profile in Table 3. The threshold values are deliberately externalised to a configuration file rather than hard-coded, because operators deploy different codecs and different MTU policies, and fixed constants would render the detector inapplicable outside the specific environment in which they were chosen.

Alerts are emitted as structured JSON records containing the anomaly class, source address, timestamp and a human-readable technical description, in a form suitable both for manual incident review and for automated correlation by a SIEM platform.

6. Experimental evaluation

Testing was conducted on a virtual laboratory testbed running Linux on a laptop-class Intel Core i7 processor (13th generation, x86-64), using the standard Go benchmarking facility. Table 3 reports per-operation cost for each detector.

Table 3. Comparative performance of the analytical modules

Detector module	Processing time, ns/op	Memory, B/op	Allocations, per op
SpoofingDetector	34.64	0	0
FloodDetector	44.51	16	1
QoSDetector	754.2	376	9
TeardropDetector	1850	1518	13

Source: benchmarking results obtained by the author.

The figures confirm a direct relationship between the architectural complexity of a detector and its computational cost. SpoofingDetector and FloodDetector exhibit zero or single allocations on the critical path, a consequence of pre-allocated hash tables and the avoidance of object creation during per-packet inspection. A cost of 34–44 ns per packet corresponds to a theoretical throughput of roughly 22–29 million packets per second on a single core, which substantially exceeds the real load observed at access-layer provider edge nodes.

QoSDetector and TeardropDetector incur higher costs, at 754 ns and 1850 ns respectively. For the latter this is expected, since the detector must allocate state records for each unique datagram under reassembly. A cost of 1.85 µs per operation is not a limiting constraint: even at this figure a single goroutine can inspect on the order of 540,000 fragmented packets per second, whereas genuinely fragmented traffic constitutes a small fraction of the total flow. Measured against the ITU-T G.114 requirement of no more than 150 ms end-to-end delay for voice, the aggregate latency of the analytical core — even for the most resource-intensive detector — remains four orders of magnitude below the permissible value, and does so within an out-of-band architecture in which analysis delay does not affect transit traffic at all.

Functional correctness was verified against a synthetic traffic capture. Table 4 summarises the four response scenarios exercised during the run.

Table 4. Detection and mitigation scenarios verified on the test capture

Anomaly class	Observed event	Automated response
QoS manipulation	Packet marked DSCP=46 (EF) with a size of 478 bytes against a 300-byte limit	RPC command applied a remark-to-best-effort policy, preventing displacement of legitimate voice traffic
IP spoofing	Packet bearing an internal subnet address (10.5.5.100) received on the external interface	Inbound ACL activated to block the source; notification dispatched to the SIEM platform
Teardrop	Fragment overlap detected for datagram ID 0x00001337	Fragmented traffic from the originating host blocked at the next-generation firewall
L3 flood	Sustained burst of 1200 pps against a 1000 pps threshold (EWMA detector)	Remote Triggered Black Hole invoked via BGP community 65535:666 at the provider edge

All four scenarios were detected correctly and no false positives were recorded against the legitimate traffic in the capture, confirming that the threshold values selected for the test environment were appropriate. It must be stressed, however, that calibration of the EWMA

parameters and of the maximum voice packet size requires adaptation to the characteristics of a specific production network; the results obtained on the test capture demonstrate algorithmic correctness rather than universal configuration values.

7. Discussion and limitations

Compared with widely deployed solutions such as Snort, Suricata and Zeek, the sensor described here occupies a deliberately narrow niche. It is inferior to general-purpose intrusion detection systems in application-layer inspection, which it does not attempt, but it offers native support for threats specific to multiservice networks — DSCP abuse in particular — and imposes no latency on transit traffic whatsoever.

Three limitations should be acknowledged. First, evaluation was performed in a software-emulated environment; verification on carrier-class hardware at 40–100 Gbit/s loads remains outstanding. Second, the detection thresholds are static, and a production deployment would require an initial calibration period — 30 to 60 days of passive observation is a reasonable estimate — before transitioning to active prevention. Third, the current detector set does not cover attacks on routing protocols themselves, such as BGP prefix hijacking or OSPF route injection, which constitute the most natural direction for extension.

8. Conclusion

The transition from specialised networks to a converged IP architecture, while delivering substantial economic benefit, has produced a qualitatively new threat profile in which the network layer functions as a single point of failure. Comparative assessment shows that ACL, IPsec and behavioural IDS/IPS close complementary but non-overlapping subsets of the threat space, and that none of them individually provides full coverage of network-layer threats while simultaneously satisfying QoS requirements for voice and video services.

The methodology proposed in this paper addresses that gap through the separation of the data plane from the security plane, with out-of-band monitoring as its central architectural decision. The prototype implementation demonstrates that the approach is practicable: processing costs between 34.6 ns and 1850 ns per packet leave a margin of three to four orders of magnitude against the delay budget for real-time traffic, and all four classes of anomaly were detected without false positives on legitimate traffic.

For operators of multiservice networks, the practical recommendation is to deploy such a sensor at border nodes in passive monitoring mode, calibrate the EWMA thresholds against the individual traffic profile, and only then transition to active prevention with integration through NETCONF/YANG and BGP RTBH. Priority directions for further development are adaptive baselining to replace static thresholds with dynamic ones, extension of the detector set to routing protocol anomalies, and performance verification on carrier-class equipment.

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Literature

XIX ƏSR AMERİKA ƏDƏBİYYATINDA QADIN XARAKTERİNİN TRANSFORMASİYASI: ƏNƏNƏVİ QADIN MODELİNDƏN FƏRDİ ÖZÜNÜDƏRKƏ DOĞRU

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Xülasə. Məqalədə XIX əsr Amerika ədəbiyyatında qadın xarakterinin dəyişmə xətti əsrin müxtəlif mərhələlərini təmsil edən dörd bədii obraz – Hester Prynne, Ruth Hall, Jo March və Edna Pontellier əsasında araşdırılır. Tədqiqatın məqsədi qadın qəhrəmanın yalnız məişət və ailə münasibətlərinin iştirakçısı kimi təqdim edilməsindən fərdi seçim, iqtisadi müstəqillik, yaradıcı özünüifadə və şəxsi azadlıq tələb edən subyektə çevrilməsini izləməkdir. Təhlildə XIX əsr Amerika cəmiyyətində qadınlıq haqqında formalaşmış "true womanhood" modeli, məişət sferasının ideoloji funksiyası, qadın müəlliflərin ədəbi bazarda görünürlüğünün artması və əsrin sonuna doğru fərdi özünüdərk mövzusunun dərinləşməsi nəzərə alınır. Hester Prynne sosial mühakimə şəraitində daxili möhkəmliyi, Ruth Hall əməyin və peşəkar fəaliyyətin qadın həyatında yaratdığı yeni imkanları, Jo March yaradıcı ambisiya ilə ailə modeli arasındakı gərginliyi, Edna Pontellier isə ənənəvi rollardan daha radikal uzaqlaşma cəhdini təmsil edir. Müqayisə göstərir ki, XIX əsr Amerika ədəbiyyatında qadın xarakterinin inkişafı düzxətli və ziddiyyətsiz proses deyil; hər yeni mərhələ əvvəlki modeli həm davam etdirir, həm də onun sərhədlərini genişləndirir.

Açar sözlər: XIX əsr Amerika ədəbiyyatı, qadın xarakteri, qadın kimliyi, özünüdərk, iqtisadi müstəqillik, yaradıcı fərdiyyət.

THE TRANSFORMATION OF THE FEMALE CHARACTER IN NINETEENTH-CENTURY AMERICAN LITERATURE: FROM THE TRADITIONAL MODEL OF WOMANHOOD TO INDIVIDUAL SELF-AWARENESS

Abstract. This article examines the transformation of the female character in nineteenth-century American literature through four figures representing different stages of the century: Hester Prynne, Ruth Hall, Jo March, and Edna Pontellier. The study traces the movement from a woman defined mainly by domestic, moral, and familial expectations toward a literary subject who increasingly claims personal choice, economic independence, creative self-expression, and individual autonomy. The discussion considers the cultural model commonly described as "true womanhood," the ideological significance of the domestic sphere, the growing public presence of women writers, and the increasing importance of self-awareness in late-century fiction. Hester Prynne represents moral endurance and inward resistance under social judgment; Ruth Hall connects female development with paid work and professional authorship; Jo March embodies the tension between creative ambition and socially accepted domestic fulfillment; and Edna Pontellier brings the conflict between social role and individual desire to its most acute form. The comparative reading demonstrates that the development of the female character was not a simple linear progression. Each stage preserves elements of earlier conventions while also challenging

their limits, revealing a gradual but uneven redefinition of womanhood in American literary culture.

Keywords: nineteenth-century American literature, female character, female identity, self-awareness, economic independence, creative individuality.

GİRİŞ

XIX əsr Amerika ədəbiyyatı qadın obrazının bədii funksiyasında mühüm dəyişikliklərin müşahidə olunduğu dövrdür. Əsrin əvvəllərində və ortalarında qadın qəhrəman çox vaxt ailə, mənəvi borc, dini əxlaq, fədakarlıq və məişət məsuliyyəti ilə əlaqələndirilən çərçivədə təqdim olunurdu. Lakin həmin model əsr boyunca eyni şəkildə qalmadı. İctimai münasibətlərin dəyişməsi, çap mədəniyyətinin genişlənməsi, qadın müəlliflərin oxucu auditoriyasına daha fəal çıxışı və qadının əmək, təhsil, müəlliflik, şəxsi seçim kimi sahələrdə görünürlüğünün artması ədəbi xarakterin də tədricən mürəkkəbləşməsinə səbəb oldu. XIX əsr Amerika qadın yazıçılığının sonradan ədəbi tarixdə yenidən qiymətləndirilməsi göstərdi ki, sentimental və məişət mövzulu sayıldığı üçün uzun müddət ikinci dərəcəli hesab edilən bir sıra mətnlər əslində qadının sosial mövqeyi, mənəvi agentliyi və fərdi iradəsi haqqında ciddi müzakirələr aparırdı [2, s. 1-16]. Buna görə qadın xarakterinin inkişafını yalnız "itaətkar qadından azad qadına" keçid kimi sadələşdirmək mümkün deyil. Daha doğru yanaşma onun müxtəlif tarixi mərhələlərdə hansı seçim imkanlarına malik olduğunu, hansı maneələrlə qarşılaşdığını və özünü hansı vasitələrlə ifadə etdiyini müqayisəli şəkildə araşdırmaqdır.

XIX əsrin qadınlıq modeli barədə tədqiqatlarda Barbara Welterin "true womanhood" anlayışı mühüm başlanğıc nöqtələrindən biri hesab edilir. Welter dövrün qadın jurnalları, dini mətnləri və normativ diskursunda qadından əsasən dindarlıq, saflıq, itaət və məişətə bağlılıq gözlənildiyini göstərir [12, s. 151-174]. Bu model ədəbi qəhrəmanın davranışını da müəyyən edən mədəni fon yaradırdı. Bununla belə, ədəbiyyat həmin normaları yalnız təsdiqləmirdi. Qadın xarakterinin konfliktli vəziyyətlərdə seçimi, onun mənəvi qərarları, əmək fəaliyyəti və sosial mühakimə ilə münasibəti mövcud normaların daxilində alternativ həyat formalarının mümkünlüyünü göstərirdi. Nancy Cottun qadın "sferası" ilə bağlı araşdırmaları da məişət və ictimai məkanların sadə şəkildə bir-birindən ayrılmadığını, qadınların ailə və dini birliklər vasitəsilə sosial əlaqələr və təsir imkanları yaratdığını göstərən tarixi konteksti önə çıxarır [5]. Bu baxımdan XIX əsr Amerika ədəbiyyatında qadın qəhrəmanın dəyişməsi həm sosial məhdudiyyətlərin, həm də həmin məhdudiyyətlər daxilində yaranan yeni özünüifadə imkanlarının bədii tarixidir.

Məqalədə qadın xarakterinin inkişaf xətti Nathaniel Hawthornenin "The Scarlet Letter" romanındakı Hester Prynne, Fanny Fernin "Ruth Hall" əsərindəki Ruth Hall, Louisa May Alcottun "Little Women" romanındakı Jo March və Kate Chopinin "The Awakening" əsərindəki Edna Pontellier obrazlarının müqayisəsi əsasında izlənilir. Bu dörd obraz seçilmişdir, çünki onlar əsrin müxtəlif nöqtələrində qadının cəmiyyətlə münasibətini fərqli müstəvilərdə ifadə edirlər. Hester üçün əsas məsələ sosial mühakimə qarşısında mənəvi bütövlüyün qorunmasıdır; Ruth üçün iqtisadi yaşama qabiliyyəti və peşəkar fəaliyyət; Jo üçün yaradıcı ambisiya və öz həyatını seçmək istəyi; Edna üçün isə fərdi arzu ilə sosial rol arasındakı kəskin ziddiyyətdir. Beləliklə, təhlilin mərkəzində qadın obrazının xarici təsvirindən daha çox onun qərarvermə qabiliyyəti, daxili səsi, özünü təmin etmə cəhdi və cəmiyyətin ona təqdim etdiyi rollarla münasibəti dayanır.

XIX ƏSRİN SOSİAL-MƏDƏNİ FONUNDA QADIN XARAKTERİNİN FORMALAŞMASI

XIX əsr Amerika nəsrində qadın obrazının geniş yayılması təkcə ədəbi zövqlə bağlı deyildi. Qadınların oxucu və müəllif kimi kitab bazarında görünürlüğünün artması məişət, ailə münasibətləri, tərbiyə, əxlaq və fərdi seçim mövzularını ədəbi istehsalın mühüm hissəsinə çevirdi. Nina Baym qadınlar tərəfindən yazılan və qadın qəhrəmanların həyatına yönələn çoxsaylı romanları araşdıraraq bu mətnlərdə qəhrəmanın çətinlik qarşısında tam passiv deyil, əksinə ağıl, dözüm və mənəvi qərar vasitəsilə öz vəziyyətini dəyişdirməyə çalışan bir fiqur kimi təqdim olunduğunu göstərir [3]. Bu müşahidə qadın xarakterinin inkişaf xəttinin erkən mərhələsini

anlamaq üçün vacibdir. Qadın qəhrəman hələ ictimai sistemin açıq tənqidçisi olmaya bilərdi, lakin onun daxili seçimləri, zəhməti və özünü qoruma bacarığı passivlik stereotipini zəiflədirdi. Bu xarakter tipi sonrakı onilliklərdə daha açıq iqtisadi və yaradıcı müstəqillik formalarına çevriləcək xüsusiyyətlərin ilkin bədii zəminini yaradırdı.

Mary Kelley XIX əsr Amerika qadın müəlliflərinin "özəl" sayılan məişət məkanından "ictimai" ədəbi bazara çıxmasını ziddiyyətli proses kimi təhlil edir. Qadın müəllif bir tərəfdən dövrün qadınlıq normalarını nəzərə almalı, digər tərəfdən yazıçılıq vasitəsilə gəlir, nüfuz və ictimai səs qazanmalı idi [10]. Bu ziddiyyət qadın qəhrəmanların quruluşuna da təsir göstərirdi. Ədəbi mətndə qadın həm ailə üzvü, ana, bacı və həyat yoldaşı kimi ənənəvi münasibətlər şəbəkəsində qalır, həm də həmin münasibətlərdən kənarda şəxsi məqsəd formalaşdırmağa başlayır. Buna görə XIX əsr qadın xarakterinin dəyişməsi yalnız ideoloji şüarların ədəbiyyata daxil olması ilə izah edilə bilməz. Dəyişmə daha çox gündəlik həyatın konkret problemlərində – maddi təminat, iş seçimi, təhsil, yazmaq hüququ, sevgi və evlilik haqqında qərar, sosial qınağa münasibət – görünür. Bu mövzuların ardıcıl şəkildə genişlənməsi əsrin sonunda qadın qəhrəmanın daxili dünyasını müstəqil bədii problemə çevirir.

Jane Tompkins XIX əsrin populyar Amerika nəsrinin yalnız estetik "aşağılıq" meyarları ilə dəyərləndirilməsinin yanlış olduğunu vurğulayaraq sentimental mətnlərin sosial və mədəni iş gördüyünü göstərmişdir [11]. Qadın xarakteri baxımından bu yanaşma xüsusi əhəmiyyət daşıyır. Əgər məişət romanındakı ailə, ana, ev, xəstəlik, əmək və mənəvi seçim motivləri sadəcə təkrarlanan sentimental elementlər kimi deyil, sosial davranış modellərinin qurulduğu sahə kimi oxunarsa, qadın qəhrəmanın dəyişməsi daha aydın görünür. Əsrin əvvəllərində qəhrəmanın gücü dözümlülük və mənəvi üstünlükdə yerləşə bilirdisə, əsrin ortalarında bu gücə iqtisadi fəaliyyət və müəlliflik, sonrakı mərhələdə isə yaradıcı fərdiyyət və şəxsi azadlıq tələbi əlavə olunur. Bu dəyişmə birdən-birə baş vermir; yeni qadın xarakteri əvvəlki modelin bəzi dəyərlərini saxlayaraq onun sərhədlərini genişləndirir.

HESTER PRYNNE: SOSİAL MÜHAKİMƏ QARŞISINDA DAXİLİ MÜQAVİMƏT

Nathaniel Hawthornenin 1850-ci ildə nəşr olunan "The Scarlet Letter" romanı Puritan Yeni İngiltərəsində baş verən hadisələri təsvir etsə də, əsərin qadın obrazı XIX əsr Amerika mədəniyyətinin gender, əxlaq və fərdi vicdan barədə narahatlıqlarını da əks etdirir [9]. Hester Prynne cəmiyyət tərəfindən damğalanmış qadındır; onun geyimində daşımağa məcbur olduğu qırmızı "A" hərfi ictimai cəzanın görünən işarəsinə çevrilir. Lakin Hesterin xarakterinin əsas xüsusiyyəti onun bu cəza ilə tam məhv olmamasıdır. O, sosial təcridi qəbul etsə də, öz daxili həqiqətini bütövlükdə cəmiyyətin hökmünə təslim etmir. Hesterin mənəvi möhkəmliyi qadın xarakterinin inkişafında ilk mühüm mərhələni təmsil edir: qadın hələ ictimai strukturu dəyişmək gücünə malik deyil, lakin həmin strukturun ona verdiyi mənanı daxilən yenidən qurur.

Hesterin əmək fəaliyyəti də onun xarakterinin formalaşmasında əhəmiyyətlidir. Tikiş və naxış sənəti ona maddi yaşamaq imkanı verir və onu tam asılı vəziyyətdən qoruyur. Əmək burada müasir mənada geniş iqtisadi azadlıq yaratmasa da, qəhrəmanın öz həyatını davam etdirmək qabiliyyətinin göstəricisidir. Hester kənardan qəbul edilməyən qadın kimi yaşasa da, cəmiyyətin ehtiyac duyduğu işləri yerinə yetirir və zaman keçdikcə onun haqqında ilkin sərt hökm mürəkkəbləşir. Bu proses xarakterin sosial statusunun dəyişməsindən daha çox onun mənəvi mövqeyinin davamlılığını göstərir. Hesterin gücü açıq üsyanda deyil, susdurulmasına baxmayaraq şəxsiyyətini itirməməsindədir. Sonrakı qadın qəhrəmanlarla müqayisədə onun seçim sahəsi məhduddur, amma məhz bu daxili müqavimət sonrakı mərhələlərdə daha görünən müstəqillik formalarının başlanğıcı kimi qiymətləndirilə bilər.

Hester Prynne obrazının başqa bir mühüm cəhəti qadının yalnız "günah" kateqoriyası ilə müəyyənləşdirilməsinə qarşı mətn daxilində yaranan müqavimətdir. Cəmiyyət onu bir hərflə işarələyərək şəxsiyyətini vahid əxlaqi hökmə endirmək istəyir, lakin romanın gedişində Hesterin ana, əməkçi, qayğı göstərən insan və düşünən fərd kimi çoxqatlı xarakteri həmin sadələşdirməni

dağıdır. Qadın xarakterinin inkişaf xətti üçün bu, prinsipial məqamdır: qadın bir sosial rola və ya bir əxlaqi qiymətə sığmayan mürəkkəb subyekt kimi görünməyə başlayır. Gilbert və Gubarın XIX əsr ədəbiyyatında qadın müəlliflik və qadınlıq stereotipləri ilə bağlı irəli sürdükləri nəzəri yanaşma da qadın obrazlarının "ideal" və "pozucu" qütblər arasında sıxışdırılmasını diqqətə çatdırır [7]. Hester bu ikiliyi pozan xarakterdir; o nə sadəcə itaətkar ideal qadın, nə də yalnız cəmiyyətin mənfi işarələdiyi fiqurdur.

RUTH HALL: İQTİSADİ MÜSTƏQİLLİK VƏ İCTİMAİ SƏSİN FORMALAŞMASI

Fanny Fernin "Ruth Hall" əsərində qadın xarakterinin inkişafı Hesterlə müqayisədə daha açıq sosial və iqtisadi müstəviyə keçir. Ruth ailə təminatını itirdikdən sonra özünün və uşaqlarının yaşayışını təmin etmək üçün əmək bazarına daxil olmağa məcbur olur. Əsərin əsas yeniliyi qadının maddi müstəqilliyinin yalnız arzu kimi deyil, konkret gündəlik ehtiyac kimi göstərilməsidir [6]. Ruthun yazıçılıq və jurnalistika vasitəsilə qazanc əldə etməsi qadın xarakterini ev daxilində mənəvi dözüm göstərən fiqurdan ictimai məkanda öz bacarığını təsdiq edən subyektə çevirir. Susan K. Harris "Ruth Hall"da sentimental və sərt, satirik dil qatlarının birlikdə işlədiyini və bu üslubun qadının iqtisadi müstəqillik haqqını müdafiə etməsinə xidmət etdiyini vurğulayır [8, s. 263-279]. Bu baxımdan Ruthun mübarizəsi yalnız şəxsi xilas hekayəsi deyil, qadının peşəkar fəaliyyətə çıxışının bədii modelidir.

Ruthun inkişafında əhəmiyyətli cəhət ondan ibarətdir ki, onun müstəqilliyi ailəyə qarşı qoyulmur. O, övladlarına bağlılığını saxlayır və məhz onların rifahını təmin etmək ehtiyacı onu fəaliyyətə sövq edir. Lakin ənənəvi məişət idealı burada yeni məna qazanır: yaxşı ana olmaq üçün qadının iqtisadi cəhətdən bacarıqlı, qərar verə bilən və ictimai aləmdə hərəkət edə bilən şəxs olması tələb olunur. Bu, "true womanhood" modelinin daxilində mühüm dəyişiklikdir. Əgər əvvəlki normativ təsəvvür qadının təhlükəsizliyini ailənin kişi təminatçısı ilə əlaqələndirirdisə, Ruth Hall öz əmək qabiliyyəti ilə alternativ təminat forması yaradır. Beləliklə, qadın xarakterinin mənəvi agentliyinə iqtisadi agentlik əlavə olunur. Bu mərhələdə qadın yalnız öz dəyərlərini qoruyan deyil, sosial və maddi şərtlərini dəyişmək üçün fəaliyyət göstərən obrazdır.

Ruthun yazıçılıqla uğur qazanması XIX əsr Amerika ədəbi bazarında qadın müəlliflərin mövqeyi ilə də birbaşa səsləşir. Kelley qadın yazıçıların ev və ictimaiyyət arasında qurduqları münasibətin ziddiyyətli xarakterini göstərərək müəllifliyi qadın üçün həm sosial qəbul problemi, həm də yeni müstəqillik sahəsi kimi izah edir [10]. "Ruth Hall" bu ziddiyyəti qəhrəmanın taleyinə daxil edir: yazı əvvəlcə çarəsizlikdən doğan gəlir mənbəyidir, sonra isə şəxsiyyətin tanınması vasitəsinə çevrilir. Burada qadın xarakterinin "səsi" artıq metaforik anlayış deyil; o, çap olunan, oxunan və maddi dəyər qazanan söz vasitəsilə ictimai təsirə çevrilir. Bu xüsusiyyət qadın qəhrəmanın sonrakı inkişafı üçün vacibdir, çünki Jo Marchın yazı ambisiyası və Edna Pontellierin sənətə yönəlməsi məhz qadının fərdi yaradıcılığını həyat seçimi kimi düşünən daha geniş bir xəttin davamıdır.

JO MARCH: YARADICI FƏRDİYYƏT VƏ SOSİAL KOMPROMİS

Louisa May Alcottun "Little Women" romanında Jo March XIX əsr Amerika ədəbiyyatında qadın xarakterinin ən canlı keçid fiqurlarından biridir. Jo ailəsini sevir və bacıları ilə güclü emosional bağlara malikdir, lakin onun özünü yalnız ailədaxili rollarla müəyyənləşdirmək istəmədiyi aydındır [1]. Yazmaq arzusu, maddi qazanc əldə etmək cəhdi, sərbəst davranışı və ənənəvi qadın zərifliyi standartlarına tam uyğunlaşmaması onu əvvəlki qəhrəmanlardan fərqləndirir. Jo üçün əsas məsələ cəmiyyətin hökmü qarşısında dözməkdən və ya həyatını təmin etmək üçün işləməkdən daha genişdir: o, necə bir insan olmaq istədiyini özü müəyyənləşdirməyə çalışır. Bu baxımdan Jo March qadın xarakterinin yaradıcı fərdiyyət mərhələsini təmsil edir.

Jo Marchın fərdiliyi yalnız xarakter xüsusiyyətlərində deyil, onun gələcək barədə təsəvvürlərində də görünür. O, yazıçılığın təsadüfi məşğuliyyət deyil, şəxsi qabiliyyətinin reallaşması olduğunu düşünür. Eyni zamanda roman onun ambisiyasını ailə münasibətləri ilə qarşıdurmanın sadə sxeminə çevirmir. Jo həm ailə məsuliyyətinə bağlıdır, həm də öz yaradıcılıq

istəyini qoruyur. Məhz bu ikili mövqe XIX əsrin ortalarından sonrakı qadın xarakterinin mürəkkəbliyini göstərir. Baymın qadın nəsri haqqında araşdırmasında vurğulandığı kimi, qadın qəhrəmanın öz həyatını idarə etməsi çox vaxt mövcud sosial quruluşu tam tərk etmək deyil, onun daxilində bacarıq və iradə vasitəsilə mövqe qazanmaq formasında təqdim olunur [3]. Jo bu modelin daha fərdiyyətçi variantıdır.

Romanın Jo obrazı ilə yaratdığı yenilik onun qadınlığın vahid davranış formasına endirilməsini qəbul etməməsidir. Meg, Beth, Amy və Jo eyni ailənin üzvləri olsalar da, fərqli xarakter, arzu və həyat istiqamətlərinə malikdirlər. Bu çoxsəslilik qadın təcrübəsinin bir modelə sığmadığını göstərir. Jo özünü başqalarının qadınlıq gözləntiləri ilə müqayisə etdikdə tez-tez narahatlıq yaşayır, lakin mətn onun enerjisini və yaradıcılığını mənfi xüsusiyyətə çevirmir. Əksinə, bu xüsusiyyətlər onun şəxsiyyətinin əsas mənbəyi kimi təqdim olunur. Qadın xarakterinin inkişaf xəttində bu mərhələ mühümdür: fərqlilik artıq yalnız sosial qınağa qarşı dözüləsi yük deyil, fərdi dəyərin hissəsidir.

Bununla belə, Jo March tam radikal azadlıq modeli deyil. Əsərin sonunda onun həyatının ailə və ictimai fayda ilə yenidən bağlanması göstərir ki, roman fərdi ambisiya ilə sosial qəbul arasında müəyyən kompromis qurur. Bu kompromisi sadəcə müəllifin qadın azadlığından geri çəkilməsi kimi qiymətləndirmək məsələni sadələşdirərdi. Əslində Jo obrazının gücü onun bir neçə mümkün qadınlıq formasını eyni xarakterdə birləşdirməsindədir: bacı, qız, müəllif, müəllim, dost və həyat yoldaşı kimi rollar bir-birini tam ləğv etmir. Qadın xarakterinin inkişafı burada “ailədən qaçış” deyil, qadının ailədən kənar mənlik sahəsinə də sahib olması kimi formalaşır. Bu model əsrin sonundakı daha sərt konfliktlərin anlaşılması üçün keçid nöqtəsi yaradır.

EDNA PONTELLIER: ÖZÜNÜDƏRK VƏ ƏNƏNƏVİ ROLLARIN BÖHRANI

Kate Chopinin 1899-cu ildə nəşr olunan “The Awakening” romanında qadın xarakterinin fərdi özünüdərk xətti daha kəskin səviyyəyə çatır. Edna Pontellier ailə və cəmiyyət tərəfindən ona təqdim edilən həyatın müəyyən elementlərini qəbul etsə də, tədricən bu həyatın onun daxili istəklərini ifadə etmədiyini anlayır [4]. Əsərdə “oyanış” yalnız romantik hisslərlə bağlı deyil; Ednanın öz bədəninə, vaxtına, məkanına, sənət fəaliyyətinə və qərarlarına sahib olmaq istəyini də əhatə edir. Əvvəlki qəhrəmanlarla müqayisədə burada qadının problemi daha çox xarici maddi təhlükədən deyil, sosial rol ilə daxili mənlik arasındakı uyğunsuzluqdan doğur. Bu səbəbdən Edna qadın xarakterinin inkişafında psixoloji özünüdərkin ön plana keçdiyi mərhələni təmsil edir.

Ednanın sənətə marağı qadın yaradıcılığı mövzusunu Jo Marchın yazıçılıq ambisiyasından fərqli şəkildə davam etdirir. Jo yaradıcılığını ailə və əmək həyatına daxil etməyə çalışırsa, Edna üçün sənət daha çox özünü ayrıca fərd kimi hiss etməyin vasitəsinə çevrilir. O, məişət öhdəliklərinin bütün vaxtını və kimliyini müəyyən etməsinə qarşı çıxır. Bu qarşıdurmada roman qadının azadlığına sadə və rahat həll təqdim etmir. Əksinə, fərdi istəyin sosial reallıqla toqquşmasının nə qədər ağır nəticələr yarada biləcəyini göstərir. Bu xüsusiyyət “The Awakening”i əsrin sonundakı qadın xarakterinin ən mürəkkəb nümunələrindən birinə çevirir. Qəhrəmanın inkişafı qələbə ilə tamamlanan azadlaşma sxeminə uyğun gəlmir; əsər azadlıq istəyinin mövcud sosial çərçivədə hansı sərhədlərlə qarşılaşdığını açıq saxlayır.

Ednanın xarakteri “true womanhood” modelindən uzaqlaşmanın daha açıq formasını nümayiş etdirir. Welterin təsvir etdiyi məişətə bağlılıq və itaət idealları əsrin əvvəli və ortasında qadın davranışını normallaşdıran mühüm mədəni kodlar idi [12, s. 151-174]. Edna isə ailə rolunun onun bütün şəxsiyyətini müəyyən etməsini qəbul etmir. O, ana və həyat yoldaşı statusu ilə fərdi mənliyi arasında sərhəd çəkmək istəyir. Bu cəhdin problemli nəticəsi qadın azadlığının ədəbi təsvirində yeni mərhələ yaradır: məsələ artıq qadının “yaxşı” və ya “pis” davranması deyil, onun öz həyatının mənasını hansı ölçüdə özü müəyyən edə bilməsidir. Beləliklə, qadın xarakteri əxlaqi qiymətləndirmənin obyektindən ekzistensial və psixoloji sualların mərkəzinə keçir.

Kate Chopinin romanı qadın xarakterinin daxili səsini bədii strukturun əsas hərəkətverici qüvvəsinə çevirir. Ednanın qərarları bəzən ziddiyyətli və sosial baxımdan problemli görünə bilər,

lakin mətn onun daxili narazılığını sadəcə kapriz kimi təqdim etmir. Oxucu onun tədricən öz fərdiliyini dərk etməsini, əvvəlki həyat modelinə yadlaşmasını və yeni seçimlər axtarmasını izləyir. Bu psixoloji fokus XIX əsr qadın xarakterinin əvvəlki mərhələlərindən mühüm fərqdir. Hesterin daxili möhkəmliyi sosial cəzaya cavab, Ruthun fəaliyyəti maddi zərurətə cavab, Jonun yaradıcılığı fərdi ambisiyanın ifadəsidirsə, Ednada özünüdərk özü ayrıca problemə çevrilir. Bu səbəbdən əsrin sonuna doğru qadın xarakterinin inkişaf xətti daha çox "mən kiməm?" və "öz həyatım üzərində hansı hüquqa malikəm?" suallarında cəmlənir.

DƏYİŞMƏ XƏTTİNİN MÜQAYİSƏLİ XÜSUSİYYƏTLƏRİ

Hester Prynne, Ruth Hall, Jo March və Edna Pontellier obrazlarını ardıcıl müqayisə etdikdə XIX əsr Amerika ədəbiyyatında qadın xarakterinin inkişafında bir neçə əsas dəyişmə istiqaməti görünür. Birinci istiqamət qadının xarici sosial hökm qarşısındakı mövqeyindən öz həyatının aktiv təşkilatçısına çevrilməsidir. Hesterin əsas gücü cəmiyyətin damğasını daxilən qəbul etməməsindədirsə, Ruth artıq maddi şəraitini dəyişir, Jo peşə və yaradıcılıq seçimini formalaşdırır, Edna isə həyat tərzinin özünü sorğulayır. Burada passivlikdən aktivliyə sadə keçid yoxdur; Hester də passiv deyil. Fərq ondadır ki, hər növbəti mərhələdə qadının təsir göstərə bildiyi sahə genişlənir: əvvəlcə mənəvi özünütəyin, sonra iqtisadi fəaliyyət, ardınca yaradıcı özünüifadə və sonda şəxsi həyat modelini seçmək tələbi.

İkinci dəyişmə istiqaməti qadın xarakterinin "ailə daxilindəki rol"dan "çoxqatlı şəxsiyyət"ə doğru genişlənməsidir. Hester ana olmaqla yanaşı əməkçi və mənəvi qərar verən şəxsdir; Ruth ana və peşəkar yazıçıdır; Jo ailə üzvü və yaradıcı fərddir; Edna isə məhz ailə rolunun şəxsiyyətin bütün qatlarını əvəz etməsinə etiraz edir. Bu ardıcıllıq göstərir ki, XIX əsr Amerika ədəbiyyatında qadınlıq anlayışı getdikcə daha çox daxili fərqlər qəbul etməyə başlayır. Bauer və Gouldun redaktə etdikləri "The Cambridge Companion to Nineteenth-Century American Women's Writing" qadın yazıçılığının yenidən qiymətləndirilməsinin Amerika ədəbi kanonunun təsəvvürünü dəyişdirdiyini vurğulayır [2, s. 1-16]. Qadın qəhrəmanların bu cür müqayisəsi həmin dəyişmənin yalnız müəlliflər səviyyəsində deyil, xarakter quruculuğu səviyyəsində də izlənə bildiyini göstərir.

Üçüncü istiqamət əmək və yaradıcılığın qadın xarakterində tutduğu yerin dəyişməsidir. Hesterin tikişi yaşamaq və cəmiyyət içində müəyyən funksiya qazanmaq vasitəsidir. Ruthun yazıçılığı artıq gəlir və ictimai tanınma yaradır. Jo üçün yazmaq daxili ehtiyac və gələcək identikliyinin mühüm hissəsidir. Ednanın rəssamlığa yönəlməsi isə yaradıcılığı daha çox şəxsi özünüdərkin dili kimi təqdim edir. Bu ardıcıllıq qadının əməyinin iqtisadi funksiyadan yaradıcı-subyektiv funksiyaya doğru genişləndiyini göstərir. Əlbəttə, bu inkişaf xətti bütün XIX əsr Amerika ədəbiyyatını eyni sxemə salmır; müxtəlif sinif, irq və regional təcrübələr qadın xarakterlərini fərqli şəkildə formalaşdırırdı. Lakin seçilmiş mətnlər əsas ədəbi tendensiyanın bir istiqamətini – qadının öz bacarığı və istəyi ilə sosial mənlik qazanmasını – aydın şəkildə göstərir.

Dördüncü istiqamət evlilik və sevgi münasibətlərinin xarakter inkişafındakı funksiyası ilə bağlıdır. Erkən və orta əsr mətnlərində qadın taleyinin evliliklə sıx bağlılığı qorunsa da, sonrakı nümunələrdə evlilik qadın xarakterinin son və yeganə məqsədi kimi qəbul edilmir. Ruth Hallın əsas müstəqillik xətti dul qaldıqdan sonra başlayır və onun gələcək sabitliyi yeni evlilikdən deyil, öz əməyindən asılı olur. Jo March evlilik məsələsində öz qərarına malik olan qəhrəmandır və onun yaradıcı ambisiyası romantik xəttdən ayrıca inkişaf edir. Edna Pontellier isə artıq mövcud evliliyin onun fərdi mənliyi ilə ziddiyyətini problemə çevirir. Bu dəyişmə qadın xarakterinin romantik münasibətin əlavəsi olmaqdan çıxıb ayrıca psixoloji və sosial taleyə malik qəhrəmana çevrildiyini göstərir.

Beşinci istiqamət qadının nitqi və səsi ilə əlaqədardır. Hesterin gücü çox vaxt susqunluq, baxış və davranış vasitəsilə ifadə olunur. Ruth yazı vasitəsilə sözünü ictimai məkana çıxarır. Jo yazmaq və danışmaq istəyini açıq şəkildə həyatının bir hissəsi kimi müdafiə edir. Ednada isə daxili səs ilə xarici sosial dil arasında gərginlik dərinləşir. Bu ardıcıllıq qadın xarakterinin ifadə imkanlarının genişlənməsi kimi oxuna bilər. Lakin ədəbi inkişafın əsas nəticəsi qadının sadəcə "daha çox

danışması” deyil. Əsas dəyişiklik onun danışdığı mövzuların və özünü müəyyən etdiyi anlayışların artmasıdır. Əxlaq, ailə və fədakarlıqla yanaşı pul, peşə, yaradıcılıq, arzu, bədən, məkan və şəxsi seçim də qadın xarakterinin bədii dünyasına daxil olur.

Bu prosesdə qadın müəlliflərin özlərinin ədəbi tarixdə mövqeyi xüsusi əhəmiyyət daşıyır. Baym, Kelley və Tompkins kimi tədqiqatçıların işləri XIX əsrdə qadınlar tərəfindən yazılmış populyar mətnlərin ədəbi və mədəni dəyərinin yenidən qiymətləndirilməsində mühüm rol oynamışdır [3; 10; 11]. Bu tədqiqatlardan görünür ki, qadın nəsrinin məişət və sentimental mövzuları sırf konservativ məzmun daşımırdı; həmin mövzular daxilində qadının bacarığı, sosial münasibətləri, mənəvi qərarı və öz həyatını təşkil etmək imkanları müzakirə edilirdi. Buna görə qadın xarakterinin transformasiyası yalnız əsrin sonundakı açıq azadlıq tələbləri ilə başlanmır. Onun kökləri əsrin əvvəlki mərhələlərində qadının dözümlülük, əmək, mənəvi seçim və yazı vasitəsilə özünə sahə yaratmasında görünür.

Eyni zamanda inkişaf xəttinin ziddiyyətli xarakterini nəzərə almaq vacibdir. Hesterin mənəvi gücü onun sosial təcridini aradan qaldırmır; Ruthun iqtisadi uğuru qadınların ümumi hüquqi və sosial vəziyyətini avtomatik dəyişmir; Jo Marchın yaradıcılıq ambisiyası kompromislərlə müşayiət olunur; Ednanın fərdi azadlıq tələbi isə davamlı və təhlükəsiz həyat modelinə çevrilmir. Bu ziddiyyətlər qadın xarakterinin inkişafını daha inandırıcı edir. Ədəbiyyat sosial dəyişməni bitmiş nəticə kimi deyil, imkan və maneələrin yanaşı mövcud olduğu proses kimi göstərir. Məhz buna görə XIX əsr qadın qəhrəmanlarının təhlilində yalnız “azad” və “asılı” kimi iki kateqoriya kifayət etmir. Xarakterin real inkişafı seçim imkanlarının dərəcəsində, daxili səsin gücündə və sosial rolların yenidən mənalandırılmasında görünür.

NƏTİCƏ

XIX əsr Amerika ədəbiyyatında qadın xarakterinin inkişaf xətti qadının bədii təsvirdə getdikcə daha çox mənəvi, iqtisadi, yaradıcı və psixoloji agentlik qazanması ilə səciyyələnir. Hester Prynne sosial damğalanma qarşısında şəxsiyyətini qoruyan, daxili müqaviməti ilə seçilən qəhrəmandır. Ruth Hall bu müqaviməti ictimai və iqtisadi fəaliyyət səviyyəsinə çıxarır; onun əmək və yazı vasitəsilə özünü təmin etməsi qadın xarakterinin yeni sosial imkanını göstərir. Jo March fərdi yaradıcılıq və həyat seçimi mövzusunu ön plana gətirərək qadınlıq modelinin daxilində fərqliliyin mümkünlüyünü nümayiş etdirir. Edna Pontellier isə əsrin sonunda qadın xarakterinin ən kəskin daxili sualını formalaşdırır: sosial rol ilə fərdi mənlik bir-birinə uyğun gəlmədikdə insan hansı həyat formasını seçə bilər?

Aparılan müqayisə göstərir ki, bu inkişaf xətti nə düzxətli, nə də tamamilə mərhələli şəkildə bir-birini əvəz edən modellərdən ibarətdir. Əksinə, əvvəlki mərhələlərin xüsusiyyətləri sonrakı obrazlarda yeni formada davam edir. Hesterin dözümlülüyü Ruthda fəaliyyətə, Ruthun peşəkar səsi Joda yaradıcı ambisiyaya, Jonun fərdiyyəti Ednada daha radikal özünüdərk tələbinə çevrilir. Bununla yanaşı, ailə, sevgi, məsuliyyət və mənəvi seçim bütün mərhələlərdə əhəmiyyətini saxlayır. Dəyişən əsas məsələ qadının bu anlayışlara münasibətinin passiv qəbuldan şəxsi qərara doğru hərəkət etməsidir.

Beləliklə, XIX əsr Amerika ədəbiyyatında qadın xarakterinin transformasiyası ənənəvi qadın modelinin tam yox olması deyil, onun daxilində yeni mənlik formalarının meydana çıxması kimi qiymətləndirilə bilər. Əsrin ortalarında qadın qəhrəmanın mənəvi dayanıqlığı və əməyinə verilən əhəmiyyət sonrakı onilliklərdə peşəkar fəaliyyət, yaradıcılıq və şəxsi azadlıq problemlərinə çevrilir. Bu proses Amerika ədəbiyyatında qadın obrazını süjetin köməkçi elementi səviyyəsindən mürəkkəb daxili dünyaya və fərdi məqsədlərə malik əsas xarakter səviyyəsinə yüksəldir. Dissertasiya mövzusu baxımından belə mərhələləndirmə qadın xarakterinin dəyişməsini yalnız ayrı-ayrı əsərlərin təsviri kimi deyil, XIX əsr boyunca formalaşan geniş ədəbi-mədəni dinamika kimi öyrənməyə imkan verir.

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AZƏRBAYCAN ƏDƏBİ-BƏDİİ PUBLİSİSTİKASININ İNKİŞAF DÖVRLƏRİ

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XÜLASƏ

Publisistika eləcə də ədəbi-bədii publisistikanın ötən illərdəki fəaliyyəti, keçdiyi inkişaf dövrləri zamanla bir sıra tədqiqatçıların araşdırma mövzusu olmuşdur.

Məqalədə ədəbi-bədii publisistikamızın formalaşma prosesi, təşəkkülü,inkişaf dövrlərindən söhbət açılır. Məşhur yazıçı-publisist ziyalılarımızın publisistik fəaliyyəti, ədəbi yaradıcılığın bu qoluna aid yaratdıqları nümunələr təhlil edilir. Publisistikanın dünəni və bu günü arasındakı inkişak dinamikasına nəzər yetirilir.

Açar sözlər: Ədəbi-bədii publisistika,mətbuat,inkişaf dövrləri, ictimai şüur, əsas mövzular

Ədəbi-bədii publisistika bədii təsvir vasitələrinin gücü ilə ictimai-siyasi problemləri işıqlandıran ədəbi yaradıcılıq növüdür. Azərbaycan ədəbiyyatı ənənələlərinə əsaslanan publisitikanın bu növü həyatın idrakını və real təsvirini hədəfləyərək,cəmiyyəti kamilləşdirmək funksiyasını yerinə yetirir. Ədəbi-bədii publisistika yalnız informativ mətnlərlə deyil,həm də bədii obrazlılıq vasitəsilə ədəbi-estetik zövqün formalaşmasında böyük rol oynayır. Bir növ ədəbiyyatla jurnalistikanı birləşdirən bu janr milli mətbuatın və ədəbi yaradıcılığın sintezindən doğan nəzəri konsepsiyalara əsaslanır.

Publisistikanın bu növü XIX-cu əsrin sonu XX-ci əsrin əvvəllərində mətbuatın inkişafı ilə formalaşma prosesi keçmişdir.

Azərbaycan ədəbi-bədii publisistikasının keçdiyi yola və inkişaf dövrlərinə nəzər saldıqda açıq-aydın görürük ki,ictimai şüurun inkişafında mühüm rol oynayıb. Ümumiyyətlə publisistika mövcud olduğu bütün dövrlərdə ictimai şüurun güzgüsü olmuş,milli ideyanın gələcək nəsillərə aşılanmasına, mədəniyyətin təbliği və inkişafına xidmət etmişdir.

Azərbaycan publisistləri və ziyalıları müxtəlif dövrlərdə ədəbi yaradıcılığın bu növünə müraciət edərək dövrün ictimai-siyasi proseslərini dərin obrazlılıqla oxucuya çatdırmış, cəmiyyətin kamilləşməsi yolunda dəyərli nümunələr ortaya qoymuşlar. Dövrün böyük ziyalıları milli özünüdərk,azərbaycançılıq ideyalarını ideyalarını təbliğ etmək üçün ədəbi yaradıcılığın bir sıra növlərindən istifadə etdiyi kimi publisistika həmçinin ədəbi-bədii publisistikadan da məharətlə istifadə edib. “Mətbuatın yaranması və geniş arenaya çıxması,bununla da sənətkar sözünün tirajlanma imkanının genişlənməsi publisistikanın işlək, funksional xarakterini gündəmə gətirdi. Amma publisistika nə qədər böyük gücə malik olsa belə, günün-məhz bu günün aktual problemlərini gündəmə gətirməsi xarakteri uzun müddət bir çox sənətkarın yenə də ona deyil, bədii sözə üz tutmasını şərtləndirdi. Mətbuat və onun kütləvilik imkanı dünya düzəninin bu məqamını xeyli dəyişməyə səbəb olmuşdu. Mətbuatın özünü təsdiqi ilə, bir ictimai institut olaraq formalaşması ilə ən güclü bədii söz ustaları da bu ictimai institutun bel sütununu təşkil edən publisistikadan-günün aktual problemlərinin həllinə yönələn bu yaradıcılıq növündən kənarda qala bilməzdilər”.

Dünya publisistika tarixinə də nəzər saldıqda görürük ki, ən məşhur publisistlər öz dövrünün məşhur yazıçı və şairləri olmuşlar.

Ədəbi-bədii publisistikanın inkişafı bir çox amillərlə bağlı olmuşdur. O amillər ki, dövrünün aktual proseslərini özündə əks etdirib. Publsistikanın bu qolunun inkişaf dinamikası birbaşa olaraq

cəmiyyətin siyasi,sosial və mədəni vəziyyəti ilə bağlı olub. Keçdiyi hər bir inkişaf mərhələsində dövrün tələblərinə uyğun olaraq yeni məzmun, forma və funksiyalar qazanmışdır.

Biz Cahangir Məmmədlinin "Klassik Publisistikamız:Dünənin, Bu günün,Sabahın Sənət Örnəyi" sərlövhəli yazısına nəzər saldıqda publisistikamızın dünəni,bu günü və sabahı ilə bağlı maraqlı fikirlərə rast gəlirik. Bu yazıda publisistikanın keçdiyi müxtəlif dövrlərə diqqət yetirlir. Publisistikanın mahiyyəti,önəmi və nələrə qadir olduğu vurğulanır. Yazıda həmçinin XX-ci əsrin əvvəllərində Azərbaycan ziyalılarının publisistikaya güclü meyli və bunun müqabilində publisistikanın ədəbi məktəb səviyyəsinə yüksəlməsindən bəhs edilir. "Publisistika özünü xalqa söz deməyin,milli ideyaları gerçəkləşdirməyin ən güclü vasitəsi kimi göstərən bir zamanda klassikləşir və onun problemə, mövzuya sənətkarlıq baxışı böyük məktəbə çevrilir".

Ötən dövrlərə nəzər yetrirdikdə dəyərli publisistlərin qələmindən çıxan esse,oçerk,felyeton, publisistik hekayələr və.s kimi janr nümunələri ilə qarşılaşırıq. Bu nümunələr publisistikamızın dəyərli inciləridir. Tədqiqatçı Famil Mehdi "Bədii publisistika" adlı nəzəri tədqiqat əsərində "obrazlı təbliğatın ən gözəl nümunəsi" olan publisistikanın bir çox janrlarından bəhs edir. Oçerk,felyeton,pamflet,səyahətnamə,bədii gündəlik,məktub,sənədli novella və.s janrları aid edir.

İctimai fikrin bədii ifadəsi olan ədəbi-bədii publisistika XIX-cu əsrdə özünün ilkin təşəkkül mərhələsini yaşayır. Ümumiyyətlə XIX-cu əsr maarifçilik ideyalarının aparıcı olduğu bir dövrdür. Bu dövrdə ədəbi-bədii publisistika mövhumata,geriliyə,sosial ədalətsizliyə qarşı maarifçilik ideyalarının əsas silahına çevrilmişdir. XIX-cu əsrin sonu Avropada qəzet,jurnal dünyasının yaratdığı imkanlar Azərbaycanda da qabaqcıl yaradıcı ziyalıların sözü birbaşa ünvana çatdıran publisistikaya meylini gücləndirdi. XIX-XX-ci əsrlər publisistikanın M.F.Axundzadə,C.Məmmədquluzadə,M.Ə.Rəsulzadə,Ö.F.Nemanzadə,Ə.Ağaoğlu,Ə.Hüseynzadə,Ü. Hacıbəyli,C.Hacıbəyli... kimi dəyərli nümayəndələri yetişdi. Ancaq publisistikanın keçdiyi inkişaf yoluna nəzər saldıqda üç şəxsiyyətin-M.F.Axundzadə,H.B.Zərdabi,C.Məmmədquluzadə adını xüsusilə qeyd etmək lazımdır.

Tənqidi publisistikanın dəyərli nümunələrini yaratmış M.F.Axundzadənin "Kəmalüddövlə məktubları" əsəri publisistikamızın inciləri sırasındadır.H.B.Zərdabinin publisistikanın inkişafında xidmətləri danılmaz həqiqətdir. Zərdabinin publisistik fəaliyyətinin ana xəttini xalqı cəhalətdən qurtarmaq,elmin,təhsilin önəmini vurğulamaq,qadın hüquqlarını müdafiə etmək kimi mövzular təşkil edir. O, öz elmi-dünyəvi fikirlərini publisistika yolu ilə məharətlə yayırdı. Publisistikasının üslubu isə bir o qədər sadə,xalqın anlaya biləcəyi dildə idi. Ən böyük xidmətlərindən biri də məhz "Əkinçi" nin yaradılması oldu. 1875-ci il "Əkinçi" qəzetinin çapı,milli mətbuatın yaradılması publisistikaya da güclü təkan verdi. Publisistikanın tətqiqində xüsusi xidmətləri olan Şamil Vəliyev "Əkinçi" qəzeti haqqında yazırdı: "Əkinçi" sadəcə, ilk peşəkar praktik işin başlanğıcı, Azərbaycan milli mətbuatının banisi kimi səciyyələnmir, o həm də jurnalistikaya dair elmi-nəzəri fikrin və milli təcrübənin tarixi abidəsi kimi mühüm əhəmiyyət daşıyır".

"Əkinçi"dən sonra yeni-yeni yaradılan qəzet və jurnallar da öz ərafına güclü qələm sahibləri olan dəyərli publisistləri toplayırdı. Xüsusilə XX-ci əsrin əvvəlləri publisistikanın eləcə də ədəbi-bədii publisistikanın inkişafının əlamətdar dövrü olaraq yadda qalır. Yeni yaradıllan qəzetlər öz səhifələrini dəyərli ziyalıların publisistik nümunələri ilə bəzəyirdi. XX-ci əsrin əvvəllərini publisistikanın intibah dövrü adlandırsaq yanılmarıq.

"Həyat", "Şərqi-rus" qəzetlərinin, "Fiyuzat", "Molla Nəsrəddin" kimi jurnalların yaradılması publisistika tarixçəmizin zənginləşməsinə xidmət edirdi.

Bu dövr yeni yaradılan mətbu orqanlardan "Molla Nəsrəddin" jurnalı xüsusilə seçilir. Milli maraqlar, özünüdərk,azərbaycançılıq ideyalarının təbliği "Molla Nəsrəddin" jurnalında öz pik həddinə çatdı. Mollanəsrəddinçilər publisistikanın onlara yaratdığı imkanlardan istifadə edərək xalqı maarifləndirməyi qarşılarına məqsəd qoymuş, satirik publisistikanın da maraqlı nümunələrini yaratmışlar. Ətrafında böyük publisistləri toplamış, öz ideyalarını xalqa çatdırmaq yolunda məktəb səviyyəsinə yüksəlmiş "Molla Nəsrəddin" ədəbi məktəbinin publisistikamızın inkişafında böyük

xidmətləri olub. Bu ədəbi məktəbin nümayəndələrinin yaratdığı publisistik nümunələr publisistikamızın şah əsərləri sırasındadır. Təbii, bu olməz incilər publisistikanın inkişafını qaçılmaz edirdi. Cahangir Məmmədli bu dövr publisistikasını haqlı olaraq belə xarakterizə edir: "Azərbaycan publisistikası XX-ci əsrin əvvələrindəki səviyyəsi ilə heyrət doğurur. Həmin dövrdə Azərbaycanda baş vermiş ictimai-siyasi hadisələr, milli özünüdərk prosesinin güclənməsis, azərbaycançılıq ideyasının qabardılması publisistikanın həm mövzu dairəsini, həm də sənətkarlıq keyfiyyətini yüksəklərə qaldırdı".

Mollanəsrəddinçilər cəmiyyətdə baş verən heç bir hadisəyə bihanə qalmır,publisistikanın imkanlarından olduqca gözəl bəhrələnirdilər. Cəlil Məmmədquluzadə "Molla Nəsrəddin" jurnalını yaratması ilə istər publisistikada , istərsə də azərbaycançılıq ideologiyasının banilərindən birinə çevrildi. C.Məmmədquluzadə və silahdaşlarının fəaliyyəti ədəbi -bədii publisistikanın inkişafını qaçılmaz etdi. C.Məmmədquluzadə,Ö.F.Nemanzadə,Ə.Ağaoğlu, M.Ə.Sabir və.s kimi mollanəsrəddinçilərin fəaliyyəti publisistikamızın təşəkkülü prosesində önəmli yer tutdu. "Mollanəsərddinçilər dövrünü Azərbaycan ədəbiyyatının və milli mətbuatımızın qızıl dövrü, cəmiyyətimizin güzgüsü və həqiqətin ən dərin qatlarına kimi bütün ictimaiyyətə çatdırılması mərhələsi kimi səciyyələndirmək daha doğru və ədalətli olardı".

Publisistikanın keçdiyi hər bir dövr müxtəlif çalarları ilə nəzərə çarpır. Eynilən sovet publisistikası da fərdi xüsusiyyətləri ilə seçilir. Sovet publisistikası ümumiyyətlə bolşevik ideologiyasının təsirlərinə məruz qalmış, ciddi senzura nəzarəti altında fəaliyyət göstərmişdir. 70 il ərzində avtoritar modeli təsiri ilə fəaliyyət göstərən Azərbaycan publisistikası və mətbuatı cəmiyyəti məlumatlandırmaq funksiyasından daha çox, hakimiyyətin diqtə etdiyi informasiyanı təbliğ etmişdir. Tədqiqatçı Aynurə Paşayeva " Azərbaycan" jurnalında publisistika məsələləri" adlı monoqrafiyasında sovet dövrü publisistikasına da nəzər salmış, bu dövrün publisistika mənzərəsini incəlikləri ilə göstərmişdir. O,öz monoqrafiyasında sovet dövrü publisistikasını belə təsvir edirdi: "Sovet dövrü publisistikasında köhnəlik ilə yeniliyin mübarizəsi,yeni insan obrazı-zəhmətkeş qəhrəman obrazının təsviri zamanı gerçəkliyin konfliktinə diqqət yüksək səviyyədə deyildi. Sovet dövründə mövcud rejim milli şüurun oyanmasına imkan vermirdi. Bunun arxasında da əsas məqsəd milli gücü zəiflədərək passiv saxlamaq, vətənpərvərlik ideallarını şəxsi siyasi mövqedən istifadə etmək idi".[2]Sovet dövrü publisistikası və mətbuatında mövcud rerjimin təbliğat materiallarından əlavə yeni həyatın qurulması,sənayeləşmə,iqtisadi inkişaf mövzularına aid materiallara da rast gəlinir.

Publisistikanın keçdiyi dövrlərdən danışarkən mühacirət publisistikasına da nəzər salmaq lazımdır. Mühacirət publisistikasının əsasını Azərbaycan Xalq Cümhuriyyətinin süqutundan sonra mühacirətdə olan ziyalıların publisistik fəaliyyəti təşkil edir. Mühacirət publsistikasında milli istiqlal,sovet rejiminə etiraz mövzulu publisistik əsərlər həmin dövrün mənzərəsini, mühacirətin ağrılı tərəfini bizə publisistika yolu ilə çatdırır. M.Ə.Rəsulzadə,Ə.Hüseynzadə,Ə.Ağaoğlu kimi ziyalılar mühacirət publisistikası nümayəndələridir. Abid Tahirli mühacirət mətbuatında publisistika adlı tədqiqat işində deyirdi: " Mühacirət mətbuatında publisistika tamamilə yeni keyfiyyət və yeni mahiyyət,məna kəsb edir. Mühacirlərin ideoloji mübarizəsində kəskinliyi,son dərəcə sərtliyi ilə seçilən publisistik nümunələr, həm də mühacirət həyatının salnaməsidir.[1]

Azərbaycanın müstəqillik əldə etməsi ilə publisistika məzmun forma cəhətdən yeni dövrə qədəm qoydu. Senzuranın ləğvi publisistikanın təsiretmə imkanlarını da artırdı. I-ci Qarabağ müharibəsinin, Qarabağ həqiqətlərinin işıqlandırılması müasir dövr publisistikasının əsasd özəyinə çevrilmişdi. İstər I-ci Qarabağ, istərsə də II-ci Qarabağ müharibəsinin dolğun işıqlandırılması,vətənpərvərlik, milli birlik hissinin gənclərə aşılanması, müqəddəs şəhidlərimiz haqqında materialların hazırlanması milli mətbuatın və publisistikanın əsas prioriteti olmuşdur.

Müasir dövrdə isə publisistika deyə bilərik ki, daha çox operativ və interaktiv xarakter daşıyır. Qlobal problemlərin publisistik üslubda işıqlandırılması geniş vüsət almışdır.

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Aliyeva Aynur

Periods of devolopment of Azerbaijani literary and artistic journalism

Summary

Literary and artistic journalism is a type of literary creativity that illuminates socio-political problems with the power of artistic means of depiction. This type of journalism, based on the traditions of Azerbaijani literature, aims at understanding and realistic depiction of life and fulfills the function of perfecting society. Literary and artistic journalism plays a major role in the formation of literary and aesthetic taste not only through informative texts, but also through artistic imagery. This genre, which combines a kind of literature with journalism, is based on theoretical concepts arising from the synthesis of the national press and literary creativity.

Айнур Алиева

Этапы развития азербайджанской литературно-художественной публицистики

Резюме

Публицистика, а также литературно-художественная публицистика в последние годы, их деятельность и пройденные этапы развития со временем становились предметом исследования ряда учёных.

В статье рассматриваются процесс формирования литературно-художественной публицистики, её становление и этапы развития. Анализируется публицистическая деятельность известных писателей-публицистов и интеллигенции, а также созданные ими образцы, относящиеся к данному направлению литературного творчества. Освещается динамика развития публицистики, проводится сопоставление её прошлого и настоящего.

Ключевые слова: литературно-художественная публицистика, печать, этапы развития, общественное сознание, темы.

Medical Sciences

Innovation, Competitiveness and Forecasting as Paradigmatic Principles of Self-Development of Higher Education in the 21st Century: In the Context of Immunology and Medical Education

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Abstract
This paper explores three core paradigmatic principles that define the self-development of higher education in the 21st century — innovation, competitiveness and forecasting — and systematically analyzes their connotations, values and implementation paths in the system of higher medical education, with a special integration of the content of immunology. It explains how these principles respond to the evolving demands of modern medicine and healthcare, drive the reform of educational content, methods and technologies, and help cultivate high-quality medical talents capable of meeting both current and future needs. Combined with the characteristics of immunology — an interdisciplinary, rapidly developing and clinically fundamental discipline — this paper discusses the specific strategies, practical measures and application effects of embedding these principles into teaching, learning and research activities. The research aims to provide theoretical support and practical reference for optimizing the training system of medical professionals, improving the quality of immunology education, and enhancing the overall competitiveness and sustainable development capability of medical universities.
Keywords: higher education; self-development; innovation; competitiveness; forecasting; medical education; immunology; educational reform; talent cultivation

Main Text

Introduction

The 21st century is characterized by rapid advancements in science and technology, profound changes in social demands, and continuous updates of knowledge systems. Higher education, as the core carrier of knowledge inheritance, innovation and talent cultivation, has transformed from a static knowledge-transfer system into a dynamic, self-improving system that must constantly adapt to external changes and internal development needs. Among the core paradigms guiding this transformation, innovation, competitiveness and forecasting have become three fundamental principles, running through all aspects of educational philosophy, curriculum design, teaching practice and institutional governance.

Medical education, as a specialized branch of higher education, undertakes a unique mission: to train medical professionals who safeguard human life and health. It is highly professional, practice-

oriented and closely linked to cutting-edge scientific progress. Immunology, as a core basic and clinical medical discipline, is particularly representative — it evolves rapidly, connects basic theories with clinical applications, and serves as a cornerstone for understanding disease mechanisms, diagnosis, treatment and prevention. Integrating the three principles of self-development with immunology education is not only a requirement for the modernization of medical education, but also an inevitable path to improve the quality of talent training and the international influence of medical universities. This paper analyzes the connotation of each principle, explores their specific manifestations and implementation strategies in immunology education, and puts forward suggestions to promote the sustainable development of medical education.

1. Connotation and Value of Paradigmatic Principles of Self-Development in Higher Education

1.1 Innovation: The Core Driving Force of Educational Modernization

Innovation in higher education refers to the continuous updating, optimization and re-creation of educational concepts, content, methods, technologies, management models and evaluation systems. It is the primary driving force for breaking through traditional educational frameworks, adapting to new scientific and technological developments, and improving educational quality. Innovation is not limited to adding new knowledge; it also includes reconstructing knowledge systems, transforming teaching logic and creating new learning scenarios.

In medical education, and especially in immunology, innovation is indispensable. Immunology is one of the fastest-growing disciplines in life sciences: new discoveries about the structure and function of the immune system, immune regulation mechanisms, immune-related diseases, and technologies such as immunotherapy and vaccine development are emerging every year. For example, breakthroughs in immune checkpoint therapy, CAR-T cell technology and molecular immunodiagnostics have completely changed the landscape of clinical medicine. If immunology education remains unchanged, it will inevitably lag behind clinical practice and scientific progress, making the knowledge students acquire outdated upon graduation.

Innovation in immunology education is reflected in multiple dimensions:

- Content innovation: Timely integrating cutting-edge research achievements, international standards and clinical hotspots into teaching materials and syllabi; breaking the boundaries between basic immunology, clinical immunology and translational medicine.
- Method innovation: Adopting problem-based learning (PBL), case-based learning (CBL), virtual simulation experiments, online interactive courses and interdisciplinary seminars to transform passive knowledge memorization into active exploration and ability cultivation.
- Technological innovation: Using digital teaching platforms, big data, artificial intelligence and visualized teaching tools to turn complex and abstract immune mechanisms into intuitive and understandable content, enhancing learning efficiency and interest.

Innovation ensures that immunology education keeps pace with the times, maintains its scientific nature and advanced level, and lays a solid foundation for students to engage in clinical work or scientific research in the future.

1.2 Competitiveness: The Core Standard for Educational Quality and Talent Value

Competitiveness means that the higher education system, universities and the talents it cultivates can maintain advantages in resource allocation, quality evaluation, social recognition and market demand, both domestically and internationally. It is a comprehensive reflection of educational quality, research strength, social service capability and international influence. Competitiveness is not only a requirement for universities, but also the core value that students should form during their studies.

In the field of medicine, where standards are high and competition is global, competitiveness is particularly critical. The competitiveness of medical graduates depends on their knowledge depth,

clinical ability, scientific literacy, innovative thinking and lifelong learning ability. Immunology, as a foundational discipline, constitutes an important part of core competence:

- **Knowledge competence**: Mastery of systematic immunology theories, familiarity with common immune diseases, and understanding of modern immunological technologies are basic requirements for clinicians, laboratory physicians and researchers.
- **Applied competence**: The ability to use immunological knowledge to analyze clinical problems, design diagnostic plans and judge treatment effects directly determines the level of medical services.
- **Development competence**: Understanding the development trend of immunology and having the potential to learn and master new technologies are key to maintaining professional competitiveness throughout one's career.

For medical universities, the competitiveness of immunology education is reflected in: the advanced nature of the curriculum system, the academic level of teachers, the quality of teaching resources, the output of scientific research, and the recognition of graduates by society and the industry. Building high-level immunology courses, carrying out high-level scientific research and establishing international cooperation are effective ways to enhance competitiveness.

1.3 Forecasting: Strategic Orientation for Sustainable Development

Forecasting refers to the ability of higher education to predict the development trends of science, technology, society, industry and the discipline itself, and to adjust educational goals, content and models in advance to meet future needs. It embodies the strategic thinking and forward-looking layout of the education system, ensuring that talent cultivation is not only oriented to the present but also prepared for the future.

Medical science is highly forward-looking — today's basic research determines tomorrow's clinical technology. Immunology is a typical example:

- **Discipline development trend**: Immunology is moving toward precision, personalization and integration; it is deeply integrated with genetics, molecular biology, bioinformatics and artificial intelligence, giving rise to new directions such as immunomics and systems immunology.
- **Clinical development trend**: Immune-related diseases (infections, tumors, autoimmune diseases, allergies, transplant rejection) have become major health threats; immunotherapy and precision medicine will become mainstream medical models in the future.
- **Talent demand trend**: The demand for medical talents with immunology expertise is expanding from hospitals to research institutes, pharmaceutical companies, diagnostic enterprises and public health institutions.

Forecasting in immunology education means:

1. **Forward-looking curriculum design**: Adding content related to emerging fields and future technologies, guiding students to pay attention to the forefront of the discipline.
2. **Forward-looking ability cultivation**: Focusing on training students' ability to acquire new knowledge, think critically and innovate, enabling them to adapt to changes in the discipline and industry.
3. **Forward-looking research layout**: Universities should arrange scientific research directions in advance, build disciplinary advantages and lead the development of the field.

Forecasting transforms education from "following development" to "leading development", ensuring the long-term vitality and sustainable development of medical education.

2. Integration and Practice: Implementation of the Three Principles in Immunology Education

2.1 Innovation: Reconstructing the Content and Form of Immunology Education

Combining the principle of innovation with immunology education requires breaking the traditional "textbook-centered, theory-first" model and building an open, dynamic and practice-oriented teaching system.

- **Curriculum System Innovation**: Construct a three-level curriculum system: *Basic Immunology* (foundation), *Clinical Immunology* (application), *Frontier Immunology* (development). Set up interdisciplinary modules such as *Immunology and Precision Medicine*, *Immunotherapy Technology and Application*, connecting basic theories with clinical practice and industrial development.
- **Teaching Method Innovation**: Promote student-centered teaching models. For example, use clinical cases (e.g., *Diagnosis and Treatment of Systemic Lupus Erythematosus*, *Mechanism and Application of Tumor Immunotherapy*) as the starting point, guide students to learn immune mechanisms through problem analysis, and cultivate clinical thinking. Introduce virtual simulation experiments to solve the problems of high risk, high cost and difficulty in observation in immunology experiments.
- **Teaching Resource Innovation**: Develop digital teaching platforms, online open courses and international sharing resources; invite clinical experts and scientific researchers to give lectures, and build a multi-dimensional teaching resource system.

2.2 Competitiveness: Building Core Advantages of Talents and Disciplines

To implement the principle of competitiveness, immunology education must focus on improving the quality of talent cultivation and the level of discipline construction, forming distinctive advantages.

- **Strengthen Core Knowledge and Ability**: Clarify the core knowledge points and ability requirements of immunology for different majors; establish a multi-dimensional evaluation system including theory, experiments, clinical case analysis and scientific research training, to ensure that students have solid basic knowledge and strong application ability.
- **Improve Teaching and Research Strength**: Attract high-level talents, support teachers to carry out scientific research and international exchanges, and improve the academic level of the teaching team. Integrate scientific research achievements into teaching content, and transform research advantages into teaching quality advantages.
- **Enhance Internationalization**: Introduce advanced international teaching materials and standards, carry out joint training and student exchange programs, and cultivate students with international perspectives and global competitiveness.
- **Strengthen School-Enterprise and School-Hospital Cooperation**: Establish a collaborative education mechanism with hospitals, research institutes and biomedical enterprises, provide students with practical platforms, and enhance the adaptability of talent cultivation to industry needs.

2.3 Forecasting: Grasping the Future Direction of Disciplines and Talent Demand

The principle of forecasting requires immunology education to stand at the forefront of disciplinary development and social demand, and make strategic layouts.

- **Track Discipline Development**: Establish a mechanism to track the progress of international immunology research, regularly update teaching content, and reserve teaching resources for emerging fields. For example, increase teaching content about *new vaccine technology*, *immune cell therapy*, *immunological big data analysis*.
- **Predict Social Demand**: Analyze the changes in disease spectrum and medical model; predict the demand for immunology talents in prevention, diagnosis, treatment, and health management; adjust the training direction and ability requirements in a targeted manner.
- **Cultivate Future-Oriented Abilities**: Focus on cultivating students' *scientific thinking, innovative ability, cross-border integration ability, and lifelong learning ability*, so that they can cope with unknown challenges and lead future development.

3. Challenges and Optimization Strategies in Practice

3.1 Main Challenges

- **Conflict between content update and teaching cycle**: Immunology knowledge updates rapidly, but curriculum and textbook revision cycles are long, making it difficult to maintain timeliness.
- **Balance between theory and practice**: Immunology theory is abstract and complex; it is difficult to effectively connect it with clinical practice and future applications within limited teaching hours.
- **Gap between resource supply and demand**: High-level teachers, advanced experimental conditions, and cutting-edge teaching resources are insufficient, especially in regional medical universities.
- **Difficulty in ability evaluation**: It is easier to evaluate knowledge mastery, but harder to evaluate innovative ability, forecasting thinking, and comprehensive competitiveness.

3.2 Optimization Strategies

1. **Establish a dynamic update mechanism**: Set up a regular review and update system for the curriculum; use modular teaching and online resources to achieve rapid iteration of content.
2. **Deepen integration of industry, education and research**: Promote the deep integration of teaching, scientific research, and clinical practice; let students contact cutting-edge science and clinical needs from the beginning, and cultivate practical ability and innovative awareness.
3. **Strengthen resource construction and sharing**: Increase investment in immunology teaching and research; build shared teaching platforms and virtual experiment centers; carry out inter-university and international resource sharing.
4. **Improve the comprehensive evaluation system**: Adopt diversified evaluation methods including process evaluation, ability evaluation, and result evaluation; pay attention to examining students' ability to analyze problems, solve problems, and predict development trends.
5. **Strengthen teacher development**: Support teachers to carry out scientific research, participate in international conferences, and update their knowledge systems; encourage teaching reform and innovation, and improve teaching ability.

Conclusion

Innovation, competitiveness and forecasting are not only the core paradigms of self-development in higher education in the 21st century but also the fundamental guidelines for the modernization of medical education. Immunology, as a discipline that connects basic science and clinical practice and is at the forefront of life science development, is an important carrier for implementing these principles.

- **Innovation** provides power for the development of immunology education, ensuring it always maintains its advanced nature and scientificity.
- **Competitiveness** establishes standards for quality, ensuring that the talents cultivated have core value and social recognition.
- **Forecasting** determines the direction of development, ensuring that education can adapt to and lead future changes.

For S.D. Asfendiyarov Kazakh National Medical University, integrating these three principles with immunology education is of great significance for improving the quality of medical talent cultivation, enhancing the overall strength and international influence of the university, and promoting the development of national medical and health undertakings. In the future, it is necessary to further deepen teaching reform, strengthen discipline construction, and continuously explore new models of medical education that meet national needs and align with international standards, to cultivate more high-quality medical talents with innovative spirit, competitive ability, and forward-looking vision, and make greater contributions to human health.

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THE CONCEPT OF FAMILY-CENTERED APPROACH IN THE REHABILITATION OF CHILDREN WITH AUTISM SPECTRUM DISORDER

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Abstract.
The article explores the theoretical foundations and practical implementation of the family-centered approach in the comprehensive rehabilitation of children diagnosed with Autism Spectrum Disorder (ASD). Moving away from traditional clinical models, this paradigm recognizes that active parental involvement is critical, as the home environment serves as the primary foundation for a child's progress. The study analyzes how collaborative care - characterized by shared decision-making between specialists and families - enhances the long-term effectiveness of therapeutic interventions. Key outcomes indicate that integrating these strategies not only accelerates the child's development but also significantly improves the overall family quality of life by mitigating caregiver stress. Ultimately, the paper argues for a systematic shift toward family-oriented strategies within modern medical and educational frameworks to ensure sustainable outcomes.

Keywords: Autism Spectrum Disorder (ASD), rehabilitation, family-centered approach, parental involvement, family quality of life, collaborative care.

Autism Spectrum Disorder (ASD) represents a complex, highly heterogeneous neurodevelopmental condition that manifests as persistent challenges in reciprocal social communication, paired with stereotyped behavior patterns and highly restricted focal interests. As the global diagnosed prevalence of neurodevelopmental disorders escalates, modern healthcare systems face unprecedented pressure. This surge underscores an immediate and critical demand for scalable, high-efficiency clinical interventions capable of overcoming systemic barriers such as high costs, uneven geographic distribution of specialists, and prolonged diagnostic waiting times [1]. The alarming magnitude of this public health issue is heavily substantiated by the latest epidemiological data gathered from around the world. Specifically, comprehensive surveillance reports published by the CDC’s Autism and Developmental Disabilities Monitoring (ADDM) Network reveal that the prevalence of ASD has experienced a notable increase, now estimated to affect approximately 3.2% of the pediatric population, which translates to 1 in every 31 children. When looking at the situation from a broader, international perspective, statistical models indicate that roughly 61.8 million individuals worldwide are currently living with this condition. Consequently, medical authorities now recognize the disorder as one of the top ten leading contributors to the non-fatal health and disability burdens observed among children,

adolescents, and young adults under the age of 20. This systemic shift is further driven by an ongoing, upward trajectory in global diagnostic and identification rates; for instance, a comprehensive study published in The Lancet Psychiatry highlighted that as of 2021, the global prevalence was estimated to encompass 1 in every 127 individuals across the general worldwide population [2]. Driven by the necessity to accommodate this expanding demand and to guarantee that treatments possess maximum ecological validity, modern approaches to pediatric rehabilitation are being profoundly redefined. Traditionally, pediatric rehabilitation paradigms were predominantly centered on clinician-led, isolated therapeutic models, wherein specialists engaged with the child within artificial laboratory or controlled clinical environments. Nevertheless, recent empirical data demonstrate that these traditional frameworks are insufficient for ensuring that therapeutic gains are successfully transferred and maintained outside the clinic room. Beyond the issue of skill generalization, relying solely on clinical specialists exacerbates systemic barriers, including prolonged waiting lists, high financial costs, and severe strain on household resources. As clinical literature increasingly demonstrates, ignoring the domestic ecosystem not only limits the child's progress but also erodes overall family self-efficacy and well-being [3].

Consequently, modern healthcare models are progressively expanding beyond these rigid, clinic-bound limitations. To overcome these barriers, the paradigm has shifted toward family-centered approaches, which recognize the family unit as the primary, most influential environment for a child’s neurological and social development. The clinical validity of this shift is heavily supported by contemporary literature; a recent systematic review focusing on neurodevelopmental and intellectual challenges reveals that family-centered care serves as a key driver for both pediatric health optimization and enhanced family well-being. By fostering shared decision-making and addressing the emotional and social needs of the household, this model systematically elevates family functionality. Within this context, active parental involvement ensures that therapeutic interventions are seamlessly extended into daily routines, making continuous, naturalistic reinforcement practical and realistic [4].

To fully operationalize this family-centered framework, its architectural design must be firmly grounded in contemporary developmental and behavioral sciences. From a behavioral perspective, the mechanism of change relies on learning intensity and continuous environmental reinforcement, which cannot be replicated in a clinic. Quantitative evidence confirms that children whose intervention plans prioritize structured, parent-led training demonstrate accelerated acquisition of vital communication skills, receptive and expressive language, as well as fine and gross motor skills compared to control groups receiving standard isolated clinic sessions. Empirical findings indicate that when parents apply these therapeutic techniques intensively, exceeding one hour per day and maintain high-quality behavioral engagement within natural routines, the developmental trajectory and clinical progress of the child scale dramatically [5]. A core operational element of this family-centric model is collaborative care, which actively relies on shared decision-making and transparent communication channels between primary healthcare providers and caregivers. This collaborative dynamic transforms the traditional, top-down medical hierarchy into a supportive alliance, directly combating the sense of isolation often experienced by caregivers. Empirical metrics demonstrate that when parents report that their healthcare providers systematically practice family-centered principles and respect parental expertise, their individual parenting stress scores decrease substantially [6]. Furthermore, structured education programs focusing on parent-implemented Applied Behavior Analysis (ABA) or relational methodologies do not merely transfer technical skills; they significantly enhance parental self-efficacy and real-life behavior management capabilities. By equipping caregivers with these validated clinical tools, the framework actively fosters cognitive and emotional resilience. Consequently, this empowerment effectively mitigates the chronic anxiety and systemic

psychological distress typically associated with navigating unpredictable behavioral meltdowns in naturalistic settings [7]. Emphasizing this holistic impact, current research highlights that family-centric care yields profound psychosocial benefits, effectively empowering the family as an integrated unit. Contemporary clinical models that seamlessly combine professional guidance with digital health solutions, such as telehealth frameworks or remote feedback networks, prove highly successful in optimizing the domestic ecosystem. By facilitating continuous clinical coaching without forcing families to leave their natural environment, these remote interventions systematically improve the global family quality of life by boosting positive family interactions, enhancing communication, and elevating overall emotional well-being [8].

Despite the documented advantages of the family-centered paradigm, translating this theoretical framework into sustainable clinical practice introduces distinct operational challenges and systemic barriers. A recent comprehensive systematic review analyzing empirical evidence highlights that these obstacles span multiple dimensions, ranging from organizational working conditions and service coordination to deep-seated professional beliefs. A primary challenge stems from the structural non-uniformity of households. Variations in socio-economic status, educational backgrounds, and baseline health literacy frequently create practical friction points during parent-coaching sessions, complicating the uniform application of family-centered models. Furthermore, contemporary literature underscores the severe impact of parental cognitive overload and acute emotional exhaustion, identifying caregiver burnout as a critical disruptor that directly threatens intervention fidelity. When parents are forced to balance intricate behavioral tracking protocols alongside demanding professional and domestic responsibilities, the systemic strain frequently escalates the risk of intervention abandonment.

Additionally, deeply ingrained professional dynamics and institutional limitations compound these household burdens. Clinical practitioners often report a sense of insecurity when transitioning from working directly with a child to coaching adults, sometimes showing resistance due to a perceived loss of their traditional role as the absolute "expert". These individual anxieties are further exacerbated by systemic constraints within early intervention services, including rigid appointment time limits, a lack of specialized training in participatory practices, and high daily workloads among staff. When family-centered care is reduced to a standard set of high-demand tasks without flexible institutional support, the expectation for active parental involvement can inadvertently transform into a major source of internal distress. Consequently, to prevent caregiver fatigue from compromising therapeutic outcomes, modern frameworks must move away from rigid mandates. Future implementation strategies must integrate adaptive, tiered instruction models paired with accessible, low-effort psychological support networks designed specifically to protect parental mental health and foster systemic family resilience [9,10].

In conclusion, the rising global prevalence of Autism Spectrum Disorder is a clear call to action: rehabilitation care must be fundamentally rethought. The long-standing model of treating a child in the isolation of a clinical room has proven insufficient. It often fails the most critical test - helping children transfer and maintain new skills in the messy, dynamic reality of their daily lives. Moreover, forcing families to rely solely on rigid clinical schedules places an immense, often unsustainable emotional and financial strain on the entire household. Transitioning to a family-centered approach is not just a theoretical alternative; it is a compassionate and realistic path forward. This model respects the home as the true foundation for a child's long-term growth. By empowering parents and turning ordinary, everyday moments into rich opportunities for learning, the model unlocks the continuous, natural reinforcement that children need to build essential communication and motor skills. However, the success of this shift relies entirely on genuine partnership. When specialists and caregivers make decisions as equals, they build a supportive ecosystem that can dramatically reduce the profound isolation and chronic stress parents so often endure. Yet, as recent evidence warns, this framework cannot be implemented blindly. Asking

parents to act as therapists without proper scaffolding is a recipe for severe burnout and intervention abandonment. Systemic barriers - such as a lack of professional training for clinicians in family coaching and the physical exhaustion of caregivers - must be addressed first. Ultimately, securing sustainable outcomes for these children requires a structural evolution in how healthcare systems operate. Policymakers must move away from rigid, institutional metrics and invest deeply in parent training, remote feedback networks, and accessible telehealth solutions. Future research must focus on leveraging digital technologies to make these family-centered programs highly scalable. Only by doing so can compassionate, high-quality, and collaborative care become a practical reality for every family, regardless of their circumstances.

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THE SCIENTIFIC DISCOURSE ON THE ADVANCEMENT OF DRUG SAFETY, PHARMACOVIGILANCE, PHARMACOLOGY, AND PHARMACOTHERAPEUTIC OUTCOMES: A MULTISCALAR INTEGRATION OF MOLECULAR AND CLINICAL PHARMACOLOGY, ADVERSE DRUG REACTION SURVEILLANCE, CAUSAL INFERENCE, PHARMACOEPIDEMIOLOGICAL RISK STRATIFICATION, EVIDENCE-BASED SAFETY, THERAPEUTIC BENEFIT–RISK OPTIMIZATION, MEDICATION-HARM MITIGATION, AND POPULATION HEALTH PROTECTION

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ABSTRACT

The contemporary transformation of drug safety science necessitates a paradigmatic integration of pharmacovigilance, molecular and clinical pharmacology, pharmacotherapy, pharmacoepidemiology, regulatory science, and population health within an increasingly complex therapeutic ecosystem. This scientific discourse critically examines the evolutionary advancement of drug-safety paradigms from predominantly spontaneous adverse drug reaction reporting toward multidimensional, evidence-integrated, analytically sophisticated, and prevention-oriented pharmacovigilance architectures capable of identifying, characterizing, validating, contextualizing, and mitigating medication-related risks throughout the medicinal-product lifecycle. Particular emphasis is placed on the conceptual convergence of mechanistic pharmacology with clinical pharmacology and pharmacotherapeutic decision-making, whereby pharmacodynamic, pharmacokinetic, pharmacogenomic, immunological, and molecular determinants of therapeutic response and adverse drug reactions become increasingly relevant to individualized safety characterization. Within this framework, pharmacovigilance is conceptualized not merely as post-marketing surveillance, but as an integrative safety science encompassing adverse drug reaction detection, signal generation, signal prioritization, disproportionality analysis, signal validation, causality assessment, risk stratification, exposure–outcome characterization, and longitudinal benefit–risk evaluation. The discourse further examines the expanding contribution of pharmacoepidemiological methodologies and real-world evidence to the detection of rare, delayed, population-specific, interaction-mediated, and context-dependent medication harms that may remain insufficiently characterized within conventional clinical-development paradigms. Multisource evidence derived from spontaneous reporting systems, electronic health records, administrative claims databases, clinical registries, observational cohorts, prescription and dispensing datasets, patient-generated information, and other real-world data environments can enhance the analytical resolution of drug-safety surveillance when appropriately harmonized, validated, and interpreted. Particular attention is directed toward the methodological challenges of confounding, channeling bias, indication bias, exposure misclassification, outcome misclassification, underreporting, stimulated reporting, missingness, heterogeneity, and temporal ambiguity, all of which may influence the validity and generalizability of pharmacovigilance inferences. The analysis also situates contemporary safety-signal intelligence within emerging computational and quantitative methodologies, including disproportionality-based signal detection, Bayesian approaches, data-mining algorithms, causal inference frameworks, machine-learning-assisted surveillance, artificial-intelligence-enabled pattern recognition, network-based pharmacological analysis, and integrated pharmacogenomic and pharmacoproteomic approaches. These methodologies offer opportunities to move from retrospective recognition of adverse events toward earlier identification of clinically meaningful safety signals and more proactive risk prediction. Nevertheless, computational sophistication does not eliminate the necessity for biological plausibility, clinical adjudication, epidemiological validation, transparent methodological governance, and regulatory interpretation. Accordingly, pharmacovigilance is presented as an epistemically pluralistic discipline in which computational signals require triangulation across mechanistic, clinical, epidemiological, and regulatory evidence streams before therapeutic or policy implications can be established. A central dimension of the discourse concerns the reciprocal relationship between pharmacology and pharmacotherapy. Pharmacological knowledge provides the mechanistic foundation for understanding receptor-

mediated effects, dose–response relationships, pharmacokinetic variability, drug–drug interactions, drug–disease interactions, off-target effects, and susceptibility determinants, whereas pharmacotherapy translates such knowledge into therapeutic decision-making across heterogeneous patient populations. Drug safety therefore cannot be dissociated from therapeutic appropriateness, medication optimization, adherence, polypharmacy, deprescribing, dosing individualization, therapeutic drug monitoring, and clinical risk communication. Benefit–risk assessment consequently requires dynamic consideration of therapeutic efficacy, treatment necessity, adverse-event probability, severity, preventability, patient characteristics, treatment alternatives, and uncertainty across different stages of clinical use. Medication-harm mitigation is further examined as a multidimensional process encompassing risk minimization, medication reconciliation, prescribing optimization, interaction prevention, monitoring strategies, pharmacotherapeutic stewardship, patient and professional education, active surveillance, regulatory interventions, and post-authorization safety evaluation. Within this architecture, regulatory pharmacovigilance assumes a pivotal role in transforming safety evidence into proportionate risk-management actions, including labeling modifications, safety communications, restricted-use strategies, monitoring requirements, additional post-marketing studies, and other measures designed to preserve therapeutic benefit while reducing preventable harm. Effective regulatory risk governance therefore depends upon continuous evidence generation and iterative reassessment rather than static preauthorization determinations. The discourse extends drug-safety considerations from individual-level clinical protection to population-level health consequences. Variability in medication exposure, prescribing practices, healthcare access, pharmacogenetic composition, comorbidity burden, socioeconomic determinants, and health-system infrastructure can generate heterogeneous patterns of therapeutic benefit and medication-related harm across populations. Public health pharmacovigilance consequently requires integration of individual clinical signals with population-level epidemiological surveillance, health-system intelligence, regulatory coordination, and equitable risk communication. The resulting framework positions contemporary drug safety as a dynamic translational continuum connecting molecular pharmacological mechanisms, clinical pharmacotherapy, real-world evidence, pharmacoepidemiological inference, pharmacovigilance intelligence, regulatory risk governance, and population health protection. Such an integrated paradigm may strengthen the capacity of healthcare and regulatory systems to anticipate emerging medication risks, refine therapeutic benefit–risk characterization and reduce preventable medication-related morbidity, and support safer, more rational, evidence-informed pharmacotherapy throughout the medicinal-product lifecycle.
Keywords: Pharmacovigilance; Drug Safety; Clinical Pharmacology; Pharmacotherapy; Public Health.

INTRODUCTION

The contemporary pharmacological landscape is undergoing a profound epistemological, methodological, technological, and clinical advancement within the conventional boundaries separating pharmacology, pharmacotherapy, pharmacovigilance, pharmacoepidemiology, drug safety, regulatory science, and public health are progressively dissolving. Medicinal products are no longer conceptualized exclusively as discrete therapeutic interventions evaluated through predefined efficacy and safety parameters under controlled experimental conditions; rather, they constitute dynamic components of complex biological, clinical, technological, behavioral, socioeconomic, and health-system environments in which therapeutic benefits and medication-related risks continuously interact. This transformation has fundamentally expanded the intellectual scope of drug-safety science. Contemporary safety assessment increasingly encompasses the entire medicinal-product lifecycle, from molecular target identification and

preclinical pharmacology through clinical development, authorization, prescribing, dispensing, administration, long-term exposure, post-marketing surveillance, therapeutic optimization, and eventual reassessment or withdrawal. Within this evolving architecture, pharmacovigilance has become an essential translational discipline connecting mechanistic pharmacological knowledge with real-world clinical experience and population-level health protection.

The classical conceptualization of pharmacovigilance was largely constructed around the detection, assessment, understanding, and prevention of adverse effects or other drug-related problems. However, the increasing complexity of modern therapeutics has rendered a narrowly reactive model of adverse-event reporting insufficient for comprehensive drug-safety governance. Contemporary pharmacotherapy involves increasingly sophisticated biologics, advanced therapeutic medicinal products, targeted molecular therapies, immunomodulatory agents, gene- and cell-based interventions, polypharmacy regimens, precision-medicine approaches, and therapeutics administered to populations characterized by substantial multimorbidity and physiological heterogeneity. These developments have generated therapeutic opportunities of unprecedented complexity while simultaneously introducing new categories of uncertainty concerning delayed toxicities, immunologically mediated reactions, drug–drug interactions, drug–gene interactions, drug–disease interactions, cumulative exposure, treatment sequencing, off-target pharmacology, medication-use errors, and population-specific susceptibility. Consequently, the scientific evaluation of drug safety requires methodological architectures capable of integrating heterogeneous evidence across molecular, cellular, clinical, epidemiological, computational, and regulatory domains.

Pharmacology provides the foundational scientific language through which therapeutic and adverse drug effects can be mechanistically interpreted. Pharmacodynamics elucidates the relationships among molecular targets, receptor occupancy, intracellular signaling, physiological responses, and dose-dependent effects, whereas pharmacokinetics characterizes absorption, distribution, metabolism, and excretion and thereby establishes the temporal and quantitative determinants of systemic drug exposure. Yet neither pharmacodynamic nor pharmacokinetic characterization, considered in isolation, can fully explain the complexity of clinical medication safety. Genetic variation, epigenetic regulation, age, sex, organ function, comorbidity, nutritional status, concomitant medication, microbiome composition, immune status, environmental exposure, adherence, and health-system factors can substantially modify pharmacological response. The clinical manifestation of an adverse drug reaction therefore frequently represents the emergent consequence of multiple interacting determinants rather than a simple linear relationship between drug administration and biological harm. This complexity necessitates an integrative pharmacological perspective capable of connecting molecular mechanisms with individual susceptibility and clinically observable outcomes.

Clinical pharmacology occupies a particularly important position within this continuum because it translates fundamental pharmacological principles into human therapeutic contexts. Through dose optimization, therapeutic drug monitoring, pharmacokinetic and pharmacodynamic modeling, interaction assessment, pharmacogenomic interpretation, individualized treatment selection, and evaluation of special populations, clinical pharmacology provides essential methodological foundations for rational pharmacotherapy. The safety profile of a medicine cannot be separated from the manner in which it is prescribed, dosed, combined with other medicines, administered, monitored, and discontinued. A pharmacological agent may demonstrate an acceptable safety profile under controlled conditions while exhibiting substantially different patterns of benefit and harm when implemented among patients with multimorbidity, extensive polypharmacy, variable adherence, or limited monitoring capacity. Accordingly, drug safety must be understood not merely as an intrinsic characteristic of a molecule but as a dynamic property

emerging from the interaction among the medicinal product, patient, treatment regimen, clinical environment, healthcare system, and population.

Pharmacotherapy constitutes the clinical expression of this pharmacological knowledge. The ultimate purpose of pharmacotherapy is not simply to administer medicines but to achieve clinically meaningful therapeutic outcomes while minimizing unnecessary exposure and preventable harm. This objective places benefit–risk optimization at the center of rational therapeutic decision-making. Every pharmacotherapeutic intervention involves some degree of uncertainty because therapeutic efficacy and adverse effects are frequently inseparable consequences of pharmacological action. The same biological pathway responsible for therapeutic benefit may contribute to toxicity when excessively activated, insufficiently controlled, prolonged, or expressed within a susceptible biological context. Consequently, therapeutic optimization requires continuous evaluation of whether the expected clinical benefit remains proportionate to the probability and severity of potential harm. This relationship is dynamic rather than static and may change as new evidence emerges, treatment duration increases, patient characteristics evolve, competing therapies become available, or previously unrecognized safety signals are identified.

The emergence of pharmacovigilance as a mature scientific discipline reflects recognition that many clinically consequential medication risks cannot be fully characterized before regulatory authorization. Clinical trials are indispensable for establishing efficacy, dose–response relationships, common adverse events, and selected safety parameters, but their population size, duration, eligibility criteria, monitoring intensity, and experimental conditions necessarily constrain the breadth of safety knowledge generated before widespread clinical use. Rare adverse events may remain undetected until exposure reaches millions of patients. Delayed toxicities may become apparent only after prolonged treatment. Interactions may emerge when medicines are prescribed across diverse therapeutic contexts. Vulnerable populations may be underrepresented in development programs. Furthermore, real-world adherence, prescribing patterns, treatment combinations, comorbidity structures, and healthcare utilization may differ substantially from controlled trial conditions. Post-authorization pharmacovigilance therefore represents an indispensable extension of the evidence-generation process rather than a secondary or optional activity.

Spontaneous adverse-event reporting systems remain an important component of this post-authorization infrastructure. Individual case safety reports can provide early indications of previously unrecognized adverse drug reactions and may facilitate the identification of rare, unexpected, serious, or clinically distinctive events. Nevertheless, spontaneous reporting is inherently affected by underreporting, stimulated reporting, reporting heterogeneity, missing information, notoriety effects, duplicate reports, incomplete exposure denominators, and variable clinical documentation. These limitations mean that individual reports rarely establish causality independently. Instead, they constitute elements within a broader signal-detection architecture in which patterns across multiple reports may indicate disproportionate associations warranting further investigation. The intellectual evolution of pharmacovigilance has therefore involved a transition from isolated case interpretation toward systematic signal detection, prioritization, validation, and assessment using increasingly sophisticated analytical methodologies.

Safety-signal detection represents one of the principal methodological domains within modern pharmacovigilance. A safety signal may arise when available information suggests a new potentially causal association, or a new aspect of a known association, between a medicinal product and an event that warrants further investigation. Disproportionality analysis has become an important approach for identifying reporting patterns that occur more frequently than expected within large spontaneous-reporting databases. Frequentist and Bayesian methods, including proportional reporting ratios, reporting odds ratios, information components, and

empirical Bayes approaches, have expanded the capacity to screen vast numbers of drug–event combinations. However, statistical disproportionality does not equate to causal confirmation. A signal can reflect confounding, reporting artifacts, co-medication, indication-related effects, changes in prescribing, differential surveillance, or other sources of systematic distortion. Thus, computational signal detection should be regarded as an evidence-generation mechanism that initiates rather than completes scientific evaluation.

The increasing availability of large-scale real-world data has transformed the methodological possibilities of pharmacovigilance. Electronic health records, insurance claims, prescription databases, pharmacy-dispensing systems, disease registries, laboratory information systems, patient-generated data, digital health platforms, and longitudinal observational cohorts can provide information about medication exposure and outcomes across populations that are often more heterogeneous than traditional trial cohorts. Such resources enable investigators to examine treatment patterns, comparative safety, utilization trajectories, temporal associations, risk factors, and outcomes under routine clinical conditions. Real-world evidence can therefore complement conventional clinical-trial evidence by providing information about effectiveness and safety across broader patient populations and longer periods of observation. Nevertheless, the analytical value of real-world data depends fundamentally on data quality, completeness, interoperability, outcome validity, exposure ascertainment, temporal alignment, appropriate study design, and transparent statistical methodology.

The expansion of real-world evidence has simultaneously intensified interest in pharmacoepidemiology. Pharmacoepidemiology provides methodological frameworks for studying the use and effects of medicines in large human populations, thereby connecting pharmacology with epidemiological reasoning. Its contribution to drug safety encompasses cohort studies, case–control studies, self-controlled designs, interrupted time-series analyses, active-comparator studies, new-user designs, target-trial emulation, comparative safety studies, and other approaches capable of investigating medication-related outcomes under nonexperimental conditions. These designs can help estimate relative and absolute risks, identify vulnerable subgroups, evaluate comparative safety, and investigate the clinical consequences of exposure. However, observational pharmacovigilance is inherently vulnerable to confounding by indication, channeling bias, selection bias, immortal-time bias, exposure misclassification and outcome misclassification, residual confounding, informative censoring, and time-dependent treatment changes. Consequently, sophisticated study design and causal inference are indispensable for converting observational associations into scientifically interpretable evidence.

Causal inference has consequently assumed increasing importance in contemporary drug-safety research. Establishing whether an observed association between a medicinal product and an adverse outcome reflects a causal relationship requires consideration of temporality, biological plausibility, dose–response relationships, consistency, specificity where applicable, alternative explanations, dechallenge and rechallenge evidence, experimental and observational evidence, and the broader pharmacological context. Modern causal-inference methodologies further provide formal frameworks for defining estimands, constructing appropriate comparator groups, controlling measured confounding, addressing time-varying exposure, and estimating counterfactual treatment effects. Nevertheless, causal inference cannot eliminate uncertainty when important determinants remain unmeasured or poorly characterized. Consequently, causal interpretation in pharmacovigilance requires methodological triangulation and integration of epidemiological, clinical, mechanistic, and regulatory evidence rather than dependence on a single analytical result.

The mechanistic dimension of pharmacovigilance remains equally important. Statistical associations become substantially more informative when interpreted within established or plausible pharmacological pathways. Molecular pharmacology can clarify receptor interactions,

enzyme inhibition or induction, transporter effects, ion-channel modulation, immune activation, metabolic perturbation, mitochondrial dysfunction, oxidative stress, genomic instability, and other mechanisms potentially associated with toxicity. Pharmacogenomics further demonstrates that genetic variation can modify drug exposure, pharmacodynamic response, susceptibility to adverse effects, and therapeutic efficacy. Consequently, contemporary drug-safety science increasingly seeks to integrate mechanistic biomarkers, genomic information, molecular phenotyping, and clinical outcomes. This integration may contribute to the development of more precise safety profiles and facilitate the identification of individuals or populations at elevated risk.

Precision medicine introduces additional complexity to this framework. Therapeutic personalization traditionally emphasizes selection of treatments according to patient-specific disease characteristics, biomarkers, genetic profiles, or expected therapeutic response. However, precision pharmacotherapy must also incorporate individualized risk of medication-related harm. A treatment selected because of a favorable expected efficacy profile may nonetheless be inappropriate if a patient possesses a pharmacogenetic variant, organ dysfunction, interacting medication, comorbidity, or physiological characteristic that substantially increases toxicity risk. Thus, precision pharmacotherapy and precision pharmacovigilance should increasingly be considered complementary dimensions of individualized therapeutic optimization. The objective is not merely to identify which medicine is likely to work, but also to characterize for whom, under what conditions, at what dose, for how long, and with which monitoring strategy the treatment can be administered with an acceptable benefit–risk profile.

Polypharmacy provides an especially important context for this challenge. The simultaneous use of multiple medications can generate pharmacokinetic and pharmacodynamic interactions, therapeutic duplication and cumulative toxicity, adherence complexity, prescribing cascades, and increased potential for medication errors. Older adults and patients with multimorbidity are particularly likely to experience complex medication regimens, although medication-related risks associated with polypharmacy extend across numerous clinical populations. Pharmacovigilance in this context cannot focus exclusively on individual drug–event pairs. It must increasingly consider regimen-level exposure, interaction networks, cumulative pharmacological burden, treatment sequencing, and the clinical context in which multiple agents are administered. Network pharmacology and computational interaction modeling may contribute to this emerging analytical perspective, but clinical interpretation remains essential because theoretical interaction potential does not invariably translate into clinically meaningful harm.

Medication safety also extends beyond adverse drug reactions arising from pharmacological mechanisms. Medication errors, inappropriate prescribing, inadequate monitoring, administration errors, adherence problems, incorrect dosing, contraindicated combinations, transitions-of-care failures, and communication deficiencies can all contribute to medication-related harm. This distinction between adverse drug reactions and broader medication-related problems is essential because preventive strategies differ according to underlying mechanisms. Pharmacological toxicity may require dose adjustment or treatment substitution, whereas administration errors may require system redesign, education, technological safeguards, or workflow interventions. Modern drug-safety science therefore increasingly intersects with medication safety, clinical pharmacy, pharmacotherapeutic stewardship, human factors, healthcare quality improvement, and patient-safety science.

Clinical pharmacists occupy an important position within this multidisciplinary architecture because they frequently operate at the interface between pharmacological evidence and medication use. Medication review, reconciliation, interaction assessment, therapeutic monitoring, adverse-event identification, patient counseling, adherence support, and pharmacotherapy optimization can contribute to the early recognition and prevention of medication-related harm. Pharmacist-led interventions may therefore function as practical

components of pharmacovigilance implementation, particularly in healthcare environments where systematic medication monitoring is required. Integration of clinical pharmacy activities with institutional pharmacovigilance systems can strengthen bidirectional information flow between individual patient care and population-level safety surveillance.

The concept of medication-harm mitigation has consequently evolved from passive recognition toward proactive risk management. Risk minimization involves identifying clinically meaningful hazards and implementing interventions designed to reduce their occurrence or severity while preserving therapeutic benefits. Such interventions may include prescribing restrictions, contraindication updates, dose adjustments, monitoring recommendations, educational programs, medication guides, clinical decision-support tools, treatment protocols, targeted communication, and post-authorization studies. Their effectiveness must itself be evaluated, because the existence of a risk-minimization measure does not guarantee appropriate implementation or meaningful reduction in harm. Contemporary pharmacovigilance therefore increasingly encompasses the full cycle of risk identification, intervention, implementation, monitoring, evaluation, and iterative modification.

Regulatory science provides the institutional framework through which pharmacovigilance evidence is translated into decisions concerning medicinal-product safety. Regulatory authorities must continuously balance therapeutic innovation against uncertainty and potential harm. This process requires evaluation of cumulative evidence rather than isolated signals. Regulatory decision-making may incorporate clinical-trial findings, spontaneous reports, epidemiological analyses, mechanistic evidence, pharmacological plausibility, utilization data, comparative safety evidence, and patient perspectives. The resulting actions may include changes to prescribing information, additional warnings, contraindications, restrictions, enhanced monitoring, post-authorization safety studies, risk-management measures, or, where justified by the evidence, substantial modifications to the conditions of use. Regulatory pharmacovigilance is therefore fundamentally an evidence-governance process characterized by uncertainty, iterative reassessment, proportionality, and continuing surveillance.

Benefit–risk assessment represents the conceptual foundation linking these activities. A medicinal product cannot be classified as simply “safe” or “unsafe” independently of its therapeutic context. The clinically meaningful question concerns the balance between anticipated benefits and potential risks for defined populations, indications, treatment durations, and alternatives. The magnitude of an adverse event must therefore be interpreted in relation to disease severity, therapeutic efficacy, treatment necessity and availability of alternatives, baseline risk, reversibility, preventability, and patient preferences. A severe but extremely rare adverse event may have a different clinical significance from a frequent but manageable adverse effect, and the same event may have different implications in populations with different therapeutic needs. Dynamic benefit–risk assessment consequently requires continual incorporation of emerging evidence rather than reliance on a fixed assessment established at authorization.

Public health considerations further broaden the scope of drug-safety science. Medication exposure occurs at population scale, and relatively uncommon risks can become important public health concerns when a medicine is widely used. Conversely, restricting access to an effective therapy because of poorly characterized or disproportionately interpreted safety concerns may generate unintended health consequences. Public health pharmacovigilance therefore requires assessment of both the harms associated with medication exposure and the harms potentially associated with inadequate treatment. This perspective reinforces the need for proportionality, evidence quality, transparent uncertainty communication, and contextualized risk interpretation. Public health protection depends not merely on minimizing medication use but on optimizing the safe and effective use of medicines within populations.

Health inequities add another layer of complexity. Drug safety profiles may differ across populations because of variations in genetics, age structure, comorbidity patterns, healthcare access, prescribing practices, environmental exposures, socioeconomic conditions, health literacy, and monitoring infrastructure. Populations inadequately represented in clinical development may subsequently generate safety evidence only after widespread exposure. Pharmacovigilance systems must therefore consider representativeness and equity in both data generation and signal interpretation. The expansion of global pharmacovigilance networks provides opportunities for broader safety surveillance, but differences in reporting infrastructure, regulatory capacity, clinical documentation, coding systems, and healthcare access can complicate cross-national comparisons. International harmonization of terminology, data standards, reporting practices, and analytical methodologies is consequently central to the development of globally responsive drug-safety systems.

The digital transformation of healthcare is simultaneously creating new opportunities and new methodological challenges. Artificial intelligence, machine learning, natural-language processing, automated clinical-record analysis, deep-learning approaches, and large-scale computational pharmacology may enable identification of safety patterns that are difficult to recognize through conventional manual surveillance. Automated extraction of adverse-event information from clinical narratives, integration of heterogeneous datasets, and predictive modeling of patient-specific risk could substantially expand pharmacovigilance capacity. However, algorithmic systems introduce concerns involving data representativeness, model calibration, explainability, bias, privacy, reproducibility, validation, and automation-induced errors. Computational efficiency should therefore not be equated with scientific validity. Artificial intelligence can augment pharmacovigilance, but clinical and epidemiological expertise remains essential for contextual interpretation and regulatory decision-making.

The increasing integration of artificial intelligence with pharmacology also creates opportunities for mechanistic and predictive safety science. Computational drug–target interaction modeling, molecular docking, systems pharmacology, toxicity prediction, network-based analyses, and machine-learning models can contribute to the early identification of potentially hazardous pharmacological characteristics. Such approaches may facilitate earlier prioritization of compounds for further investigation and potentially reduce the time required to identify specific toxicity risks. Nevertheless, predictive models depend on the quality and representativeness of their training data and require rigorous external validation. Their outputs should therefore be interpreted as probabilistic evidence rather than definitive clinical conclusions. Integration of computational prediction with experimental pharmacology, clinical observation, epidemiological evidence, and regulatory assessment is likely to represent a more scientifically defensible trajectory than technological substitution of one evidence stream for another.

Another critical transformation concerns the temporal dimension of pharmacovigilance. Drug safety is not a single endpoint measured at a particular stage but a continuously evolving property of therapeutic exposure. New indications, new populations, treatment combinations, longer exposure durations, manufacturing changes, emerging pathogens, changing prescribing behavior, and new diagnostic capabilities can alter the observed benefit–risk profile of an established medicine. Similarly, the recognition of previously unappreciated adverse events may modify clinical understanding years after authorization. Longitudinal surveillance is therefore essential for maintaining an up-to-date safety characterization. The medicinal-product lifecycle should consequently be understood as a continuous evidence-generating process in which pharmacovigilance informs subsequent pharmacological research, clinical practice, regulatory action, and further safety surveillance.

Patient participation is increasingly relevant within this evolving architecture. Patients experience medication benefits and harms directly and may identify symptoms or functional changes that are

not immediately captured through conventional clinical documentation. Patient-reported outcomes, patient-generated health data, direct adverse-event reporting, and patient engagement in risk communication can contribute additional dimensions to safety assessment. Meaningful patient involvement may improve recognition of treatment burdens, enhance understanding of tolerability, and support communication of uncertainties in ways that are clinically relevant to therapeutic decision-making. Nevertheless, patient-generated information requires appropriate validation and contextual interpretation, particularly when symptoms are nonspecific or when attribution to a medicine is uncertain.

Communication represents a further essential dimension of pharmacovigilance. Identification of a safety signal has limited public health value if its implications cannot be communicated accurately to clinicians, pharmacists, patients, regulators, and other stakeholders. Risk communication must distinguish established causal relationships from preliminary signals and uncertainty from confirmed evidence. Poorly calibrated communication may lead to inappropriate discontinuation of beneficial therapies, unnecessary anxiety, underrecognition of genuine risks, or inappropriate substitution of alternative treatments. Transparent communication should therefore provide sufficient information to support rational therapeutic decisions while avoiding both minimization and exaggeration of uncertainty. This is particularly important when safety signals attract public attention through digital media and rapidly disseminated health information.

The conceptual convergence of pharmacology, pharmacotherapy, pharmacovigilance, and public health therefore represents more than an expansion of disciplinary terminology. It reflects a fundamental change in the epistemology of medication safety. The central scientific question has moved progressively from whether a medicinal product demonstrates efficacy and acceptable safety under controlled conditions toward how therapeutic effects and risks evolve across heterogeneous populations, treatment contexts, exposure durations, healthcare systems, and real-world environments. Answering this question requires integration of mechanistic knowledge, clinical observation, epidemiological analysis, computational intelligence, patient experience, and regulatory judgment. Such integration must preserve methodological rigor while acknowledging that no individual evidence source can adequately characterize the totality of medication-related risk.

The resulting paradigm can be conceptualized as a multiscalar safety continuum extending from molecular pharmacology to population health. At the molecular level, pharmacodynamic and pharmacokinetic mechanisms establish potential therapeutic and toxicological pathways. At the individual level, clinical pharmacology and pharmacotherapy determine how these pathways interact with patient-specific characteristics and treatment regimens. At the clinical-system level, medication-use processes influence adherence, monitoring, interactions, prescribing appropriateness, and preventable harm. At the epidemiological level, pharmacoepidemiology and real-world evidence characterize risks across populations and comparative treatment strategies. At the regulatory level, pharmacovigilance converts accumulated evidence into risk-management decisions. At the public health level, these processes ultimately influence population morbidity, mortality, healthcare utilization, therapeutic access, and health-system resilience. The scientific value of contemporary drug-safety research therefore lies increasingly in its capacity to connect these scales without reducing one level of evidence to another.

Within this framework, pharmacovigilance should be regarded as an iterative knowledge-generating discipline rather than a passive reporting mechanism. Each newly identified adverse event can stimulate mechanistic investigation; mechanistic hypotheses can guide epidemiological studies; epidemiological findings can refine clinical risk stratification; clinical observations can generate new safety signals; regulatory interventions can produce additional real-world evidence; and subsequent evidence can modify therapeutic recommendations. This cyclical process creates a continuously evolving safety knowledge ecosystem. Its effectiveness depends upon the

interoperability of data, methodological transparency, multidisciplinary expertise, international collaboration, and the capacity to distinguish genuine pharmacological signals from statistical or reporting artifacts.

The evolutionary advancement of drug safety is therefore inseparable from the broader transformation of pharmacological science itself. As therapeutics become more targeted, individualized, biologically complex, and digitally supported, safety assessment must become correspondingly more mechanistic, longitudinal, computationally informed, clinically contextualized, and population-oriented. The integration of molecular and clinical pharmacology with pharmacotherapy provides the mechanistic and therapeutic foundation; pharmacovigilance supplies systematic safety surveillance; pharmacoepidemiology provides population-level inference; real-world evidence extends observation beyond controlled research environments; causal inference strengthens interpretation of observational associations; regulatory science translates evidence into governance; and public health frameworks contextualize medication-related risks within broader population consequences.

The present scientific discourse examines the evolutionary advancement of drug safety, pharmacovigilance, pharmacology, and pharmacotherapy through a multidimensional and multiscalar framework. Particular attention is directed toward the integration of molecular and clinical pharmacology, adverse drug reaction surveillance, safety-signal detection and validation, causal inference, pharmacoepidemiological risk stratification, real-world safety evidence, therapeutic benefit–risk optimization, medication-harm mitigation, regulatory risk governance, and population health protection. The overarching premise is that contemporary drug safety requires a transition from fragmented and predominantly reactive surveillance toward an integrated, evidence-generating, analytically rigorous, clinically actionable, and prevention-oriented ecosystem. Such a framework recognizes that the ultimate objective of pharmacovigilance is not merely to detect adverse events, but to transform heterogeneous safety information into scientifically defensible knowledge that improves therapeutic decision-making, strengthens medication-use systems, supports proportionate regulatory action, reduces preventable harm, and protects population health throughout the medicinal-product lifecycle.

Background

The intellectual development of drug safety has paralleled the transformation of pharmacology from a predominantly descriptive discipline into an increasingly quantitative, molecularly informed, clinically embedded, and population-oriented science. Early pharmacological investigation concentrated primarily on identifying biologically active substances, characterizing their therapeutic actions, establishing dose–response relationships, and describing observable toxicities. The subsequent emergence of clinical pharmacology, therapeutic drug monitoring, pharmacokinetics, pharmacodynamics, pharmacoepidemiology, and regulatory science progressively expanded the scientific understanding of how medicines behave across individuals and populations. Pharmacovigilance emerged within this historical trajectory as a systematic response to the recognition that clinically important medication-related harms may remain incompletely characterized during preauthorization development and may only become apparent when medicinal products are used extensively under heterogeneous real-world conditions. The contemporary discipline consequently represents the cumulative product of several intellectual transitions: from toxicity description to risk characterization, from individual case recognition to population surveillance, from passive reporting to active signal generation, and from retrospective identification of harm toward anticipatory and preventive safety management.

The contemporary concept of a medicinal product's safety profile is inherently dynamic. Safety cannot be reduced to the frequency of adverse events observed in randomized clinical trials or to a binary designation of “safe” versus “unsafe.” Rather, it represents a multidimensional

relationship among pharmacological exposure, biological susceptibility, therapeutic indication, dose, duration, concomitant treatments, disease state, patient characteristics, healthcare processes, and competing therapeutic alternatives. The same pharmacological property may produce benefit in one clinical context and harm in another. A mechanism responsible for therapeutic efficacy may simultaneously generate dose-limiting toxicity; inhibition of a physiological pathway may be therapeutically desirable in one disease while clinically hazardous in another; and an otherwise acceptable exposure may become problematic in the presence of renal impairment, hepatic dysfunction, pharmacogenetic variation, interacting medicines, or altered physiological reserve. Drug safety therefore requires contextual interpretation rather than simple enumeration of adverse events.

Molecular pharmacology provides an essential foundation for such contextualization. Contemporary understanding of drug action extends beyond classical receptor–ligand interactions to encompass complex signaling networks, allosteric modulation, biased agonism, intracellular pathways, ion-channel regulation, transporter biology, enzyme activity, protein degradation, epigenetic mechanisms, immune signaling, mitochondrial function, and systems-level biological responses. Therapeutic and adverse effects may emerge from intended target engagement, secondary target interactions, active metabolites, altered endogenous signaling, immune-mediated processes, or downstream network perturbations. This mechanistic complexity creates both opportunities and challenges for pharmacovigilance. Mechanistic knowledge can strengthen the biological plausibility of suspected adverse reactions and assist in distinguishing potentially meaningful safety signals from spurious associations. Conversely, incomplete mechanistic understanding can delay recognition of unexpected toxicities, particularly when adverse outcomes arise through previously unrecognized pathways.

Pharmacokinetics adds another essential dimension by determining the relationship between administered dose and systemic or tissue exposure. Variability in absorption, distribution, metabolism, and excretion can generate substantial interindividual differences in drug concentrations and consequently in therapeutic and toxic effects. Genetic polymorphisms affecting drug-metabolizing enzymes and transporters, age-related physiological changes, renal and hepatic impairment, nutritional status, concomitant medicines, inflammatory states, and organ-support interventions can modify pharmacokinetic parameters. Pharmacodynamic variability further complicates this relationship because equivalent concentrations do not necessarily generate equivalent biological responses among individuals. Consequently, pharmacological exposure should not be interpreted as a uniform determinant of clinical effect. The emerging field of pharmacometrics, through population pharmacokinetic and pharmacodynamic modeling, exposure–response analysis, and model-informed precision dosing, contributes increasingly sophisticated tools for understanding and managing this variability.

Clinical pharmacology transforms these mechanistic principles into therapeutic knowledge applicable to human populations. Its contribution to drug safety extends from first-in-human investigation to postmarketing therapeutic optimization. Dose selection, therapeutic drug monitoring, interaction assessment, pharmacogenomic interpretation, special-population pharmacology, exposure–response modeling, and individualized treatment strategies all influence the safety of pharmacotherapy. Clinical pharmacology also provides an important bridge between preclinical toxicology and clinical pharmacovigilance by interpreting whether observed adverse events are pharmacologically plausible and by identifying patient or treatment characteristics that may increase susceptibility. As therapeutic regimens become increasingly individualized, clinical pharmacology is progressively integrated with precision medicine, thereby creating opportunities to move beyond population-average safety estimates toward individualized predictions of treatment-related benefit and harm.

Pharmacotherapy represents the operational domain in which these pharmacological principles become therapeutic decisions. Rational pharmacotherapy requires simultaneous consideration of indication, expected efficacy, patient characteristics, dose, duration, route of administration, concomitant medications, contraindications, monitoring requirements, and alternative treatment options. The safety of pharmacotherapy is therefore dependent not only on the intrinsic properties of a medicinal product but also on the quality of the therapeutic decision and its implementation. Inappropriate prescribing, excessive dosing, therapeutic duplication, unrecognized interactions, inadequate monitoring, medication reconciliation failures, and poor communication can convert a potentially appropriate therapy into a source of preventable harm. This recognition has encouraged closer integration between pharmacovigilance and clinical pharmacy, medication safety, pharmacotherapeutic stewardship, and healthcare quality improvement.

The distinction between adverse drug reactions and medication-related harm is particularly important in this context. An adverse drug reaction generally concerns a harmful and unintended response associated with medicinal-product use, whereas medication-related harm encompasses a broader spectrum that may include adverse reactions, medication errors, administration problems, nonadherence, inappropriate prescribing, monitoring failures, and system-level vulnerabilities. The scientific management of these phenomena requires different but interconnected approaches. Mechanistically mediated toxicity may require dose modification or treatment substitution, whereas a prescribing error may require decision-support intervention, clinician education, workflow redesign, or organizational safeguards. Pharmacovigilance therefore increasingly operates within a broader patient-safety ecosystem in which pharmacological, clinical, behavioral, and organizational determinants of harm are jointly considered.

The expansion of pharmacovigilance has been strongly influenced by recognition of the limitations inherent in premarketing evidence. Randomized clinical trials provide the strongest framework for controlled evaluation of many therapeutic effects, but their capacity to identify rare or delayed adverse events is inherently constrained by sample size, observation period, inclusion criteria, treatment protocols, and monitoring intensity. Participants may differ from routine clinical populations with respect to age, comorbidity, concomitant medication, adherence, disease severity, socioeconomic circumstances, and healthcare utilization. Consequently, authorization represents an important regulatory milestone but not the endpoint of safety knowledge generation. Postauthorization evidence is necessary to determine whether observed risks change when medicinal products are used at scale, in diverse populations, over longer periods, and under less controlled circumstances.

Spontaneous reporting systems have historically provided a principal infrastructure for postmarketing safety surveillance. Their major scientific value lies in the capacity to generate early hypotheses concerning previously unrecognized adverse reactions. A single well-documented case may occasionally identify a clinically important phenomenon, while accumulation of multiple reports may reveal unusual patterns that justify systematic investigation. However, spontaneous reporting systems lack complete exposure denominators and are affected by underreporting, selective reporting, reporting stimulated by publicity, variable clinical documentation, differential reporting behavior, duplicate reports, missing data, and temporal changes in awareness. These characteristics make spontaneous reporting particularly valuable for hypothesis generation but insufficient as an independent basis for most causal conclusions.

The development of quantitative signal-detection methodologies has substantially transformed the interpretation of large pharmacovigilance databases. Disproportionality analysis enables systematic screening for drug–event combinations whose reporting frequency differs from a predefined background expectation. Proportional reporting ratios, reporting odds ratios, Bayesian confidence propagation neural networks, empirical Bayes methods, and related approaches have

enabled pharmacovigilance organizations to process large quantities of safety information more efficiently. Yet statistical disproportionality remains conceptually distinct from causality. A disproportionately reported event may result from confounding by indication, co-medication, disease-related risk, reporting bias, stimulated reporting, differential surveillance, or other artifacts. Signal detection should therefore initiate a structured process of signal assessment rather than terminate it.

Signal validation represents the transition from statistical observation to scientific interpretation. Validation may involve clinical case review, examination of temporal relationships, assessment of dechallenge and rechallenge information, evaluation of alternative explanations, mechanistic plausibility, examination of dose–response relationships, comparison with previous literature, and targeted epidemiological investigation. The quality of this process depends upon multidisciplinary expertise because pharmacological interpretation alone may be insufficient to establish population-level relevance, while epidemiological association may remain difficult to interpret without mechanistic understanding. Modern pharmacovigilance consequently increasingly emphasizes triangulation, whereby independent evidence streams are evaluated collectively rather than relying on a single analytical method.

Pharmacoepidemiology provides a critical methodological bridge between pharmacotherapy and population-level drug safety. It examines medication utilization, therapeutic effects, adverse outcomes, comparative safety, and determinants of treatment-related events across populations. Pharmacoepidemiological designs enable researchers to estimate relative and absolute risks and to identify populations with differential susceptibility. Cohort studies, case–control studies, self-controlled designs, case-crossover approaches, interrupted time-series analyses, active-comparator studies, new-user designs, and target-trial emulation have expanded the methodological repertoire available for medication-safety research. Each design offers distinct advantages and limitations, and appropriate selection depends on the research question, exposure characteristics, outcome frequency, available data, and anticipated sources of bias.

The increasing emphasis on causal inference reflects the recognition that association alone is insufficient for robust drug-safety decision-making. Observational data are vulnerable to confounding because treatment allocation in routine care is not random. Patients receiving different medicines may differ systematically in disease severity, comorbidity, socioeconomic circumstances, healthcare utilization, or baseline risk. Confounding by indication is particularly consequential because the disease prompting treatment may itself increase the probability of the adverse outcome under investigation. Advanced causal-inference methods, including propensity-score approaches, inverse probability weighting, marginal structural models, instrumental-variable strategies, and target-trial frameworks, can strengthen observational analyses when appropriately designed and implemented. Nevertheless, these methods cannot fully compensate for unmeasured or poorly measured determinants, and their validity remains dependent on assumptions that must be explicitly considered.

Real-world data have further expanded the evidentiary infrastructure of pharmacovigilance. Electronic health records can provide longitudinal clinical information, laboratory results, diagnoses, procedures, prescribing data, and clinical narratives. Claims databases can facilitate large-scale analysis of treatment exposure and healthcare outcomes. Pharmacy-dispensing databases provide additional information concerning medication acquisition and utilization patterns. Registries may offer disease-specific clinical detail, while patient-generated data can capture symptoms, functional outcomes, and treatment experiences not routinely documented in conventional healthcare systems. The integration of these sources can increase the temporal resolution and population coverage of drug-safety research, although differences in coding practices, data completeness, interoperability, exposure definitions, and outcome ascertainment create substantial methodological challenges.

The concept of real-world evidence has therefore evolved beyond simply analyzing large datasets. The scientific value of real-world evidence depends upon whether the underlying data are sufficiently valid and appropriately analyzed to address a clearly defined clinical or regulatory question. Large datasets do not automatically produce reliable evidence. Misclassification, missingness, selection effects, inconsistent exposure measurement, incomplete clinical documentation, and systematic differences between data sources can substantially influence estimates. Consequently, high-quality real-world pharmacovigilance requires rigorous data curation, prespecified analytical strategies, appropriate comparator selection, transparent definitions, sensitivity analyses, and validation of key variables.

The growing importance of longitudinal evidence is particularly relevant for chronic pharmacotherapy. Many adverse outcomes are cumulative, delayed, or dependent on treatment duration. Long-term exposure may alter risk in ways that cannot be detected during short-duration clinical trials. Conversely, some adverse events may occur primarily during treatment initiation and then decline as susceptibility or exposure patterns change. Temporal heterogeneity therefore represents a central component of pharmacovigilance. Time-varying exposure, treatment discontinuation, switching, dose escalation, adherence changes, and competing risks must be considered when evaluating longitudinal safety outcomes. This has encouraged the development of increasingly sophisticated analytical strategies capable of modeling changing exposure and risk over time.

Polypharmacy intensifies these methodological challenges. The simultaneous use of multiple medicinal products creates an extensive interaction network in which individual agents may modify the pharmacokinetics, pharmacodynamics, or toxicity of other agents. Polypharmacy may also increase therapeutic complexity, reduce adherence, complicate attribution of adverse events, and generate cumulative physiological burden. Conventional pharmacovigilance approaches based on isolated drug–event pairs may consequently overlook important regimen-level interactions. Network-based pharmacology, interaction databases, systems pharmacology, and computational modeling provide emerging tools for investigating multidrug exposure. Nevertheless, clinical interpretation remains essential because a theoretical pharmacological interaction may not necessarily produce a clinically significant outcome under every exposure condition.

Pharmacogenomics further demonstrates why population-average safety estimates may be insufficient for individualized pharmacotherapy. Genetic variation can influence drug metabolism, transporter activity, receptor sensitivity, immune responses, and susceptibility to severe adverse reactions. Certain drug–gene relationships are sufficiently established to inform prescribing or dosing decisions, whereas others remain investigational. The incorporation of genomic information into pharmacovigilance offers opportunities to identify genetically defined risk groups and explain heterogeneity in treatment response. At the same time, genomic data introduce considerations involving ancestry representation, population transferability, analytical validity, ethical governance, and equitable access to precision therapeutics. Precision pharmacovigilance therefore requires integration of genomic evidence with clinical and epidemiological information rather than isolated reliance on genetic markers.

The immune system represents another increasingly important dimension of drug safety. Biological medicines, immune-modulating agents, vaccines, and other advanced therapeutics can produce adverse events through mechanisms that differ substantially from those associated with conventional small-molecule drugs. Immunogenicity, cytokine-mediated responses, hypersensitivity, autoimmunity, and immune-mediated organ injury may require specialized approaches to signal identification and clinical characterization. The complexity of these events illustrates the growing need for pharmacovigilance systems capable of integrating laboratory biomarkers, clinical phenotypes, treatment timing, immune status, and mechanistic evidence.

Advanced therapies have also expanded the conceptual boundaries of pharmacovigilance. Cell therapies, gene therapies, tissue-engineered products, and other complex biological interventions may involve long latency periods, individualized manufacturing processes, novel biological mechanisms, and specialized administration pathways. Their safety surveillance may therefore require extended follow-up, traceability, specialized registries, and integration of product-specific characteristics with clinical outcomes. The traditional distinction between pharmacovigilance and broader biomedical surveillance becomes increasingly blurred as therapeutic products become more biologically sophisticated.

Artificial intelligence and machine learning are increasingly incorporated into these emerging pharmacovigilance architectures. Natural-language processing can facilitate extraction of adverse-event information from clinical narratives, while machine-learning algorithms can identify complex associations across large heterogeneous datasets. Predictive models may assist in patient-level risk stratification, while network-based computational approaches can explore relationships among drugs, targets, diseases, phenotypes, and adverse outcomes. Nevertheless, algorithmic pharmacovigilance raises concerns regarding data drift, model interpretability, algorithmic bias, false-positive signals, false-negative detection, external validity, and reproducibility. An algorithmic association should therefore be regarded as a candidate signal requiring appropriate clinical, epidemiological, and mechanistic assessment rather than as definitive evidence of causality.

The emergence of computational pharmacovigilance also reinforces the importance of data governance. Safety databases may contain sensitive clinical information, and integration across systems creates challenges concerning privacy, security, data ownership, interoperability, and ethical use. International pharmacovigilance increasingly depends on standardized terminologies, coding frameworks, data models, and reporting structures that permit information exchange while preserving appropriate safeguards. Harmonization is especially important for multinational surveillance because differences in healthcare systems, regulatory frameworks, prescribing patterns, reporting practices, and population characteristics can otherwise produce misleading comparisons.

Regulatory science provides the framework through which these heterogeneous forms of evidence are translated into risk-management decisions. Regulatory assessment must operate under uncertainty because safety evidence is rarely complete. Authorities must determine whether available evidence justifies changes in labeling, additional monitoring, restrictions of use, postauthorization studies, educational interventions, or other risk-minimization strategies. Such decisions require proportional interpretation of evidence and consideration of therapeutic alternatives, disease burden, exposed population size, severity of potential harm, and feasibility of risk mitigation. Regulatory pharmacovigilance is consequently neither purely statistical nor purely clinical; it is an interdisciplinary process of evidence synthesis and risk governance.

Risk-management planning has progressively shifted from reactive responses toward proactive strategies. Identification of potential risks can be followed by targeted monitoring, additional studies, enhanced surveillance, educational interventions, controlled-access programs, laboratory monitoring, dose restrictions, or other measures. The effectiveness of these interventions must subsequently be assessed. A risk-minimization measure that exists formally but is poorly implemented may have little practical effect. Thus, pharmacovigilance increasingly encompasses not only detection of risks but also evaluation of whether regulatory and clinical interventions actually reduce medication-related harm.

Benefit–risk assessment remains the central integrating principle within this framework. The existence of adverse effects does not automatically imply that a medicinal product has an unfavorable therapeutic profile. Many effective therapies involve predictable and manageable risks that must be evaluated against disease severity and therapeutic alternatives. Conversely, a

rare but catastrophic adverse event may become highly consequential when exposure is widespread or when susceptible populations are difficult to identify. Benefit–risk characterization must therefore incorporate event frequency, severity, reversibility, preventability, therapeutic efficacy, treatment alternatives, patient characteristics, exposure duration, and uncertainty. Modern benefit–risk assessment is consequently dynamic and context-specific rather than a fixed property established at authorization.

Public health pharmacovigilance expands this reasoning from individual patients to populations. The consequences of medication-related harm depend not only on individual risk but also on the scale of exposure. A rare adverse event affecting millions of users can represent a substantial public health burden, whereas a more common adverse effect associated with a narrowly indicated therapy may have a different population impact. Public health surveillance must therefore integrate incidence, prevalence, exposure volume, severity, preventability, healthcare utilization, mortality, and distribution of risk across demographic and clinical groups. This population-level perspective is essential for prioritizing safety interventions and allocating surveillance resources.

Population heterogeneity is particularly important in global pharmacovigilance. Differences in genetic architecture, disease epidemiology, prescribing behavior, nutritional status, healthcare infrastructure, regulatory systems, medication availability, and cultural practices can influence both drug exposure and observed adverse outcomes. Underrepresentation of particular populations in clinical trials may generate uncertainty when treatments are subsequently introduced into those populations. Global pharmacovigilance systems therefore require strategies that can accommodate heterogeneous data while preserving methodological comparability. International collaboration, standardized terminology, interoperable data systems, and harmonized analytical principles are important components of this infrastructure.

Health-system organization itself can function as a determinant of drug safety. Medication reconciliation processes, prescribing technologies, pharmacist involvement, clinical decision support, laboratory monitoring, continuity of care, and communication across healthcare settings influence the probability that medication-related problems will be identified and addressed. Transitions between inpatient and outpatient care are particularly important because changes in medication lists, incomplete communication, and therapeutic duplication can generate preventable risk. Consequently, drug safety cannot be understood exclusively at the molecular or pharmacological level; it also requires analysis of the systems within which medicines are prescribed and used.

Patient and caregiver engagement increasingly contributes to this systems perspective. Individuals receiving pharmacotherapy possess experiential knowledge concerning tolerability, treatment burden, adherence barriers, and functional effects that may not be fully captured through traditional clinical documentation. Patient-reported outcomes and direct safety reporting can supplement clinician-generated information. Effective engagement can also improve understanding of risk communication and shared therapeutic decision-making. Nevertheless, patient-reported observations require appropriate contextualization because symptoms may be nonspecific and causal attribution may remain uncertain. Their value is greatest when integrated systematically with clinical and pharmacological evidence.

The communication of uncertainty is therefore central to contemporary pharmacovigilance. Safety evidence frequently evolves incrementally, and early signals may be insufficient to establish causal relationships. Communicating preliminary findings as definitive can generate inappropriate treatment discontinuation, whereas minimizing uncertain but potentially important risks can delay protective action. Scientifically rigorous communication should distinguish signal detection from signal confirmation, association from causation, and uncertainty from absence of evidence. Such distinctions are particularly important in an environment characterized by rapid digital information

dissemination, where incomplete or decontextualized safety information can influence medication behavior at population scale.

The increasing complexity of medication safety has also reinforced the need for interdisciplinary collaboration. Pharmacologists contribute mechanistic interpretation; clinical pharmacologists provide exposure–response and therapeutic expertise; pharmacists contribute medication-use and stewardship perspectives; epidemiologists contribute population-level methodological frameworks; statisticians contribute quantitative inference; clinicians contextualize outcomes; data scientists develop computational approaches; regulatory scientists translate evidence into governance; and patients provide experiential perspectives. No single discipline can adequately characterize the full multidimensionality of contemporary drug safety. The future of pharmacovigilance therefore depends on collaborative epistemologies capable of integrating evidence across disciplinary boundaries while preserving methodological specificity.

A particularly important conceptual transition is the movement from “adverse-event surveillance” toward “therapeutic safety intelligence.” The former emphasizes detection of harmful outcomes after they occur, whereas the latter incorporates mechanistic prediction, risk stratification, continuous evidence synthesis, contextual interpretation, and proactive prevention. Therapeutic safety intelligence is not simply a technological concept. It represents a broader organizational capacity to convert dispersed medication-related information into actionable knowledge. Such capacity requires interoperable data, validated analytical methods, skilled interpretation, responsive clinical systems, and regulatory mechanisms capable of acting upon emerging evidence.

Within this emerging paradigm, the relationship between pharmacovigilance and pharmacotherapy becomes reciprocal. Pharmacovigilance identifies safety patterns that can modify prescribing recommendations, while pharmacotherapeutic practice generates new observations that subsequently inform surveillance. Clinical pharmacists and clinicians may recognize unusual adverse events, treatment failures, interaction patterns, or unexpected therapeutic responses that become hypotheses for broader investigation. Conversely, validated safety signals may result in changes in dosing, monitoring, contraindications, treatment selection, or patient counseling. The clinical and surveillance domains therefore form a continuous feedback system.

The same reciprocal relationship exists between pharmacology and pharmacovigilance. Emerging safety signals may reveal previously unrecognized pharmacological mechanisms, while advances in molecular pharmacology can predict potential safety liabilities before widespread clinical exposure. Mechanistic toxicology, systems pharmacology, pharmacogenomics, and translational pharmacology can therefore contribute to earlier risk identification. This bidirectional relationship suggests that future drug-safety science should not treat pharmacovigilance as a post hoc regulatory function but as an integrated component of the broader pharmacological knowledge-production process.

The public health implications of this integration are substantial. Preventable medication-related harm contributes to morbidity, mortality, healthcare utilization, treatment discontinuation, loss of therapeutic benefit, and economic burden. At the same time, fear or misinterpretation of medication risks can reduce adherence to effective therapies and generate avoidable disease burden. Public health protection therefore requires a balanced evidence-based approach that seeks to minimize preventable harm while preserving access to beneficial pharmacotherapy. This balance cannot be achieved through isolated surveillance measures; it requires integrated assessment of pharmacological mechanisms, clinical outcomes, population exposure, therapeutic alternatives, and health-system consequences.

The background to contemporary drug safety thus reflects a convergence of scientific disciplines and methodological paradigms. Molecular pharmacology explains biological mechanisms; clinical

pharmacology characterizes therapeutic exposure and response; pharmacotherapy operationalizes treatment decisions; pharmacovigilance detects and investigates medication-related safety signals; pharmacoepidemiology estimates risks across populations; real-world evidence extends surveillance into routine clinical practice; causal inference strengthens interpretation; computational science increases analytical capacity; regulatory science converts evidence into risk governance; and public health contextualizes the ultimate consequences of therapeutic decisions. These domains are increasingly interdependent, and their integration provides the conceptual basis for a modern safety ecosystem.

The evolutionary advancement of drug safety should be understood as a transition from fragmented, predominantly reactive approaches toward an integrated, longitudinal, multiscale, evidence-generating framework. Such a framework recognizes that safety is produced through interactions among molecular properties, patient characteristics, treatment regimens, clinical environments, healthcare systems, regulatory structures, and population contexts. It also recognizes that uncertainty is an intrinsic characteristic of medicine and that responsible pharmacovigilance does not require elimination of uncertainty but rather its systematic characterization, communication, and management.

The contemporary challenge is therefore not simply to increase the volume of pharmacovigilance data but to improve the scientific quality, interpretability, interoperability, and clinical utility of safety information. More data do not automatically produce better evidence. The central objective is to establish analytical architectures capable of distinguishing clinically meaningful signals from statistical artifacts, integrating mechanistic and epidemiological evidence, identifying vulnerable populations, evaluating interventions, and continuously updating benefit–risk assessments. Such architectures should be sufficiently sensitive to detect emerging hazards while sufficiently specific to avoid unnecessary disruption of effective pharmacotherapy.

The drug safety becomes an iterative translational enterprise extending from molecular discovery to population health protection. The medicinal product is understood not as an isolated chemical or biological entity but as a component of a dynamic therapeutic system. Its safety profile evolves as knowledge accumulates, clinical use expands, patient populations diversify, treatment combinations change, and analytical technologies improve. Pharmacovigilance consequently functions as an essential mechanism for maintaining alignment between pharmacological innovation and responsible therapeutic implementation.

The conceptual foundation for examining drug safety through an integrated framework encompassing pharmacology, pharmacotherapy, pharmacovigilance, pharmacoepidemiology, real-world evidence, causal inference, regulatory science, medication-harm prevention, and public health. The central scientific premise is that effective protection from medication-related harm requires continuous integration of mechanistic knowledge, clinical evidence, population surveillance, computational analysis, regulatory governance, and therapeutic practice. Within such a framework, the ultimate objective of drug-safety science is not merely to identify adverse events after their occurrence, but to develop increasingly anticipatory systems capable of recognizing vulnerability, detecting emerging signals and clarifying causality, optimizing benefit–risk relationships, guiding rational pharmacotherapy, mitigating preventable harm, and protecting population health across the complete medicinal-product lifecycle.

GOAL

The overarching goal of this scientific discourse is to develop a comprehensive, multiscalar and translational conceptual framework for the contemporary advancement of drug safety, pharmacovigilance, pharmacology, and pharmacotherapy, integrating mechanistic, clinical, epidemiological, computational, regulatory, and public-health dimensions of medication-related risk. Specifically, the discourse seeks to elucidate the interconnected relationships among

molecular and clinical pharmacology, therapeutic decision-making, adverse drug reaction surveillance, safety-signal detection and validation, causal inference, pharmacoepidemiological risk stratification, real-world evidence generation, pharmacotherapeutic optimization, and benefit–risk characterization. It further aims to examine emerging approaches for medication-harm prevention and mitigation, including precision pharmacotherapy, pharmacogenomic risk assessment, computational pharmacovigilance, longitudinal safety monitoring, and evidence-informed regulatory risk governance. An additional objective is to conceptualize pharmacovigilance as a proactive and continuously evolving scientific infrastructure capable of translating heterogeneous safety information into clinically actionable knowledge. The framework seeks to strengthen the scientific basis for rational pharmacotherapy, improve individualized and population-level medication safety, support proportionate regulatory decision-making, identify vulnerable populations, reduce preventable medication-related morbidity, and advance sustainable public health protection throughout the medicinal-product lifecycle.

METHODOLOGY

This scientific discourse employed an integrative, multiscalar, and translational methodological framework designed to synthesize contemporary knowledge concerning the evolutionary advancement of drug safety, pharmacovigilance, pharmacology, and pharmacotherapy across molecular, mechanistic, clinical, epidemiological, computational, regulatory, and population-health domains. The methodological architecture was conceptualized as a structured narrative synthesis incorporating principles of pharmacological reasoning, clinical pharmacology, pharmacoepidemiology, pharmacovigilance science, medication-safety research, causal inference, real-world evidence generation, and regulatory risk governance. Rather than restricting the analysis to a single methodological paradigm, the approach sought to establish an interdisciplinary evidence architecture capable of integrating heterogeneous forms of scientific knowledge generated throughout the medicinal-product lifecycle.

The evidentiary domain encompassed peer-reviewed biomedical and pharmaceutical literature addressing adverse drug reactions, adverse events, medication-related harm, pharmacokinetic and pharmacodynamic determinants of toxicity, pharmacogenomic susceptibility, drug–drug and drug–disease interactions, safety-signal detection, signal validation, causality assessment, pharmacoepidemiological risk estimation, real-world safety evidence, pharmacotherapeutic optimization, risk-minimization strategies, benefit–risk assessment, and regulatory pharmacovigilance. Particular analytical emphasis was placed on contemporary developments involving spontaneous reporting systems, electronic health records, administrative claims databases, disease and product registries, prescription and dispensing datasets, patient-generated information, longitudinal observational cohorts, and other real-world data infrastructures capable of supporting post-authorisation safety surveillance.

The synthesis incorporated a multilevel analytical perspective linking molecular mechanisms with clinical phenotypes and population-level outcomes. At the mechanistic level, pharmacodynamic pathways, pharmacokinetic variability, receptor and transporter biology, metabolic pathways, immune-mediated mechanisms, pharmacogenomic determinants, and biological susceptibility factors were considered as potential substrates of heterogeneous medication response. At the clinical level, therapeutic indication, dosing intensity, treatment duration, comorbidity, polypharmacy, patient vulnerability, adherence, monitoring intensity, and concomitant pharmacotherapy were examined as determinants of benefit–risk heterogeneity. At the epidemiological level, exposure–outcome relationships, confounding, indication bias, channeling bias, selection effects, exposure and outcome misclassification, underreporting, stimulated reporting, missing data, and temporal ambiguity were incorporated into the interpretive framework.

Contemporary computational approaches to pharmacovigilance were additionally examined, including disproportionality analysis, Bayesian signal-detection methodologies, statistical learning, machine-learning-assisted pattern recognition, network-based pharmacological analysis, and artificial-intelligence-enabled safety-signal prioritization. However, computational outputs were conceptually treated as hypothesis-generating rather than intrinsically causal, requiring contextualization through biological plausibility, clinical adjudication, epidemiological validation, and regulatory interpretation. The methodological framework therefore emphasized triangulation across complementary evidence streams rather than reliance upon isolated analytical signals.

The synthesized evidence was interpreted through a translational benefit–risk perspective, connecting pharmacological mechanisms, therapeutic decision-making, medication-harm mitigation, regulatory risk-management interventions, and population-health consequences. This integrative methodology enabled the discourse to conceptualize pharmacovigilance not as a passive reporting activity, but as a continuously evolving scientific infrastructure for generating actionable therapeutic-safety intelligence throughout the complete medicinal-product lifecycle.

RESEARCH FINDINGS, RESULTS AND DISCUSSION

The present research synthesis identifies a profound epistemological and methodological advancement of contemporary drug-safety science, demonstrating that pharmacovigilance can no longer be conceptualized exclusively as a post-marketing surveillance mechanism centered on spontaneous adverse-event reporting. The findings indicate that drug safety has progressively evolved into a multiscalar, longitudinal, evidence-integrative scientific domain encompassing molecular pharmacology, clinical pharmacology, pharmacotherapy, pharmacoepidemiology, real-world evidence, computational analytics, causal inference, regulatory science, medication-safety engineering, and population health. This transformation reflects the increasing complexity of therapeutic systems in which medicinal products interact simultaneously with molecular targets, biological substrates, patient characteristics, disease processes, concomitant therapies, healthcare environments, and societal determinants of health.

The principal research finding is that drug safety is dynamically constituted rather than intrinsically fixed. A medicinal product possesses identifiable pharmacological properties, but the clinical expression of risk depends upon dose, exposure duration, pharmacokinetic disposition, pharmacodynamic sensitivity, indication, patient susceptibility, comorbidity, polypharmacy, treatment adherence, monitoring intensity, healthcare-system organization, and availability of alternative therapies. Consequently, a pharmacological hazard and an observed clinical risk should not be regarded as synonymous constructs. Hazard represents the capacity to produce harm under specified conditions, whereas clinical risk incorporates the probability, magnitude, timing, context, and consequences of that harm within an exposed population.

This distinction provides a fundamental conceptual foundation for contemporary pharmacovigilance. The same pharmacological mechanism may produce substantially different clinical outcomes across patient populations because biological susceptibility and exposure conditions vary. Genetic polymorphisms affecting drug metabolism or transport may modify systemic exposure; renal or hepatic dysfunction may alter elimination; inflammatory states may influence pharmacokinetics and pharmacodynamics; concomitant medicines may generate pharmacokinetic or pharmacodynamic interactions; and disease severity may modify both baseline outcome risk and treatment intensity. The observed safety phenotype is therefore an emergent property of the medicine–patient–disease–treatment system.

The synthesis further demonstrates that the historical distinction between pharmacology and pharmacovigilance has become increasingly porous. Pharmacology establishes the mechanistic basis through which medicines exert therapeutic and adverse effects, whereas pharmacovigilance observes how those effects manifest across heterogeneous real-world populations.

Pharmacotherapy translates pharmacological knowledge into therapeutic decisions, while pharmacoepidemiology examines treatment effects and risks at the population level. These domains are therefore complementary components of a broader therapeutic-safety knowledge architecture.

A particularly important finding is the emergence of bidirectional translationality. Traditionally, scientific translation has been conceptualized as movement from laboratory discovery toward clinical application. Contemporary drug-safety science requires a reciprocal process. Molecular findings generate hypotheses for clinical surveillance, while clinical and epidemiological signals can stimulate mechanistic investigation. An unexpected clinical association may identify a biological pathway not previously appreciated, whereas knowledge of a receptor, transporter, metabolic enzyme, or immune pathway can generate anticipatory hypotheses concerning potential toxicity. This bidirectionality transforms pharmacovigilance into an active generator of pharmacological knowledge rather than a passive recipient of adverse-event information.

The research synthesis identifies three major epistemic layers of drug safety: mechanistic evidence, observational evidence, and decision evidence. Mechanistic evidence addresses biological plausibility and pharmacological causation; observational evidence characterizes exposure–outcome relationships under real-world conditions; and decision evidence integrates uncertainty, therapeutic benefit, comparative risk, clinical relevance, and possible intervention. None of these layers is sufficient independently. Their scientific value increases when they converge while retaining their methodological distinctions.

Mechanistic evidence may explain how a medicine could cause an adverse effect but cannot alone establish its frequency in clinical populations. Observational evidence may demonstrate an association but can remain vulnerable to confounding and measurement error. Regulatory or clinical decision-making requires an additional interpretive layer that considers the magnitude and severity of risk relative to therapeutic benefit and alternatives. The research therefore supports a triangulated evidence paradigm in which pharmacological, epidemiological, clinical, and regulatory knowledge are integrated without collapsing one form of evidence into another.

A major finding concerns the transformation from passive surveillance toward intelligent surveillance. Traditional spontaneous-reporting systems remain foundational because they can identify unexpected and rare safety concerns. However, contemporary pharmacovigilance increasingly combines spontaneous reports with electronic health records, administrative claims, disease registries, prescription and dispensing databases, literature surveillance, patient-reported information, digital health technologies, and other real-world data. WHO explicitly identifies pharmacovigilance as encompassing detection, assessment, understanding, and prevention of adverse effects and other medicine-related problems, while its recent global strategy emphasizes risk-based and adaptive strengthening of national systems. This transition does not imply that passive reporting has become obsolete. Rather, the findings demonstrate that spontaneous reports occupy a distinctive epistemological position. They provide an early-warning mechanism capable of identifying unexpected medicine–event combinations without requiring investigators to prespecify every potential outcome. Their limitations—including underreporting, stimulated reporting, selective reporting, incomplete denominators, variable documentation, and reporting heterogeneity—mean that they are particularly powerful for signal generation but generally insufficient for estimating population incidence or establishing causality independently.

The research consequently identifies signal intelligence as a central intermediate stage between raw safety information and validated safety knowledge. Signal intelligence encompasses the detection, characterization, prioritization, contextualization, validation, and longitudinal evaluation of potential safety signals. Current European regulatory practice explicitly distinguishes detection from validation and subsequent assessment, emphasizing that a safety signal does not itself establish that a medicinal product caused the reported event.

This distinction is scientifically consequential. A statistical association, reporting disproportionality, or computational anomaly should be treated as a hypothesis requiring structured investigation rather than as an established adverse drug reaction. Signal validation must therefore consider the quality of individual case reports, consistency across reports, temporal relationships, alternative explanations, biological plausibility, previous knowledge, clinical seriousness, and the potential implications for the benefit–risk profile. (See Table-1).

Table 1. Principal Research Findings and Their Scientific Reconfiguration

Research finding	Conventional perspective	Reconfigured scientific perspective	Principal implication
Drug risk is context dependent	Safety attributed primarily to the product	Risk emerges from medicine–patient–disease–system interaction	Contextual risk stratification
Pharmacovigilance is lifecycle-based	Predominantly post-marketing activity	Continuous evidence generation across the product lifecycle	Longitudinal surveillance
Signal detection is hypothesis generation	Signal interpreted as potential evidence of harm	Detection, validation, characterization, and assessment are distinct	Reduced causal overinterpretation
Pharmacology and pharmacovigilance are interconnected	Separate disciplinary domains	Mechanistic and observational knowledge are reciprocally informative	Translational pharmacology
Real-world data expand safety knowledge	Supplementary post-market information	Major infrastructure for longitudinal safety evidence	RWE-enabled surveillance
Causality requires triangulation	Temporal association often emphasized	Mechanistic, epidemiological, clinical, and statistical convergence	Stronger causal inference
Population averages are insufficient	Aggregate risk estimates dominate	Heterogeneity and susceptibility require stratification	Precision pharmacovigilance
Medication harm exceeds ADRs	Focus on adverse reactions	Includes errors, interactions, system failures, and preventable harm	Integrated medication safety
AI primarily automates detection	Computational signal generation	Human–AI collaborative safety intelligence	Augmented surveillance
Benefit–risk is static	Primarily authorization-stage evaluation	Dynamic and continuously updated	Adaptive regulatory governance
Patient information is supplementary	Professional reporting predominates	Patient experience is an evidence stream	Patient-centered pharmacovigilance

Safety interventions are endpoints	Action assumed to produce benefit	Intervention effectiveness must be evaluated	Closed-loop pharmacovigilance

A third major finding is that causal inference constitutes the central methodological bridge between pharmacovigilance and evidence-based safety. Modern safety surveillance generates enormous quantities of association data, but the scientific question is ultimately causal: whether exposure to a medicinal product contributes to an observed outcome under specified conditions. The distinction between association and causation is particularly important because real-world medication use is non-randomized. Treatment assignment is influenced by disease severity, prognosis, clinician preference, previous treatment failure, socioeconomic factors, healthcare access, and other variables.

The resulting confounding structure can be extensive. Patients receiving one therapy may systematically differ from those receiving another before treatment begins. Consequently, a higher event rate among treated patients may reflect underlying disease risk rather than pharmacological toxicity. Similarly, a medicine may be preferentially prescribed to patients already considered high risk, generating channeling effects that can distort comparative safety analyses.

The research findings support increasingly explicit causal frameworks incorporating active-comparator designs, propensity-score methods, inverse-probability weighting, self-controlled designs, target-trial emulation, sensitivity analysis, negative controls, and other approaches where scientifically appropriate. These methods do not eliminate uncertainty but can make assumptions explicit and reduce avoidable bias.

The emergence of ICH M14 further reflects this methodological evolution. The 2026 final guidance establishes general principles for planning, designing, analyzing, and reporting non-interventional studies using real-world data for safety assessment of medicines. This development is important because it formalizes the movement toward higher methodological rigor in observational safety research.

The findings further indicate that real-world data and real-world evidence should be conceptually distinguished. Real-world data represent routinely collected information concerning health status or healthcare delivery, including electronic health records, claims, registries, and digital health sources. Real-world evidence represents the clinical evidence generated through appropriate analysis of such data. FDA explicitly distinguishes these concepts and recognizes the expanding potential of fit-for-purpose real-world data to support regulatory oversight across the therapeutic lifecycle.

The scientific transformation therefore does not arise simply from possessing larger databases. It depends upon whether those data can answer clearly defined clinical and causal questions with adequate validity. Data provenance, completeness, coding practices, exposure ascertainment, outcome validation, temporal structure, representativeness, and confounding control become essential determinants of evidence quality.

A major finding is consequently the emergence of the principle of fit-for-purpose evidence. No single database is universally optimal for every pharmacovigilance question. Spontaneous reporting may be highly suitable for rare unexpected signals; claims databases may be valuable for utilization and comparative outcomes; electronic health records may provide greater clinical granularity; disease registries may provide disease-specific follow-up; and prospective cohorts may offer detailed exposure and phenotype characterization. Methodological appropriateness therefore depends upon the causal question and the characteristics of the outcome.

The synthesis identifies evidence-source complementarity as superior to evidence-source competition. A pharmacovigilance system should not ask whether spontaneous reporting,

electronic health records, registries, or claims are the “best” source in isolation. Rather, it should determine how each source contributes distinct information to an integrated causal assessment.
Another important finding concerns temporal pharmacovigilance. The safety profile of a medicine may change over time because exposure accumulates, populations expand, treatment patterns evolve, new combinations become common, and previously underrepresented groups receive therapy. Accordingly, safety should be monitored longitudinally rather than interpreted as a static attribute established at authorization.
The temporal dimension also affects causality. Different adverse outcomes have different latency structures. Immediate hypersensitivity reactions, acute hemodynamic effects, cumulative organ toxicity, withdrawal phenomena, and delayed immune or neoplastic outcomes require different exposure windows. Failure to align analytic risk windows with plausible biological latency can create both false associations and missed associations.
The research therefore supports the development of mechanism-informed temporal windows. Pharmacological knowledge should inform the design of epidemiological exposure periods rather than treating time windows as purely statistical choices.
Another finding is that dose is not equivalent to exposure. Prescribed dose may differ from actual intake, absorbed dose, systemic concentration, tissue concentration, or biologically active exposure. Pharmacokinetic variability can produce substantial interindividual differences even when prescribed regimens are identical. This reinforces the importance of pharmacokinetic and pharmacodynamic integration in safety research.
Drug–drug interactions further complicate exposure assessment. One medicine may inhibit metabolism of another, alter transporter activity, modify renal elimination, or produce additive pharmacodynamic effects. In polypharmacy, therefore, the relevant exposure unit may be the entire regimen rather than an individual medicine.
The synthesis identifies regimen-level pharmacovigilance as an important extension of conventional medicine–event surveillance. Instead of evaluating each medicine independently, future research should increasingly characterize combinations, treatment sequences, cumulative medication burden, and interaction networks. This is particularly relevant to multimorbidity and aging populations.
The findings also demonstrate that pharmacological vulnerability is heterogeneous. Genetic variation, age, organ function, immune status, body composition, nutritional state, comorbidity, prior treatment history, and concomitant medications can all influence susceptibility. A population-level average risk may consequently obscure clinically meaningful high-risk subgroups. Precision pharmacovigilance seeks to address this limitation by identifying patient characteristics associated with differential risk. Pharmacogenomic information may contribute to this process, but it should be integrated with clinical phenotype rather than treated as a standalone determinant. Genotype modifies probability; it rarely determines outcome independently of environmental and clinical context.
The research further identifies pharmacovigilance as an instrument of precision pharmacotherapy. Safety surveillance can inform individualized treatment decisions when evidence identifies specific patient characteristics associated with increased risk. Conversely, individualized pharmacotherapy generates more detailed safety information that can improve population-level surveillance.
The convergence of pharmacovigilance and precision medicine therefore creates a reciprocal learning system. Another major finding concerns the expansion from adverse drug reaction surveillance to medication-harm surveillance. An adverse drug reaction is only one component of the broader medication-safety domain. Medication-related harm may arise through prescribing errors, dispensing errors, administration errors, contraindicated use, inadequate monitoring, interaction-related toxicity, inappropriate duration, adherence problems, therapeutic duplication, and transitions-of-care failures.

WHO has specifically emphasized the relationship between pharmacovigilance centers and medication-error reporting and learning systems, underscoring the importance of integrating pharmacovigilance evidence with broader patient-safety structures.This finding has substantial implications for clinical pharmacy. Pharmacists can contribute to medication reconciliation, interaction screening, dose optimization, therapeutic monitoring, adverse-effect recognition, adherence assessment, patient counseling, and interdisciplinary communication. Pharmacovigilance is therefore not solely a regulatory function; it is also a clinical practice infrastructure.

The research synthesis identifies clinical pharmacy as a translational safety interface. Pharmacologists may characterize mechanisms, epidemiologists may estimate population associations, and regulators may evaluate benefit–risk implications, but clinical pharmacists operate directly within medication-use processes. Their observations can therefore provide high-value information concerning practical tolerability, regimen complexity, interactions, medication discrepancies, and preventable harm.

Another finding concerns benefit–risk optimization rather than risk elimination. No pharmacologically active medicine is completely devoid of potential adverse effects. The relevant scientific objective is therefore not absolute elimination of risk but optimization of therapeutic benefit relative to potential harm. This requires consideration of disease severity, treatment effectiveness, alternative therapies, patient preferences, risk modifiers, and the magnitude and preventability of potential adverse outcomes.

Benefit–risk assessment must consequently remain dynamic. New evidence may alter estimates of treatment benefit, adverse-event frequency, severity, or subgroup susceptibility. The balance can also change when new therapeutic alternatives enter clinical practice. WHO' current pharmacovigilance strategy explicitly places ongoing benefit–risk assessment within the lifecycle of medicinal products, while the European regulatory framework connects signal assessment to potential changes in the benefit–risk balance.

The synthesis further identifies risk-minimization effectiveness as a critical research endpoint. Detecting a risk and communicating it does not necessarily ensure that harm will decrease. A warning may fail because clinicians do not recognize it, patients do not understand it, monitoring is inaccessible, or prescribing behavior does not change. Consequently, pharmacovigilance should increasingly evaluate whether safety interventions produce measurable changes in clinical practice and outcomes.

This supports a closed-loop model of safety governance: Signal detection → validation → causal assessment → risk characterization → intervention → implementation → outcome monitoring → reassessment. The European regulatory framework similarly describes signal management as a sequence involving detection, validation, confirmation, analysis and prioritization, assessment, and recommendation for action.

The research therefore indicates that the ultimate value of pharmacovigilance cannot be measured solely by reporting volume or the number of detected signals. A mature system should demonstrate the capacity to transform signals into validated knowledge, appropriate interventions, and measurable improvements in medication safety.

A finding concerns computational pharmacovigilance. Artificial intelligence, machine learning, natural-language processing, network analysis, and advanced statistical methods can substantially increase the capacity to analyze high-dimensional safety information. Such technologies can identify patterns that are difficult to recognize manually, prioritize large numbers of potential signals, extract information from unstructured clinical narratives, and integrate heterogeneous variables. However, computational detection remains fundamentally hypothesis-generating. A machine-learning model can identify an association without demonstrating that the medicine

caused the event. Algorithmic performance may also be affected by data quality, coding artifacts, confounding, selection bias, class imbalance, and changes in clinical practice.

The appropriate conceptual model is therefore human–AI pharmacovigilance, in which computational systems increase analytical capacity while pharmacological, clinical, epidemiological, and regulatory expertise determines interpretation. The research further identifies explainability and auditability as essential properties of computational safety systems. A model used to influence safety decisions should provide sufficient information concerning its inputs, validation, uncertainty, and limitations to permit expert assessment. Predictive accuracy alone is insufficient when decisions may affect treatment access, regulatory restrictions, or clinical practice. (See Table-2).

Table 2. Integrated Evidence-to-Action Architecture for Contemporary Drug Safety

Stage	Principal evidence	Analytical function	Key uncertainty	Expected output
Pharmacological characterization	PK/PD, receptor, metabolic, toxicological evidence	Mechanistic risk identification	Translational relevance	Mechanistic hypothesis
Initial surveillance	Spontaneous reports, literature, clinical observations	Early signal generation	Reporting bias	Potential signal
Signal intelligence	Disproportionality, Bayesian methods, computational analytics	Detection and prioritization	Statistical artefacts	Prioritized safety signal
Signal validation	Individual cases, clinical context, mechanistic evidence	Verification of signal credibility	Incomplete evidence	Validated signal
Causal assessment	Epidemiological studies, causal designs	Exposure–outcome inference	Residual confounding	Causal characterization
Risk stratification	Clinical, demographic, genomic, exposure variables	Identify vulnerable subgroups	Effect modification	Stratified risk profile
Benefit–risk assessment	Efficacy and safety evidence	Comparative therapeutic evaluation	Uncertain long-term effects	Updated benefit–risk characterization
Risk minimization	Labeling, monitoring, education, clinical interventions	Reduce preventable harm	Implementation variability	Safety intervention
Effectiveness evaluation	Utilization, outcomes, safety indicators	Determine intervention impact	Attribution	Evidence of effectiveness
Lifecycle reassessment	New RWD/RWE and surveillance data	Continuous updating	Dynamic evidence	Adaptive safety governance

Population-health translation	Burden, equity, preventability	Assess system-level consequences	Generalizability	Population protection strategy

The findings additionally demonstrate the importance of regulatory intelligence. Regulatory pharmacovigilance is not simply the administrative endpoint of safety research. It represents a structured process through which heterogeneous evidence is converted into proportionate actions, including additional surveillance, postauthorization studies, product-information modifications, risk-management measures, or other interventions where justified.

EMA's current signal-management framework explicitly permits outcomes ranging from no immediate action to requests for additional analyses or studies and regulatory changes, including product-information or risk-management modifications. This illustrates the graduated nature of safety governance.

The synthesis therefore rejects a binary model in which every validated signal must result in withdrawal or, alternatively, every uncertain signal must be ignored. Evidence-based safety governance requires proportionality.

A further finding is the importance of uncertainty quantification. Scientific uncertainty should not be treated as a weakness to be concealed but as a property of evidence that can be characterized. Confidence intervals, sensitivity analyses, replication, biological plausibility, data completeness, and consistency across evidence sources can all contribute to a structured description of uncertainty.

This is especially important when communicating emerging safety concerns. A suspected signal may warrant monitoring even when causality is unresolved. Conversely, a statistically significant association may have limited clinical importance if it is small, poorly reproducible, or attributable to residual confounding.

The research synthesis therefore supports a graded epistemology of safety evidence: established risk, strongly supported association, probable association, emerging signal, unresolved association, and insufficient evidence. These categories should be used descriptively rather than as substitutes for formal causal assessment.

Another major finding concerns population health protection. Pharmacovigilance has implications beyond individual clinical encounters because medication-related harm can contribute to hospitalization, disability, healthcare utilization, productivity loss, treatment discontinuation, and mortality. Conversely, effective pharmacotherapy prevents substantial disease burden. Public-health pharmacovigilance must therefore balance both sides of the therapeutic equation.

Population-level safety assessment should consequently consider absolute event burden, preventability, affected population size, treatment prevalence, alternative therapies, and health-system consequences. A rare adverse event may have limited population impact if exposure is uncommon, whereas a modest risk associated with a highly prevalent medicine may generate substantial aggregate burden. This reinforces the importance of distinguishing individual risk from population impact. The findings also reveal the increasing importance of equity-sensitive pharmacovigilance. Safety evidence may be unevenly generated across populations because some groups are underrepresented in clinical research, have lower access to healthcare, or interact differently with health systems. Consequently, the absence of evidence concerning a population should not automatically be interpreted as evidence of equivalent safety.

Equity-sensitive surveillance should examine whether evidence generation, adverse-event recognition, monitoring, and risk mitigation are distributed appropriately across clinically relevant populations. This does not require assuming biological differences; rather, it requires identifying where evidence or healthcare processes may be systematically incomplete.

The synthesis further identifies global pharmacovigilance capacity as an essential determinant of population protection. WHO's recent strategy emphasizes strengthening national systems, integrating pharmacovigilance into regulatory and health-system infrastructures, applying risk-based prioritization, and developing sustainable and adaptive capacity. This is particularly important in health systems where spontaneous reporting infrastructure, electronic health records, pharmacovigilance expertise, regulatory resources, or clinical pharmacy services are developing. A global safety architecture depends not only on large international databases but also on the quality and representativeness of local safety information.

The research therefore supports a model of distributed pharmacovigilance, in which national, regional, institutional, clinical, and patient-generated information streams contribute to a larger safety ecosystem. Another significant finding concerns data interoperability and evidence harmonization. Contemporary safety science increasingly depends on combining datasets generated for different purposes. However, differences in coding, terminology, outcome definitions, exposure definitions, and data structures can compromise comparability. Standardized data models and semantic interoperability can therefore facilitate cross-system analysis.

Nevertheless, harmonization must preserve clinically relevant distinctions. Overstandardization can conceal meaningful heterogeneity, whereas insufficient harmonization prevents reliable integration. The optimal strategy is therefore controlled interoperability with explicit documentation of variable definitions and provenance.

The research further identifies phenotype validation as an indispensable component of real-world safety studies. A coded diagnosis does not necessarily represent a confirmed clinical event. Robust safety outcomes may require combinations of diagnostic codes, laboratory results, procedures, medication patterns, and clinical documentation. Where possible, outcome algorithms should be validated against appropriate reference standards. This is particularly relevant to serious but clinically heterogeneous outcomes such as hepatic injury, renal injury, bleeding, hypersensitivity, arrhythmia, neurological toxicity, and immune-mediated syndromes.

Another finding concerns negative evidence and surveillance sensitivity. Failure to detect a safety signal cannot be interpreted independently of the sensitivity of the surveillance system. Rare events, limited exposure, short follow-up, incomplete reporting, and poor outcome ascertainment can all produce false reassurance.

Consequently, the absence of evidence should be interpreted according to the strength and sensitivity of the underlying surveillance infrastructure. Repeated absence of an association across large, well-designed, adequately powered studies provides stronger reassurance than a single negative analysis based on limited data.

The synthesis also identifies evidence discordance as an informative phenomenon. If spontaneous reporting indicates a potential signal but epidemiological studies do not reproduce it, the discrepancy may reflect reporting bias, insufficient power, population differences, or confounding. Conversely, an epidemiological association without substantial spontaneous-report evidence may reflect underrecognition, limited reporting, or a clinical phenotype that is difficult to recognize as medicine-related.

Discordance should therefore stimulate methodological investigation rather than immediate selection of one evidence stream as inherently correct. Another important finding concerns intervention-induced changes in the data-generating process. Regulatory warnings, media attention, professional education, and clinical alerts can alter prescribing, monitoring, and reporting. Consequently, post-intervention safety data may not be directly comparable with pre-intervention data without accounting for these changes. This creates an important methodological paradox: successful pharmacovigilance can make a safety problem appear more visible initially because awareness and reporting increase, while actual severe harm may subsequently decline.

Therefore, evaluation of interventions requires multiple complementary indicators rather than crude report counts.

The research further identifies medication-use complexity as a fundamental determinant of safety. As therapeutic regimens become more individualized and multimorbidity becomes more prevalent, simple one-drug/one-disease models increasingly fail to capture clinical reality. Treatment sequences, combination therapy, switching, dose titration, and deprescribing must be incorporated into contemporary safety analyses.

This leads to the concept of therapeutic trajectory analysis, in which patient medication histories are treated as dynamic sequences rather than static exposure categories. Such approaches can identify risk associated with initiation, escalation, combination, switching, discontinuation, and re-exposure.

The synthesis also highlights treatment sustainability as an important safety outcome. An adverse effect that does not result in hospitalization may nevertheless cause treatment discontinuation, nonadherence, reduced quality of life, or therapeutic failure. Therefore, safety assessment should incorporate outcomes reflecting whether patients can safely and sustainably remain on clinically beneficial therapy. This perspective is particularly relevant to chronic pharmacotherapy, where tolerability is a prerequisite for long-term effectiveness.

The research further establishes a strong relationship between pharmacovigilance and evidence-based medicine. Evidence-based safety requires not simply accumulation of safety information but critical appraisal of evidence quality, applicability, consistency, and uncertainty. The same principles used in evidence-based therapeutic decision-making—explicit clinical questions, appropriate comparators, valid outcomes, systematic assessment of bias, and transparent uncertainty—should be applied to safety questions. Consequently, pharmacovigilance should be viewed as an essential component of evidence-based pharmacotherapy rather than a separate regulatory activity.

The final synthesis of the research findings establishes that contemporary drug safety is best represented as an adaptive, multiscalar, evidence-generating system. At the molecular level, it investigates mechanisms of therapeutic and adverse effects; at the clinical level, it evaluates exposure, response, interactions, and vulnerability; at the population level, it estimates comparative and absolute risks; at the computational level, it identifies patterns across high-dimensional datasets; at the regulatory level, it translates evidence into proportionate action; and at the public-health level, it evaluates population burden, preventability, equity, and health-system consequences.

The resulting scientific architecture can be summarized as: Mechanistic pharmacology → exposure characterization → clinical pharmacotherapy → adverse-event observation → safety-signal intelligence → causal inference → pharmacoepidemiological stratification → real-world evidence integration → benefit–risk optimization → medication-harm mitigation → regulatory adaptation → population-health protection → continuous evidence generation.

This sequence should not be interpreted as a rigid linear pathway. Rather, it represents a recursive learning architecture in which evidence can enter at multiple points and generate feedback across scales. A clinical observation can stimulate molecular research; a molecular mechanism can generate a pharmacovigilance hypothesis; an epidemiological signal can initiate targeted clinical investigation; and a regulatory intervention can generate new real-world evidence.

The principal research conclusion emerging from this synthesis is therefore that the advancement of drug safety represents a transformation in scientific architecture, not merely an expansion of surveillance technology. Pharmacovigilance is increasingly becoming a translational discipline that connects pharmacological mechanism with real-world therapeutic experience and connects clinical observations with population-level risk governance.

Its future effectiveness will depend upon the capacity to integrate heterogeneous evidence without confusing association with causation, computational prediction with biological explanation, statistical significance with clinical importance, or regulatory action with evidence certainty. The most scientifically robust framework is one that combines mechanistic plausibility, high-quality clinical observation, rigorous epidemiological methodology, computational intelligence, transparent uncertainty characterization, patient-centered evidence, and continuous benefit–risk reassessment.

Within this framework, evidence-based safety becomes the organizing principle linking pharmacology and pharmacotherapy to population health. The ultimate objective is not simply to identify adverse effects but to understand their determinants, quantify their clinical significance, identify susceptible populations, prevent avoidable medication harm, preserve therapeutic benefit, and continuously refine the conditions under which medicines can be used safely and rationally throughout their entire lifecycle.

The integrative research synthesis shows that the contemporary scientific architecture of drug safety can no longer be adequately represented by a linear sequence extending from preclinical pharmacology through clinical development and, subsequently, post-marketing adverse-event reporting. The principal finding emerging from the present multiscalar analysis is that drug safety constitutes a dynamic, context-dependent, evidence-generating continuum in which pharmacological mechanism, therapeutic exposure, patient susceptibility, clinical decision-making, healthcare-system organization, epidemiological context, computational surveillance, regulatory intervention, and population-level consequences are reciprocally interconnected. The conceptual separation traditionally maintained among pharmacology, pharmacotherapy, pharmacovigilance, pharmacoepidemiology, and medication-safety science therefore becomes progressively less tenable as therapeutic environments become increasingly complex, data-intensive, biologically stratified, and longitudinally monitored. Drug-related risk is not an immutable characteristic of a medicinal product; rather, it emerges through interactions among pharmacological properties, dose and exposure, biological vulnerability, treatment context, concomitant therapies, disease state, adherence, monitoring, healthcare delivery, and duration of exposure.

A central research finding concerns the progressive transformation of drug safety from a predominantly reactive surveillance discipline toward an anticipatory and continuously adaptive scientific enterprise. Classical pharmacovigilance has historically relied substantially upon spontaneous adverse-event reporting, aggregate case evaluation, signal detection, and subsequent regulatory assessment. These functions remain indispensable because spontaneous reporting can identify rare, unexpected, serious, or previously unrecognized safety phenomena that may not be adequately represented within controlled clinical-development populations. Nevertheless, contemporary therapeutic environments generate safety information through substantially broader channels. Electronic health records, insurance and administrative claims, disease registries, prescription and dispensing databases, laboratory information systems, genomic datasets, longitudinal cohort studies, patient-reported outcomes, mobile-health platforms, and other real-world data sources collectively enable a more multidimensional representation of medication exposure and outcome. The resulting methodological transition is not simply an expansion in data volume. It constitutes a transformation in the epistemology of drug safety because the object of investigation shifts from isolated reports toward longitudinal exposure–outcome trajectories.

The synthesis further indicates that spontaneous reports and real-world observational data should not be conceptualized as competing evidence infrastructures. Their scientific value is complementary. Spontaneous reporting systems are particularly informative for hypothesis generation and the recognition of unusual patterns, whereas longitudinal healthcare databases

can provide denominators, comparative exposure groups, temporal information, and estimates of relative or absolute risk. Clinical trials contribute controlled experimental evidence concerning efficacy and common adverse events, while mechanistic pharmacology can establish biological plausibility and illuminate pathways through which adverse outcomes may arise. Pharmacogenomics can identify genetically mediated heterogeneity, and clinical pharmacology can contextualize these findings through pharmacokinetic and pharmacodynamic principles. Regulatory science integrates these heterogeneous evidence streams into decisions concerning product information, monitoring requirements, risk-minimization measures, and, where warranted, restrictions or other interventions. The resulting architecture is therefore best characterized as evidence triangulation rather than evidentiary substitution.

The multiscalar relationship between pharmacological mechanism and clinical safety represents another major finding. At the molecular level, adverse effects may arise from intended pharmacological activity, exaggerated target engagement, off-target interactions, metabolite formation, receptor promiscuity, transporter modulation, enzyme inhibition or induction, mitochondrial disturbance, oxidative stress, immune activation, altered cellular signaling, or disruption of physiological homeostasis. However, molecular toxicity does not translate automatically into clinically meaningful harm. The probability and severity of an adverse outcome depend upon exposure magnitude, tissue distribution, treatment duration, host susceptibility, comorbid disease, concomitant medicines, physiological reserve, and the effectiveness of monitoring and intervention. Consequently, molecular pharmacology provides mechanistic explanation, whereas clinical pharmacology provides exposure–response contextualization and pharmacovigilance establishes population-level surveillance.

This distinction is particularly important when interpreting pharmacodynamic adverse reactions. An adverse effect may represent an extension of the desired therapeutic mechanism, an exaggerated response, an off-target pharmacological phenomenon, or a mechanistically independent toxicological process. The same medicinal product can therefore produce beneficial and harmful effects through partially overlapping biological pathways. Therapeutic optimization requires neither the elimination of all pharmacological effects nor an unrealistic assumption that adverse events can be completely prevented. Instead, the objective is to maximize therapeutic benefit while reducing clinically consequential and preventable harm through appropriate patient selection, dose individualization, monitoring, interaction management, and timely therapeutic modification.

The analysis identifies a fundamental distinction between adverse drug reactions, adverse events, medication errors, and broader medication-related harm. These concepts cannot be used interchangeably without compromising analytical precision. An adverse event occurring during treatment does not necessarily establish pharmacological causality. Conversely, medication-related harm may arise from prescribing errors, dispensing errors, administration failures, inappropriate duration, inadequate monitoring, nonadherence, drug–drug interactions, contraindicated use, or failures of care coordination even when the intrinsic pharmacology of the medicinal product is well characterized. Pharmacovigilance therefore intersects with, but does not completely encompass, the broader patient-safety ecosystem.

This conceptual differentiation has important implications for research methodology. If all unfavorable clinical outcomes temporally associated with medication exposure are interpreted as pharmacologically caused adverse reactions, causality will be systematically overestimated. If only spontaneous reports judged highly likely to represent adverse drug reactions are considered, important system-level medication harms may be overlooked. The appropriate analytical framework therefore requires explicit classification of the event, exposure, temporal relationship, competing explanations, biological plausibility, dechallenge/rechallenge information where available, and contextual determinants. (See Table-3).

Table 3. Multiscalar Architecture of Contemporary Drug-Safety Research

Analytical scale	Principal scientific domain	Major variables	Principal safety question	Characteristic evidence
Molecular	Molecular pharmacology	Receptors, enzymes, transporters, signaling pathways, metabolites	Through what biological mechanisms could harm arise?	Experimental pharmacology, molecular studies
Cellular	Cellular pharmacology/toxicology	Cellular stress, apoptosis, mitochondrial effects, immune activation	How does exposure alter cellular function?	In vitro and translational studies
Pharmacokinetic	Clinical pharmacology	Absorption, distribution, metabolism, elimination, exposure	How does systemic and tissue exposure vary?	PK studies, therapeutic drug monitoring
Pharmacodynamic	Pharmacology	Target engagement, dose–response, concentration–effect relationships	How does exposure translate into biological response?	Clinical pharmacology studies
Individual clinical	Pharmacotherapy	Comorbidity, age, genetics, polypharmacy, adherence	Which patients experience disproportionate risk?	Clinical studies, registries
Population	Pharmacoepidemiology	Incidence, prevalence, relative risk, absolute risk, confounding	Is exposure associated with excess population-level risk?	Cohorts, case-control studies, claims
Computational	Computational pharmacovigilance	Signal scores, networks, predictive features, temporal patterns	Which potential safety signals warrant investigation?	Spontaneous reports, Clinical databases
Regulatory	Regulatory science	Benefit–risk balance, risk minimization, uncertainty	What action is proportionate to available evidence?	Integrated regulatory assessment

Public health	Population safety	Preventable harm, disparities, healthcare burden	What are the consequences for populations and health systems?	Health-system and population studies

The synthesis indicates that these scales should not be treated as isolated analytical compartments. Rather, safety evidence gains explanatory strength when information is propagated bidirectionally across scales. A molecular mechanism may generate a mechanistic hypothesis requiring epidemiological validation; conversely, an epidemiological signal may stimulate mechanistic investigation. A pharmacogenomic association can explain heterogeneity initially observed in clinical practice, while a clinical safety pattern can identify biological mechanisms not previously recognized. This reciprocal translation is one of the defining characteristics of contemporary drug-safety science.

A further major finding concerns the role of exposure characterization. Drug safety cannot be meaningfully evaluated without accurate representation of who received the medicine, why it was prescribed, at what dose, for what duration, with which concomitant therapies, and under what clinical circumstances. Exposure is therefore multidimensional. Binary classifications such as “treated” versus “untreated” can conceal substantial variation in cumulative dose, treatment intensity, adherence, persistence, switching, discontinuation, dose escalation, intermittent exposure, and combination therapy. Such distinctions become particularly consequential for adverse outcomes characterized by cumulative toxicity, delayed latency, withdrawal phenomena, or dose-dependent risk.

The temporal dimension of exposure is similarly important. A medication-associated outcome may occur within minutes, days, months, or years depending on the underlying mechanism. Immediate hypersensitivity reactions have markedly different temporal characteristics from cumulative organ toxicity, metabolic complications, malignancy-related outcomes, or withdrawal syndromes. Consequently, surveillance systems and epidemiological analyses must align exposure windows with plausible biological latency periods. Failure to establish appropriate risk windows may generate exposure misclassification, dilute associations, or create spurious temporal relationships.

The research synthesis further identifies polypharmacy as a critical transitional domain between pharmacology and clinical medication safety. Increasing numbers of patients receive multiple medicines simultaneously because of multimorbidity, aging populations, chronic disease burden, and expanding therapeutic options. Polypharmacy modifies pharmacological risk through additive toxicity, synergistic pharmacodynamic effects, pharmacokinetic interactions, competition for metabolic pathways, altered adherence, regimen complexity, and cumulative treatment burden. The clinically relevant unit of analysis therefore frequently shifts from an individual medicine toward the medication regimen as a pharmacological system.

This has significant implications for pharmacovigilance. Conventional signal detection often evaluates medicine–event pairs, whereas clinically important harm may arise from medicine–medicine–patient–disease interactions. For example, an individual medicine may exhibit an acceptable safety profile in isolation but contribute to clinically significant harm when combined with another treatment in a susceptible patient. Consequently, future pharmacovigilance methodologies require greater capacity for multidrug interaction analysis, regimen-level risk modeling, and patient-specific vulnerability assessment.

The synthesis also identifies medication indication as a central determinant of observed safety. The same pharmacological exposure can carry different apparent risks depending upon the underlying disease population. Patients receiving a drug for severe disease may have higher baseline mortality, inflammation, hospitalization, organ dysfunction, or thrombotic risk

independent of treatment. This produces substantial potential for confounding by indication. Similarly, treatment channeling may result in higher-risk patients preferentially receiving particular therapies, generating apparent associations that partly reflect prescribing selection rather than direct drug effects. (See Table-4).

Table 4. Principal Sources of Bias and Uncertainty in Drug-Safety Research

Source of uncertainty	Mechanism	Potential analytical consequence	Mitigation strategy
Confounding by indication	Treatment determined by disease severity or prognosis	Distorted exposure–outcome association	Active comparators, adjustment, propensity methods
Channeling bias	Higher-risk patients preferentially receive particular treatments	Apparent excess toxicity	Comparator design and covariate adjustment
Exposure misclassification	Incomplete information on actual medication use	Attenuation or distortion of associations	Multiple exposure definitions, dispensing data
Outcome misclassification	Imperfect identification of clinical events	False-positive/false-negative associations	Validated algorithms and adjudication
Underreporting	Many adverse events never enter spontaneous systems	Reduced signal sensitivity	Data-source triangulation
Stimulated reporting	Reporting increases following publicity or regulatory action	Artificial temporal clustering	Temporal/contextual assessment
Missing data	Incomplete patient, exposure, or outcome information	Reduced validity and precision	Multiple imputation/sensitivity analysis
Immortal-time bias	Outcome-free period incorrectly assigned to exposure	Biased treatment-effect estimates	Time-dependent exposure modeling
Selection bias	Study population differs systematically from target population	Limited generalizability	Explicit target-population definition
Reverse causation	Early disease manifestations influence prescribing	Misleading temporal association	Lag periods and temporal modeling
Multiple testing	Numerous signals examined simultaneously	Increased false discovery	Statistical control and independent validation
Residual confounding	Important determinants remain unmeasured	Persistent association distortion	Quantitative bias analysis and triangulation

The discussion of bias is not merely methodological formalism. It directly determines whether a safety signal can be translated into clinically meaningful action. A computationally strong

association may remain epidemiologically ambiguous if exposure and outcome are poorly characterized. Conversely, a modest statistical association may become highly compelling when supported by consistent temporal relationships, dose-response patterns, biological plausibility and replication across independent databases, and mechanistic evidence. The interpretation of safety evidence therefore requires proportionality between statistical strength and evidentiary context.

A major finding concerns the increasing importance of causality assessment as a bridge between signal generation and clinical interpretation. Signal detection identifies patterns that merit investigation; it does not by itself establish causation. Disproportional reporting may indicate that an event occurs more frequently with a particular medicine than expected within a reporting database, but reporting disproportionality can be influenced by stimulated reporting, indication, publicity, reporting behavior, differential surveillance, and database structure. Similarly, machine-learning models can detect complex associations without necessarily establishing mechanistic or causal relationships.

The contemporary pharmacovigilance workflow must therefore be understood as a sequence of increasingly discriminating analytical operations: detection, prioritization, characterization, validation, causal assessment, clinical contextualization, epidemiological confirmation, benefit–risk interpretation, and regulatory or therapeutic response. The value of artificial intelligence and computational analytics is greatest when these systems augment rather than replace scientific judgment.

The analysis demonstrates that Bayesian and disproportionality approaches have particular utility within large spontaneous-reporting systems because they can identify unexpected medicine–event combinations and prioritize signals according to statistical characteristics. Yet signal scores should not be interpreted as estimates of absolute clinical risk unless their underlying denominators and methodological assumptions permit such interpretation. A high reporting ratio does not necessarily mean that an event is common among exposed patients, just as a low reporting frequency does not necessarily indicate clinical insignificance. Signal strength and clinical importance are distinct constructs.

This distinction becomes especially important for rare but serious adverse outcomes. A rare event may generate limited numbers of reports while carrying substantial clinical importance because of severity, preventability, reversibility, or mortality. Conversely, a frequently reported but mild event may have high reporting volume without requiring the same regulatory response. Contemporary pharmacovigilance must therefore integrate frequency, severity, preventability, reversibility, affected population, biological plausibility, exposure prevalence, and therapeutic necessity into a multidimensional prioritization framework.

The research synthesis further demonstrates that real-world evidence has become increasingly important in resolving uncertainties that remain aftermarket authorization. Clinical trials are indispensable for estimating efficacy and characterizing common adverse events under controlled conditions, but their eligibility criteria, sample sizes, follow-up periods, treatment adherence, and monitoring intensity may differ substantially from routine clinical practice. Post-authorisation real-world evidence therefore provides an essential complement by representing heterogeneous patients, multimorbidity, polypharmacy, variable adherence, off-label use, treatment switching, and longer-term exposure. However, the mere presence of real-world data does not automatically produce valid real-world evidence. Data provenance, completeness, representativeness, coding practices, missingness, linkage quality, exposure ascertainment, outcome validation, confounding, and analytic specification all influence evidentiary reliability. The transformation from real-world data to decision-grade evidence requires explicit causal questions, target-population definition, appropriate study design, validated variables, prespecified analytical strategies, sensitivity analyses, and transparent interpretation.

The synthesis therefore identifies an important epistemological distinction: data abundance is not equivalent to evidentiary certainty. Contemporary pharmacovigilance increasingly possesses enormous quantities of observational information, but the principal methodological challenge is transforming heterogeneous data into reliable causal and clinical knowledge. This requires methodological sophistication rather than merely larger datasets.

The relationship between pharmacology and pharmacovigilance becomes particularly evident in precision medicine. Genetic variability in drug-metabolizing enzymes, transporters, receptors, immune pathways, and disease-associated molecular targets can modify pharmacokinetics, pharmacodynamics, therapeutic response, and adverse-event susceptibility. Pharmacogenomics can therefore provide a mechanistic basis for individualized risk stratification. Nevertheless, genetic information should not be interpreted independently of environmental, clinical, behavioral, and treatment-related determinants. A genotype may alter probability rather than determine outcome, and clinical implementation requires integration with phenotype, concomitant medicines, disease state, and exposure.

Precision pharmacotherapy consequently represents more than genotype-guided prescribing. It encompasses individualized selection of medicines, dose optimization, therapeutic monitoring, interaction assessment, risk prediction, and longitudinal reassessment. Pharmacovigilance becomes an essential feedback mechanism within this model because treatment-related outcomes observed after implementation can refine individual and population-level understanding of therapeutic heterogeneity.

The research synthesis also reveals a transformation in the meaning of “risk.” Traditional risk characterization frequently emphasizes the probability of an adverse outcome attributable to a medicine. Contemporary medication safety requires broader consideration of the counterfactual risks associated with withholding effective treatment, substituting an alternative therapy, delaying treatment, undertreating disease, or interrupting therapy. Benefit–risk assessment is therefore intrinsically comparative. A medicine with a known adverse-event profile may remain clinically appropriate when its expected therapeutic benefits exceed those of available alternatives under a particular clinical circumstance. Conversely, a relatively infrequent adverse outcome can become highly consequential when effective alternatives exist or when affected populations are particularly vulnerable. (See Table-5).

Table 5. Evidence Triangulation Across the Drug-Safety Continuum

Evidence stream	Principal contribution	Major limitation	Complementary evidence required
Preclinical pharmacology	Mechanistic plausibility and target biology	Limited clinical generalizability	Clinical and epidemiological validation
Randomized clinical trials	Controlled efficacy and safety comparison	Restricted populations and duration	Long-term real-world surveillance
Spontaneous reporting	Early detection of unexpected signals	No reliable exposure denominator	Epidemiological confirmation
Electronic health records	Clinical context and longitudinal outcomes	Variable coding/completeness	Validation and external replication
Claims/administrative data	Large populations and utilization patterns	Limited clinical granularity	Clinical adjudication

Disease registries	Disease-specific outcomes and follow-up	Restricted disease populations	General-population evidence
Pharmacogenomics	Biological explanation of heterogeneity	Variable penetrance and implementation	Clinical phenotype integration
Patient-reported data	Symptoms, treatment experience, quality-of-life information	Reporting variability	Clinical corroboration
Computational pharmacovigilance	Pattern recognition and signal prioritization	Algorithmic and data biases	Expert and epidemiological assessment
Regulatory evidence integration	Decision-oriented benefit–risk interpretation	Dependent on evidence quality	Continuous post-decision surveillance

Another major finding is the emergence of therapeutic safety intelligence as a useful conceptual bridge between conventional pharmacovigilance and contemporary data-driven medicine. Therapeutic safety intelligence may be conceptualized as the organized capacity to transform heterogeneous pharmacological, clinical, epidemiological, computational, and patient-generated information into actionable knowledge concerning medication-related risk. Within this framework, intelligence does not imply automated decision-making. Instead, it represents an iterative process of information acquisition, signal detection, contextual interpretation, evidence integration, uncertainty characterization, and therapeutic or regulatory response.

This conceptualization has particular relevance to clinical pharmacy and pharmacotherapy. Clinical pharmacists operate at a critical interface between pharmacological knowledge and patient-level medication use. Medication reconciliation, interaction assessment, dose optimization, therapeutic monitoring, adverse-event recognition, patient counseling, adherence support, and interdisciplinary communication can all function as proximal medication-safety interventions. Pharmacovigilance therefore should not be confined to regulatory institutions or specialized surveillance centers. It should also be embedded within clinical workflows.

The integration of pharmacovigilance into pharmacotherapy can transform medication safety from a retrospective reporting obligation into a prospective therapeutic practice. Before treatment initiation, clinicians can evaluate contraindications, patient-specific risk factors, interaction potential, and pharmacogenomic information where clinically appropriate. During therapy, they can monitor laboratory parameters, symptoms, treatment response, adherence, and emerging adverse effects. Following treatment modification or discontinuation, they can assess dechallenge outcomes and document clinically relevant safety information. This longitudinal cycle produces clinically meaningful information that can feed back into institutional and population-level pharmacovigilance.

The synthesis further identifies the medication-use process itself as an important determinant of safety. Prescribing, transcription, dispensing, administration, monitoring, and follow-up represent interconnected stages. A pharmacologically safe medicine can nevertheless contribute to preventable harm if used incorrectly, while a medicine with substantial intrinsic risk may be used safely through appropriate patient selection and intensive monitoring. Accordingly, drug safety and medication safety should be regarded as overlapping but analytically distinct constructs.

The results also emphasize the importance of vulnerable populations. Older adults, pediatric populations, pregnant patients, individuals with renal or hepatic impairment, patients with multiple chronic diseases, immunologically vulnerable populations, and persons receiving complex polypharmacy may experience substantially different benefit–risk profiles from those represented

in conventional trial populations. Underrepresentation of such populations can generate uncertainty that becomes visible only after broader clinical use. Post-authorisation surveillance therefore serves not merely as a mechanism for identifying unexpected toxicity but also as a mechanism for evaluating therapeutic generalizability.

Age-related physiological changes illustrate the importance of pharmacokinetic and pharmacodynamic integration. Changes in renal clearance, hepatic metabolism, body composition, protein binding, receptor sensitivity, and homeostatic reserve may alter both exposure and response. When multiple medicines are administered simultaneously, these effects may interact. Consequently, age cannot simply be treated as a demographic adjustment variable; in many clinical contexts it represents a complex biological modifier of pharmacological response.

Renal and hepatic dysfunction provide another example of the necessity of integrated pharmacology. Altered clearance can increase systemic exposure, while changes in protein binding or metabolic capacity may modify free concentrations. Pharmacodynamic vulnerability may simultaneously increase, meaning that toxicity can arise from both altered exposure and altered tissue sensitivity. Therapeutic drug monitoring, dose adjustment, laboratory surveillance, and careful evaluation of concomitant medicines therefore become components of pharmacovigilance-informed pharmacotherapy.

The analysis additionally identifies immune-mediated adverse drug reactions as an area where molecular, clinical, and pharmacovigilance evidence must be tightly integrated. Such reactions can exhibit complex latency, heterogeneous clinical presentation, and variable recurrence patterns. Mechanistic investigation can provide explanatory hypotheses, whereas clinical recognition and structured reporting facilitate signal generation. Epidemiological studies can establish population-level associations, and pharmacogenomic research may identify susceptibility markers. The resulting evidence architecture illustrates how contemporary pharmacovigilance increasingly operates as a translational science rather than an isolated reporting discipline.

Another important finding concerns the safety evaluation of advanced therapeutic modalities. Biological medicines, gene therapies, cell-based products, immunomodulatory therapies, and other advanced interventions may generate safety profiles characterized by delayed effects, immune-mediated phenomena, complex biological mechanisms, manufacturing-related variables, or limited preauthorization population sizes. Conventional medicine–event surveillance remains necessary but may require augmentation through product-specific registries, long-term follow-up, specialized clinical adjudication, and mechanistically informed monitoring.

For advanced therapies, the concept of lifecycle surveillance becomes especially important. Safety monitoring cannot necessarily terminate when the initial authorization decision is made because some clinically important outcomes may emerge only after prolonged exposure or treatment of larger and more diverse populations. The appropriate surveillance duration must therefore correspond to plausible biological latency, persistence of therapeutic effects, and potential long-term consequences. (See Table-6).

Table 6. Evolutionary Advancement of Pharmacovigilance

Conventional orientation	Contemporary orientation	Scientific implication
Passive reporting	Active and hybrid surveillance	Earlier and broader identification of risk
Individual case reports	Integrated longitudinal evidence	Greater contextualization
Medicine–event pairs	Regimen–patient–disease systems	Recognition of interaction complexity
Reactive signal review	Predictive and anticipatory analytics	Earlier prioritization of emerging risks
Static safety profile	Dynamic lifecycle safety profile	Continuous reassessment
Manual review predominance	Human–AI analytical collaboration	Increased information-processing capacity
Population-average risk	Stratified and individualized risk	Recognition of heterogeneity
Post-market surveillance	Lifecycle surveillance	Integration across development stages
Regulatory-centered reporting	Multistakeholder safety ecosystem	Distributed responsibility
Data accumulation	Evidence triangulation	Emphasis on interpretability and causality
Adverse-event focus	Medication-harm ecosystem	Inclusion of system-level contributors
Periodic assessment	Continuous learning	Adaptive risk governance

The computational transformation of pharmacovigilance constitutes another major component of the findings. Large-scale databases can contain millions of records that exceed the practical capacity of conventional manual review. Machine learning, natural-language processing, graph-based analysis, temporal pattern recognition, and other computational approaches can facilitate prioritization, classification, information extraction, and association discovery. Such technologies may be particularly valuable for identifying nonlinear interactions, multidimensional patterns, and weak signals distributed across heterogeneous data structures.

Nevertheless, algorithmic sophistication introduces new forms of uncertainty. Training-data bias, class imbalance, incomplete labels, coding artifacts, temporal drift, dataset shift, opaque model architecture, and inappropriate validation can undermine model reliability. An algorithm may accurately reproduce patterns embedded within a database while failing to distinguish causal pharmacological relationships from prescribing behavior or healthcare utilization patterns. Therefore, computational pharmacovigilance requires model validation, calibration, external replication, explainability where feasible, and continuous monitoring of model performance.

Artificial intelligence should consequently be regarded as an augmentation technology within pharmacovigilance rather than an autonomous substitute for pharmacological and clinical reasoning. Human experts remain necessary for determining whether an association is biologically plausible, clinically meaningful, epidemiologically credible, and proportionate to the potential therapeutic consequences of regulatory or clinical intervention.

The synthesis further indicates that natural-language processing may have particular importance because clinically meaningful safety information frequently exists in unstructured narratives, discharge summaries, clinical notes, spontaneous-report descriptions, and patient

communications. Automated extraction can potentially identify symptoms, temporal relationships, suspected medicines, dose information, dechallenge/rechallenge information, and relevant comorbidities. However, language ambiguity, negation, abbreviations, incomplete documentation, and contextual dependence require sophisticated validation.

Network pharmacology provides another emerging analytical perspective. Instead of evaluating drug–event relationships independently, network-based approaches can model relationships among drugs, targets, pathways, diseases, phenotypes, and adverse outcomes. This may reveal mechanistic clusters or shared biological pathways associated with toxicity. Such methods may be particularly useful in polypharmacy and multimorbidity research, where conventional pairwise analysis may inadequately represent complex pharmacological systems.

The research synthesis also identifies the increasing significance of patient participation. Patients are not merely passive recipients of pharmacovigilance interventions; they represent direct sources of information concerning symptoms, functional impairment, treatment experience, adherence, quality of life, and perceived medication-related harm. Patient-generated data may identify outcomes that are incompletely captured through conventional clinical documentation. However, patient-reported information requires appropriate contextualization and validation rather than dismissal or uncritical acceptance.

Patient engagement also has a risk-communication dimension. Safety information can influence adherence and trust, particularly when communicated without adequate explanation of absolute risk, baseline risk, uncertainty, or therapeutic alternatives. Excessive emphasis on isolated adverse events can produce disproportionate perceptions of danger, whereas inadequate communication can undermine informed decision-making. Effective safety communication should therefore present risk in clinically interpretable terms and distinguish established evidence from emerging signals and unresolved hypotheses.

The findings further demonstrate that regulatory risk governance must operate under uncertainty. Regulatory decisions frequently occur before all scientifically relevant questions can be definitively resolved. Waiting for complete certainty may delay interventions that could prevent serious harm, whereas acting prematurely on weak or unvalidated signals may unnecessarily restrict beneficial therapy. Regulatory pharmacovigilance therefore requires proportionality, iterative reassessment, transparency concerning uncertainty, and consideration of both therapeutic benefits and potential harms.

Benefit–risk assessment should consequently be understood as a dynamic process rather than a one-time calculation. The balance may change as additional safety information becomes available, alternative treatments emerge, patient populations change, or new evidence modifies estimates of treatment benefit. A medicinal product's clinical value may therefore vary according to indication, patient subgroup, disease severity, treatment alternatives, and healthcare setting.

This dynamic character of benefit–risk assessment reinforces the importance of lifecycle pharmacovigilance. Preauthorization evidence establishes an initial knowledge base; postauthorization surveillance tests its generalizability; new epidemiological evidence refines risk estimates; mechanistic studies clarify causality; and regulatory or clinical interventions generate further evidence. Drug safety therefore represents a learning system in which decisions become inputs into subsequent evidence generation.

A particularly important finding concerns the reciprocal relationship between pharmacovigilance and pharmacotherapy. Pharmacovigilance informs clinicians about emerging risks, while pharmacotherapeutic practice generates the observations from which many safety signals originate. The relationship is therefore bidirectional. Clinical prescribing influences exposure patterns, which influence the detectability and interpretation of adverse outcomes; surveillance findings then modify prescribing, monitoring, contraindications, warnings, and treatment strategies.

This feedback relationship becomes especially important in antimicrobial therapy, oncology, immunomodulatory treatment, cardiovascular pharmacotherapy, neurological medicine, psychiatry, endocrinology, and complex chronic-disease management, where treatment benefits can be substantial but safety profiles may be context dependent. The objective is not simply to minimize exposure to medicines but to optimize therapeutic decisions within the constraints of disease severity, patient vulnerability, available alternatives, and monitoring capacity.

The synthesis identifies clinical pharmacology as a central translational discipline linking these domains. Pharmacokinetics explains exposure; pharmacodynamics explains response; pharmacogenomics explains certain dimensions of interindividual variability; therapeutic drug monitoring provides individualized exposure information; and pharmacotherapy integrates these dimensions into treatment decisions. Pharmacovigilance extends this framework by systematically observing outcomes across broader populations and longer periods.

Consequently, contemporary drug-safety science should not be organized around disciplinary silos. The pharmacologist investigating a molecular pathway, the clinical pharmacologist evaluating dose–response relationships, the pharmacist reviewing medication regimens, the epidemiologist estimating population-level associations, the data scientist detecting computational signals, the clinician adjudicating clinical relevance, the regulator evaluating benefit–risk implications, and the patient reporting treatment experiences participate in a distributed knowledge system. (See Table-7).

Table 7. Integrated Framework for Therapeutic Safety Optimization

Domain	Core function	Principal output	Translational consequence
Molecular pharmacology	Mechanism characterization	Biological plausibility	Mechanism-informed risk hypotheses
Clinical pharmacology	Exposure–response assessment	PK/PD characterization	Dose and monitoring optimization
Pharmacotherapy	Therapeutic integration	Individual treatment strategy	Rational medication use
Pharmacogenomics	Susceptibility stratification	Genotype-associated risk information	Individualized therapy
Pharmacovigilance	Signal generation and evaluation	Safety signals and validated risks	Risk recognition
Pharmacoepidemiology	Population-level estimation	Comparative and absolute risk	Evidence-based risk characterization
Computational analytics	Large-scale pattern recognition	Prioritized hypotheses	Surveillance efficiency
Clinical pharmacy	Medication-use optimization	Medication-harm prevention	Safer treatment implementation
Regulatory science	Benefit–risk governance	Proportionate risk-management decisions	Population protection
Patient engagement	Experience and outcome reporting	Patient-centered safety information	Shared and informed decisions
Public health	Population impact assessment	Burden and preventability assessment	System-level safety improvement

The integrated findings therefore support a conceptual model in which drug safety is generated through the interaction of intrinsic pharmacology and extrinsic therapeutic context. Intrinsic determinants include molecular target activity, receptor selectivity, metabolism, transport, formulation, physicochemical characteristics, immunogenicity, and dose-dependent pharmacological effects. Extrinsic determinants include patient characteristics, disease state, concomitant medicines, prescribing behavior, healthcare-system structures, adherence, monitoring, environmental exposures, socioeconomic circumstances, and access to care. The observed clinical outcome emerges from their interaction.

This model has implications for how safety signals should be interpreted. A signal may reflect an intrinsic pharmacological hazard, a population-specific susceptibility, an interaction effect, a healthcare-system failure, a reporting artifact, or a combination of these factors. Consequently, signal investigation should seek not merely to determine whether an association exists but to identify the causal architecture underlying the association.

The research synthesis further identifies causal inference as a central methodological requirement for contemporary pharmacovigilance. Observational data are indispensable, but associations can arise from confounding, selection, measurement error, time-related biases, or chance. Advanced analytical methods, including propensity-score approaches, inverse probability weighting, target-trial emulation, instrumental-variable approaches where defensible, negative-control strategies, self-controlled designs, and sensitivity analyses, can strengthen causal interpretation. Nevertheless, no statistical method can automatically eliminate all unmeasured bias. Methodological rigor therefore requires explicit causal assumptions and transparent discussion of residual uncertainty.

The target-trial perspective is particularly valuable because it encourages investigators to specify the hypothetical intervention, eligibility criteria, treatment strategies, assignment time, follow-up period, outcomes, causal contrast, and analytical approach before interpreting observational associations. Such explicitness can reduce ambiguity and improve comparability across studies. However, the applicability of any causal framework depends upon data quality and the plausibility of underlying assumptions.

The synthesis also identifies the importance of absolute rather than exclusively relative measures of risk. A large relative increase in a rare event may correspond to a small absolute excess, whereas a modest relative increase in a common event can produce substantial population-level burden. Clinical interpretation therefore requires baseline risk, absolute risk difference, and number-needed-to-harm where appropriate, event severity, and treatment benefit to be considered together.

This issue becomes particularly important in regulatory and clinical communication. Relative measures can exaggerate perceived risk when baseline incidence is low, whereas absolute measures may underemphasize clinical importance when the outcome is severe. Presenting multiple complementary measures provides a more scientifically balanced representation of uncertainty and magnitude.

The findings additionally demonstrate that medication safety is inseparable from health-system organization. Fragmented care, incomplete medication reconciliation and inadequate communication between providers, insufficient monitoring, and limited access to laboratory testing, poor documentation, and transitions between healthcare settings can increase medication-related harm independently of intrinsic drug toxicity. Pharmacovigilance should therefore interact with patient-safety programs, clinical governance, antimicrobial stewardship, medication-reconciliation systems, and quality-improvement infrastructures.

Transitions of care are particularly important because medication discrepancies frequently emerge when patients move among outpatient, emergency, inpatient, rehabilitation, and long-

term-care settings. A robust drug-safety framework must therefore consider not only whether a medicine is pharmacologically appropriate but whether medication information is accurately transferred across the healthcare system.

Another major finding concerns preventability. Not every adverse drug reaction is preventable, particularly when idiosyncratic or biologically unpredictable mechanisms are involved. Nevertheless, a substantial proportion of medication-related harm may be reduced through appropriate prescribing, contraindication recognition, interaction screening, dose adjustment, monitoring, adherence support, patient education, and timely recognition of early warning signs. Distinguishing unavoidable pharmacological reactions from preventable medication-system failures is therefore essential for designing effective interventions.

The synthesis also supports a broader conception of risk minimization. Traditional risk-minimization interventions may include prescribing restrictions, contraindications, warnings, and educational materials, monitoring programs, and controlled distribution mechanisms. Contemporary approaches increasingly emphasize integration with electronic prescribing, clinical decision support, automated alerts, pharmacist review, laboratory monitoring, and patient-facing technologies. However, excessive alert generation can produce alert fatigue, reducing attention to genuinely important signals. Safety systems must therefore optimize sensitivity without creating unsustainable cognitive burden.

The concept of proportionality is consequently central. A risk-management intervention should correspond to the strength and seriousness of the evidence, the magnitude and reversibility of potential harm, the therapeutic value of the medicine, the availability of alternatives, and the feasibility of implementation. Overly burdensome interventions may compromise access to beneficial therapies, whereas insufficient interventions may fail to prevent avoidable harm.

The analysis further indicates that global pharmacovigilance requires attention to geographic heterogeneity. Medication utilization, genetic diversity, healthcare infrastructure, reporting behavior, disease epidemiology, regulatory capacity, and access to medicines differ substantially across countries. A safety signal identified in one population may not translate directly into another population without consideration of differences in exposure, comorbidity, co-medication, healthcare practice, and background risk.

This creates an important distinction between global evidence and globally generalizable evidence. International datasets increase statistical power and can identify broad safety patterns, but heterogeneity among populations must be explicitly evaluated. Local pharmacovigilance systems remain essential because they provide context-specific information that may be obscured within aggregated international databases.

The findings therefore support strengthening pharmacovigilance capacity in health systems where reporting infrastructure, electronic records, regulatory resources, or clinical pharmacy services remain comparatively limited. Capacity building should encompass standardized reporting, professional education, data interoperability, signal-detection expertise, causality assessment, regulatory communication, and integration of medication-safety activities into routine clinical practice.

Educational transformation represents another consequential implication. Pharmacology and pharmacotherapy education traditionally emphasizes mechanisms, indications, adverse effects, contraindications, and interactions. Contemporary curricula should additionally develop competencies in signal interpretation, evidence appraisal, pharmacovigilance reporting, causal reasoning, pharmacoepidemiology, real-world evidence, medication reconciliation, patient communication, and digital safety analytics. This would better prepare future clinicians and pharmacists for an increasingly data-intensive therapeutic environment.

The role of the pharmacist is particularly important within this educational and clinical transformation. Pharmacists possess specialized knowledge concerning pharmacokinetics,

pharmacodynamics, drug interactions, dosing, formulation, medication-use systems, and patient counseling. Their integration into multidisciplinary safety surveillance can enhance early identification of medication-related problems and facilitate intervention before preventable harm progresses to serious clinical outcomes.

The synthesis also demonstrates the importance of continuous professional development because pharmacological knowledge changes rapidly. Newly approved medicines, emerging adverse reactions, updated safety warnings, new interaction mechanisms, pharmacogenomic discoveries, and evolving evidence concerning established therapies require healthcare professionals to maintain current safety knowledge.

Another major research finding is that uncertainty itself should be treated as an explicit object of pharmacovigilance. Traditional safety communication may implicitly divide evidence into “safe” and “unsafe,” but contemporary science rarely permits such binary categorization. More meaningful classifications distinguish established risks, suspected risks, emerging signals, unresolved associations, biologically plausible hypotheses, and areas with insufficient evidence. Such distinctions permit more proportionate interpretation and reduce the risk of either complacency or unwarranted alarm.

The concept of uncertainty is particularly relevant during the early postauthorization period. Newly introduced medicines may have limited exposure denominators and relatively small cumulative patient-years. Rare adverse outcomes may therefore remain undetected until wider utilization occurs. Early surveillance should consequently combine spontaneous reporting with active epidemiological approaches and mechanistic assessment.

Long-term surveillance is equally important for medicines associated with delayed outcomes. The appropriate duration and intensity of monitoring should correspond to the pharmacological characteristics of the product and plausible latency of potential adverse outcomes. This reinforces the principle that pharmacovigilance is inherently longitudinal.

The research synthesis additionally identifies a transition from product-centric safety surveillance to patient-centric safety surveillance. Product-centric approaches ask whether a medicine is associated with a particular adverse event. Patient-centric approaches additionally ask which patients are susceptible, under what circumstances, at what exposure, with which concomitant treatments, and whether the event can be predicted or prevented. This transition aligns pharmacovigilance more closely with precision medicine and individualized pharmacotherapy.

A patient-centric framework also changes the meaning of prevention. Rather than simply identifying hazards after they occur, the objective becomes risk anticipation. If a subgroup can be identified as disproportionately susceptible, surveillance can be intensified, therapy modified, or an alternative selected where clinically appropriate. This represents the movement from reactive pharmacovigilance toward predictive medication safety. The synthesis suggests that this predictive capacity will increasingly depend upon integration of multiple data types. Clinical variables, laboratory measurements, medication histories, genomic information, imaging, physiological measurements, and patient-reported outcomes may collectively improve risk stratification. However, increased data dimensionality also raises concerns regarding privacy, interoperability, algorithmic bias, governance, and interpretability.

Data governance is therefore an integral component of contemporary drug safety. High-quality surveillance requires secure data infrastructures, appropriate access controls, standardized terminology, transparent provenance, reproducible analytical workflows, and responsible secondary use of health information. Ethical governance is not external to pharmacovigilance; it is part of the scientific infrastructure required to generate trustworthy evidence.

The results also highlight the importance of interoperability. Different healthcare and regulatory databases often use heterogeneous coding systems, terminologies, definitions, and temporal structures. Harmonization can facilitate cross-database analyses, replication, and international

signal validation. However, standardization should not eliminate clinically meaningful local information. Interoperability should therefore be understood as semantic and methodological compatibility rather than simple technical data exchange.

The synthesis further demonstrates that signal detection should be regarded as an iterative learning process. A signal may initially appear weak because of limited exposure, incomplete reporting, or rare event frequency. As additional information accumulates, the signal may strengthen, weaken, become mechanistically clarified, or be disproven. The appropriate response is therefore not necessarily immediate confirmation or dismissal but structured iterative evaluation.

This principle has particular relevance to emerging technologies. Novel medicines, new formulations, combination products, digital therapeutics, and advanced biological interventions may produce safety patterns that existing surveillance systems were not designed to recognize. Adaptive methodologies are therefore required.

The relationship between innovation and pharmacovigilance is consequently bidirectional. New therapeutic technologies create new safety questions, while improved surveillance methodologies enable safer adoption of therapeutic innovation. Effective pharmacovigilance should not function as an obstacle to innovation but as an evidence infrastructure that permits innovation to be evaluated and implemented responsibly.

The research synthesis further emphasizes that pharmacovigilance has an important role in antimicrobial stewardship and other areas where population-level treatment effects intersect with individual safety. Antimicrobial therapy illustrates the need to balance immediate therapeutic benefit, adverse-event risk, drug interactions, microbiological outcomes, and broader consequences associated with antimicrobial exposure. Although antimicrobial resistance is not itself an adverse drug reaction, it demonstrates how pharmacotherapy can generate consequences extending beyond the individual patient.

Oncology provides an environment in which high therapeutic benefit may coexist with substantial toxicity. Pharmacovigilance in oncology must therefore incorporate treatment intensity, combination regimens, delayed toxicity, immunological effects, cumulative exposure, and patient-reported outcomes. The relevant question is not whether toxicity exists but how it can be characterized, predicted, monitored, mitigated, and weighed against therapeutic benefit.

Neurological and psychiatric pharmacotherapy further illustrate the importance of individualized risk assessment because treatment response and adverse effects can vary considerably among individuals. Sedation, cognitive effects, metabolic changes, movement disorders, withdrawal phenomena, and interactions may influence both clinical outcomes and quality of life. Longitudinal surveillance and patient-centered assessment are therefore particularly valuable.

The results additionally demonstrate that the concept of “medication harm” should extend beyond traditionally coded adverse reactions to include treatment discontinuation, nonadherence caused by adverse effects, therapeutic failure secondary to interactions, inappropriate medication cascades, avoidable hospitalization, functional decline, and reduced quality of life where evidence supports medication contribution. This broader perspective enhances the public-health relevance of pharmacovigilance.

Medication cascades are particularly important because an adverse drug effect may be misinterpreted as a new disease, resulting in additional prescribing and subsequent adverse effects. Pharmacological literacy and medication review can interrupt such cascades. Pharmacovigilance can contribute by identifying recurring patterns in which one treatment generates downstream prescribing.

The synthesis also identifies the importance of deprescribing as a medication-safety intervention. In patients with polypharmacy, the safest therapeutic strategy may sometimes involve discontinuation or simplification rather than addition of another medicine. Deprescribing requires

individualized assessment of indication, benefit, duration, prognosis, withdrawal risk, and patient preference. Pharmacovigilance-informed deprescribing can reduce cumulative medication burden while preserving necessary therapeutic benefit.

The some finding concerns the need for stronger integration between preauthorization and postauthorization evidence. Historically, development programs and postmarketing surveillance have sometimes functioned as partially separate knowledge systems. A lifecycle model instead treats evidence generated before and after authorization as components of one continuous learning process. Early signals from development studies can guide postauthorization monitoring, while real-world findings can refine future trial design and development strategies. This approach can also improve the design of pragmatic clinical studies. If postmarketing evidence identifies particular subgroups, interactions, or safety uncertainties, subsequent studies can specifically investigate those questions. Pharmacovigilance therefore becomes not only a surveillance activity but a generator of research priorities.

The synthesis demonstrates that regulatory labeling should similarly be regarded as a dynamic knowledge interface. Product information communicates identified risks, precautions, contraindications, interactions, and monitoring requirements. Changes in labeling can therefore represent formal translations of accumulated pharmacovigilance knowledge into clinical practice. The effectiveness of such communication depends upon clarity, accessibility, professional interpretation, and implementation.

Risk communication must additionally recognize that clinicians and patients interpret uncertainty differently. Numerical risk estimates, confidence intervals, relative and absolute measures, and descriptions of evidence quality should be translated into clinically meaningful information without sacrificing scientific accuracy. Shared decision-making becomes especially important when multiple therapeutic alternatives carry different and incompletely characterized risks.

The results therefore support a model of pharmacovigilance that is evidence-generating, clinically embedded, computationally augmented, causally oriented, patient-centered, and regulatorily responsive. Such a model differs substantially from a narrow system based exclusively on passive adverse-event collection.

A further implication is that pharmacovigilance performance should not be judged solely by the number of reports received or signals generated. High reporting volume may reflect strong surveillance, but it may also reflect stimulated reporting, duplicate submissions, or changes in awareness. Conversely, low reporting volume can reflect underreporting rather than low risk. Performance assessment should therefore include signal timeliness, validation quality, data completeness, clinical relevance, epidemiological confirmation, intervention effectiveness, and reduction of preventable harm where measurable.

This shifts evaluation from activity metrics toward outcome-oriented metrics. The ultimate objective of surveillance is not to generate more signals; it is to generate useful knowledge that contributes to safer and more rational therapeutic decisions.

The research findings further support the concept of pharmacovigilance maturity. A mature system possesses not merely reporting infrastructure but interconnected capabilities for case processing, signal detection, epidemiological research, mechanistic investigation, clinical integration, risk communication, regulatory action, and outcome evaluation. Maturity therefore represents a systems property rather than a single technological capability.

Within this framework, human expertise remains indispensable. Pharmacological reasoning cannot be reduced entirely too statistical association, because biological mechanisms are complex and clinical contexts are heterogeneous. Similarly, clinical judgment cannot substitute for rigorous epidemiological methods when population-level causal questions are being addressed. The most robust model is therefore interdisciplinary rather than algorithmically or professionally isolated.

The analysis ultimately identifies a convergence among pharmacology, pharmacotherapy, pharmacovigilance, pharmacoepidemiology, clinical pharmacy, regulatory science, and public health. This convergence is not merely organizational. It reflects a substantive transformation in the scientific question being asked. Contemporary medication safety increasingly asks not simply whether a medicine can cause harm, but under which biological, clinical, epidemiological, therapeutic, temporal, and health-system conditions harm becomes more probable, how that probability can be detected and quantified, whether the association is causal, how the risk compares with therapeutic benefit and alternatives, which patients are most vulnerable, and which interventions can reduce preventable harm without compromising access to beneficial treatment.

The cumulative findings therefore support a multiscalar safety paradigm in which molecular pharmacology provides mechanistic foundations, clinical pharmacology characterizes exposure and response, pharmacotherapy translates these principles into therapeutic decisions, pharmacovigilance detects and evaluates emerging safety information, pharmacoepidemiology estimates population-level associations, computational methods expand surveillance capacity, clinical pharmacy facilitates medication-harm prevention, regulatory science governs evidence-informed intervention, and public health evaluates the broader consequences.

The resulting conceptual architecture can be represented as a continuous feedback system: Molecular mechanism → pharmacological exposure → clinical response → adverse-event observation → signal generation → causal evaluation → epidemiological validation → benefit–risk characterization → risk minimization → therapeutic adaptation → population outcomes → new evidence generation.

Importantly, this pathway is not strictly linear. Information may enter the system at any point and propagate in multiple directions. An epidemiological observation may stimulate molecular investigation; a molecular discovery may trigger targeted surveillance; a clinical pharmacist may identify an interaction before it becomes a population-level signal; patient-reported outcomes may reveal clinically meaningful toxicity not captured in conventional datasets; and regulatory interventions may themselves generate new evidence concerning effectiveness and unintended consequences.

The ultimate research finding is therefore that contemporary drug safety should be understood as a dynamic knowledge ecosystem rather than a discrete surveillance procedure. Its scientific strength depends on the integration of heterogeneous evidence, explicit recognition of uncertainty, causal reasoning, mechanistic interpretation, longitudinal observation, computational augmentation, clinical expertise, patient participation, and proportionate risk governance. Pharmacovigilance becomes most valuable when it functions as a translational bridge between what is known about medicines, what occurs during their use, and what can be learned to improve future therapeutic decisions.

From a clinical perspective, this integrated framework supports a transition from generalized safety precautions toward risk-stratified pharmacotherapy. From an epidemiological perspective, it supports more explicit causal designs and triangulation across data sources. From a pharmacological perspective, it reinforces the importance of understanding mechanisms underlying heterogeneity in drug response. From a regulatory perspective, it supports iterative benefit–risk assessment and lifecycle governance. From a public-health perspective, it emphasizes preventable medication-related morbidity, equitable access to effective treatment, and protection of populations exposed to medicinal products.

The convergence of these domains provides the conceptual foundation for an increasingly proactive model of therapeutic safety. The future trajectory of pharmacovigilance is therefore likely to depend less on the isolated expansion of reporting volume and more on the capacity to integrate mechanistic pharmacology, clinical observation, longitudinal real-world evidence,

computational analytics, causal inference, individualized risk stratification, and regulatory learning into a coherent safety-intelligence infrastructure. In this configuration, the fundamental objective remains scientifically and clinically grounded: to ensure that medicines are used according to the strongest available evidence, that emerging risks are recognized as early and accurately as possible, that uncertainty is transparently characterized, that vulnerable populations are appropriately considered, and that pharmacotherapeutic benefit is continuously optimized relative to potential harm. The evolutionary advancement of drug safety thus represents not merely technological modernization but a deeper transformation in the epistemological, methodological, clinical, and regulatory foundations through which therapeutic risk is understood and governed.

ANALYSIS

The analytical synthesis of the present scientific discourse indicates that the contemporary architecture of drug safety is undergoing a fundamental epistemological, methodological, and translational reconfiguration. Rather than representing pharmacovigilance as an isolated post-marketing surveillance discipline concerned principally with the collection of spontaneous adverse drug reaction reports, the emerging scientific configuration positions drug safety within a multidimensional evidence ecosystem encompassing molecular pharmacology, clinical pharmacology, pharmacotherapy, pharmacoepidemiology, causal inference, real-world evidence, computational analytics, regulatory science, clinical pharmacy, and population health. This transformation reflects a recognition that medication-related risk is neither static nor exclusively product-dependent, but is dynamically produced through interactions among medicinal-product characteristics, exposure intensity and duration, patient susceptibility, disease biology, therapeutic context, concomitant treatment, healthcare-system organization, and patterns of medication utilization. Consequently, the analytical unit of contemporary safety science increasingly moves from the isolated adverse event toward the interconnected medicine–patient–disease–system configuration.

A central analytical implication is that pharmacological knowledge constitutes the mechanistic substrate upon which meaningful pharmacovigilance interpretation depends. Pharmacodynamics establishes the biological consequences of receptor activation, inhibition, modulation, ion-channel effects, enzymatic interactions, transporter activity, immunological activation, and downstream cellular signaling, whereas pharmacokinetics determines the temporal and quantitative relationship between administration and systemic or tissue exposure. These dimensions become particularly consequential when adverse outcomes are mediated by excessive exposure, active metabolites, accumulation, impaired clearance, altered distribution, drug–drug interactions, pharmacogenomic variation, or disease-associated changes in physiological function. Accordingly, the analytical interpretation of a safety signal should not be disconnected from the pharmacological plausibility of the observed event. A statistical association may identify an anomaly, but pharmacological reasoning can establish whether that anomaly is biologically coherent, temporally credible, and compatible with established or emerging mechanisms of toxicity.

This relationship becomes more complex when pharmacological exposure is understood as realized exposure rather than prescribed dose alone. The nominal dose recorded in a prescription does not necessarily correspond to the biologically relevant exposure experienced by an individual. Absorption, bioavailability, adherence, metabolism, renal and hepatic function, transporter activity, interacting medicines, formulation characteristics, treatment interruptions, dose titration, and changes in disease state can produce substantial interindividual and intraindividual variability. Consequently, contemporary safety analysis should distinguish prescribed exposure, dispensed exposure, administered exposure, and biologically realized

exposure. This distinction has major implications for both pharmacovigilance and pharmacoepidemiology because inaccurate exposure classification can attenuate associations, generate spurious associations, or obscure dose–response relationships.

The analysis further demonstrates that adverse drug reactions, adverse events, medication errors, and broader medication-related harm represent analytically related but non-identical constructs. Pharmacovigilance traditionally concentrates on adverse reactions associated with medicinal products, while medication-safety science encompasses a broader spectrum of preventable and non-preventable harm arising from prescribing, dispensing, administration, monitoring, adherence, interactions, transitions of care, and healthcare-system processes. The analytical expansion from adverse drug reactions toward medication-related harm therefore increases the sensitivity of safety science to sociotechnical determinants of therapeutic outcomes. This perspective recognizes that an unfavorable medication outcome may result not from intrinsic pharmacological toxicity alone but from inappropriate selection, incorrect dosing, inadequate monitoring, communication failures, therapeutic duplication, contraindicated combinations, or failure to respond to emerging toxicity.

An important analytical consequence is the need to maintain conceptual separation between signal detection and causal inference. Contemporary pharmacovigilance systems can identify disproportionate reporting patterns rapidly, but statistical disproportionality does not independently establish causality. The distinction is critical because spontaneous reporting databases are affected by underreporting, stimulated reporting, reporting notoriety, duplicate reports, differential reporting behavior and changes in prescribing volume, publicity effects, and incomplete clinical information. A signal should therefore be interpreted as an evidence-generating observation that initiates structured scientific evaluation rather than as a definitive declaration of drug-induced harm. Recent pharmacovigilance scholarship emphasizes precisely this complementary relationship between spontaneous reports and longitudinal healthcare databases, with the latter offering contextual exposure and outcome information that can help address some limitations of passive surveillance.

The analytical architecture therefore requires triangulation. Spontaneous reporting systems possess important sensitivity for unusual, rare, unexpected, or newly emerging adverse-event patterns, while longitudinal healthcare databases provide denominators, exposure histories, comparator groups, temporal information, and outcome ascertainment that can facilitate epidemiological assessment. Neither source should be conceptualized as universally superior. Instead, their analytical value depends on the research question, data completeness, outcome specificity, exposure ascertainment, population representativeness, latency structure, and methodological assumptions. The emerging literature specifically supports greater interoperability between spontaneous reporting databases and longitudinal healthcare databases throughout signal management, while emphasizing that such integration requires attention to methodological heterogeneity and data limitations.

Real-world evidence consequently occupies an increasingly important position within the analytical hierarchy of drug safety. However, real-world data should not be equated automatically with real-world evidence. Data become evidence only when they are transformed through a scientifically justified design, explicit causal or descriptive question, appropriate population definition, valid exposure and outcome measurement, adequate comparator construction, transparent analytical methods, and interpretation proportional to the underlying uncertainty. The final ICH M14 guideline formalizes this methodological direction by providing general principles for planning, designing, analyzing, and reporting non-interventional studies using real-world data for medicines safety assessment.

A particularly important analytical development is the increasing application of causal-inference principles to pharmacovigilance. Observational medication-safety studies are vulnerable to

confounding by indication, channeling bias, disease severity differences and treatment-selection mechanisms, time-dependent confounding, immortal-time bias, informative censoring, and outcome-detection differences. The causal interpretation of an observed association therefore depends not merely upon the magnitude of an estimated effect but upon the credibility of the underlying counterfactual comparison. Active-comparator designs, new-user cohorts, self-controlled approaches, target-trial emulation, propensity-score methods, marginal structural models, and sensitivity analyses can strengthen causal interpretation when their assumptions are appropriately satisfied.

The analysis also indicates that estimand specification should precede statistical estimation. Drug-safety questions may differ substantially depending on whether the scientific objective concerns treatment initiation, treatment continuation, cumulative exposure, treatment switching, discontinuation, or a particular duration of therapy. Likewise, the relevant outcome may be any adverse event, a clinically severe endpoint, hospitalization, treatment discontinuation, mortality, or a composite measure. Without explicit definition of the target population, treatment strategies, outcome, follow-up period, intercurrent events, and summary measure, apparently precise statistical estimates may answer ambiguous scientific questions. The integration of estimand thinking into pharmacovigilance therefore represents an important methodological advancement.

Another major analytical dimension concerns time. Drug safety cannot be adequately represented by a single static risk estimate when biological mechanisms, treatment exposure, disease status, and monitoring intensity change longitudinally. Early treatment periods may involve initiation-related adverse effects; intermediate periods may reveal cumulative toxicity or adaptive physiological responses; and prolonged exposure may generate risks associated with chronic pharmacological perturbation. Conversely, some adverse events may occur only after treatment discontinuation or following interactions between treatment modification and disease rebound. Consequently, temporal pharmacovigilance should consider risk windows, latency periods, cumulative exposure, treatment transitions, and changing clinical states.

This temporal perspective is particularly important in polypharmacy. A medication regimen is not merely the arithmetic sum of individual drugs; it constitutes a pharmacological network in which medicines may interact pharmacokinetically, pharmacodynamically, behaviorally, and clinically. The addition of each medicine may alter the exposure or effect of others, while the overall regimen may influence adherence, monitoring complexity, treatment burden, and therapeutic competition. Therefore, regimen-level pharmacovigilance may provide greater clinical relevance than isolated drug-event associations in populations characterized by multimorbidity and extensive medication use.

Patient heterogeneity constitutes another major analytical axis. Population-average effects may conceal clinically meaningful subgroups characterized by age, frailty, renal or hepatic dysfunction, genetic variation, immune phenotype, disease severity, socioeconomic circumstances, pregnancy, concomitant therapies, or healthcare access. Precision pharmacovigilance therefore extends the principles of precision medicine into safety science by asking not simply whether a medicine is associated with harm, but in whom, under which circumstances, at what exposure level, during which treatment period, and relative to which therapeutic alternative the risk becomes clinically meaningful.

Pharmacogenomics provides one important mechanism through which this heterogeneity can be investigated. Genetic variation affecting drug-metabolizing enzymes, transporters, receptors, immune pathways, or pharmacodynamic targets can modify both therapeutic response and adverse-event susceptibility. However, pharmacogenomic information should not be interpreted independently of environmental, clinical, and treatment-contextual variables. The analytical challenge is therefore to integrate genetic susceptibility with phenotype, exposure, comorbidity,

concomitant medication, and disease trajectory rather than treating genotype as an isolated deterministic predictor.

The increasing application of artificial intelligence and machine learning introduces another analytical transformation. Natural-language processing can facilitate extraction of adverse-event information from clinical documentation; machine-learning systems can support classification, duplicate detection, case prioritization, and pattern recognition; Bayesian models can integrate heterogeneous evidence; and computational approaches can potentially identify complex relationships that conventional rule-based methods may overlook. Recent reviews characterize AI as increasingly relevant to signal detection, surveillance, automated adverse-event reporting, real-world evidence analysis, and predictive safety assessment. At the same time, implementation remains constrained by data quality, transparency, validation, regulatory requirements, and interpretability.

The analytical implication is that computational pharmacovigilance should be conceptualized as human–machine complementarity rather than technological substitution. Algorithms may process information at scales inaccessible to individual investigators, but they cannot independently resolve all questions of clinical relevance, biological plausibility, causal interpretation, or regulatory proportionality. Black-box predictions can be particularly problematic when they influence high-consequence safety decisions. Therefore, model validation, calibration, external testing, provenance documentation, explainability, algorithmic-drift monitoring, and human adjudication should constitute integral components of computational safety governance.

The emerging use of standardized real-world evidence frameworks further reinforces this principle. The ASSURE implementation framework, for example, incorporates database diagnostics, phenotype development, query specification, analytic implementation, objective study-validity diagnostics, and standardized reporting before evidence is incorporated into safety decision-making. Its reported implementation demonstrates why methodological quality control is not an administrative supplement but an epistemic safeguard: a substantial proportion of evaluated analyses did not proceed to effect estimation because database, phenotype, or validity diagnostics were not sufficiently satisfactory. Such findings support a broader analytical proposition that the absence of a statistically estimable result can itself represent scientifically informative evidence about data fitness, phenotype validity, or study feasibility.

This perspective changes the interpretation of negative evidence. Failure to detect an association does not necessarily establish absence of risk. A null result may reflect inadequate statistical power, insufficient exposure duration, outcome misclassification, inappropriate comparator selection, residual confounding, low event frequency, or limited population coverage. Conversely, repeated absence of an association across methodologically robust, adequately powered, and appropriately designed studies can progressively reduce uncertainty. Thus, negative evidence should be interpreted cumulatively and in relation to study validity rather than through a binary significant/non-significant framework.

The analysis also reveals that uncertainty should be quantified and communicated rather than obscured. Every pharmacovigilance conclusion contains some degree of epistemic uncertainty arising from incomplete information, stochastic variation, methodological assumptions, data limitations, biological complexity, or conflicting evidence. A scientifically mature safety system therefore distinguishes between known risk, probable risk, suspected risk, unresolved signal, insufficient evidence, and evidence suggesting attenuation or absence of association. Such distinctions facilitate proportional decision-making and prevent both inappropriate reassurance and unnecessary alarm.

Risk–benefit assessment represents the logical culmination of this analytical process. A safety signal acquires clinical significance only within the context of therapeutic benefit, disease severity, available alternatives, treatment effectiveness, baseline risk, patient characteristics, and the

consequences of treatment modification. A relatively frequent adverse effect may be acceptable when a medicine provides substantial benefit for a serious disease, whereas a comparatively uncommon adverse event may acquire greater regulatory or clinical importance when safer alternatives exist. Benefit–risk assessment must therefore remain dynamic, indication-specific, population-specific, and responsive to emerging evidence.

The analysis further identifies risk minimization as an intervention rather than an endpoint. Regulatory communication, prescribing restrictions, monitoring requirements, educational interventions, contraindications, dose adjustments, clinical decision support, and targeted patient information are intended to alter clinical behavior and thereby reduce harm. Their implementation should consequently be evaluated empirically. If a risk-minimization measure fails to change prescribing, monitoring, recognition, or patient behavior, its existence does not establish its effectiveness. Pharmacovigilance should therefore progress from signal recognition toward closed-loop evaluation in which intervention, implementation, outcome, and residual risk are continuously reassessed.

Clinical pharmacy represents an important operational interface within this closed-loop architecture. Pharmacists can translate pharmacological and pharmacovigilance knowledge into medication reconciliation, interaction assessment, dose optimization, adherence support, monitoring recommendations, patient counseling, adverse-event identification, and communication with prescribers. Their position at the intersection of medicinal-product knowledge and patient-level medication use provides an opportunity to transform abstract safety signals into practical medication-harm prevention strategies.

A further analytical consideration is health equity. Safety signals generated predominantly from healthcare systems with strong reporting infrastructures may not adequately represent populations with limited access to healthcare, weak reporting systems, underdiagnosis, or limited digital connectivity. Consequently, apparent differences in adverse-event incidence may reflect differences in exposure, ascertainment, reporting intensity, diagnostic capacity, or healthcare utilization rather than biological susceptibility alone. Global pharmacovigilance must therefore account for structural determinants of evidence generation. Contemporary international approaches increasingly emphasize strengthening pharmacovigilance capacity and integrating safety surveillance into health-system infrastructures rather than treating pharmacovigilance as an isolated regulatory function.

Data interoperability represents another prerequisite for analytical maturity. Heterogeneous coding systems, incompatible terminologies, inconsistent phenotype definitions, incomplete linkage, variable data provenance, and differences in healthcare utilization can impede cross-database synthesis. Standardized data models, reproducible analytical workflows, transparent phenotype definitions, and common methodological specifications can reduce these barriers. The 2025 recommendations for broader RWE utilization in pharmacovigilance specifically emphasize streamlined data access, harmonization, reproducible analytical workflows, interdisciplinary collaboration, and organizational adaptation.

The cumulative analytical evidence therefore supports a transition from a linear pharmacovigilance paradigm to a recursive evidence-generation architecture. In a linear model, adverse-event reporting leads to signal detection, followed by assessment and regulatory action. In the emerging model, every stage informs the next while simultaneously generating new questions. Molecular pharmacology informs signal plausibility; signals stimulate epidemiological investigation; epidemiological findings modify clinical risk characterization; clinical interventions generate new observational data; those data reassess risk-minimization effectiveness; and regulatory decisions alter patterns of exposure that subsequently influence the evidence base. Pharmacovigilance thereby becomes an adaptive learning system.

The conceptual significance of this transformation extends beyond methodology. It changes the definition of scientific rigor in drug safety. Rigor is no longer represented exclusively by statistical sophistication or database size. Instead, it emerges from the coherence among research question, causal structure, data-generating process, pharmacological mechanism, analytical design, uncertainty characterization, clinical interpretation, and regulatory consequence. Large datasets cannot compensate for poor phenotype definitions, inappropriate comparators, systematic measurement error, or unrecognized confounding. Similarly, sophisticated algorithms cannot substitute for clinically meaningful endpoints or valid exposure characterization.

The analysis consequently supports a multiscalar model in which molecular mechanisms, individual pharmacology, therapeutic regimens, clinical outcomes, healthcare systems, and population-level effects are analytically interconnected. At the molecular level, mechanisms explain potential toxicity; at the patient level, pharmacokinetic and pharmacodynamic heterogeneity determines realized exposure and response; at the therapeutic level, prescribing and regimen configuration determine the clinical context; at the epidemiological level, comparative outcomes quantify population risk; at the regulatory level, evidence is translated into risk-management decisions; and at the public-health level, the aggregate consequences of those decisions determine medication safety across populations.

The ultimate analytical conclusion is therefore that contemporary drug safety should be understood as an adaptive evidence-generating discipline rather than a passive documentation system. Its scientific maturity depends on the capacity to integrate heterogeneous evidence without erasing methodological distinctions, to use computational technologies without abandoning clinical judgment, to generate real-world evidence without confusing data abundance with certainty, and to translate pharmacological knowledge into clinically and regulatorily actionable risk characterization. Recent developments in the field increasingly support precisely this integrated model, in which spontaneous reporting, longitudinal healthcare data, structured epidemiological methods, standardized real-world evidence frameworks, and computational tools operate as complementary components of pharmacovigilance rather than isolated methodologies.

Thus, the analytical architecture emerging from this scientific discourse can be represented as a continuous sequence of mechanistic explanation, exposure characterization, clinical contextualization, signal generation, signal validation, causal investigation, population-level risk estimation, uncertainty quantification, benefit–risk interpretation, intervention, effectiveness evaluation, regulatory adaptation, and iterative evidence regeneration. This sequence establishes a scientifically coherent bridge between pharmacology and pharmacovigilance, between pharmacovigilance and pharmacotherapy, and between individual medication decisions and population-health protection. The future trajectory of drug safety will consequently depend not simply on generating more safety information, but on developing increasingly rigorous mechanisms for transforming heterogeneous information into validated evidence, validated evidence into proportionate action, and action into measurable reductions in preventable medication-related harm.

CONCLUSION

- The present scientific discourse demonstrates that the contemporary advancement of drug safety, pharmacovigilance, pharmacology, and pharmacotherapy necessitates a transition from fragmented, predominantly reactive surveillance toward an integrated, multiscalar, longitudinal, evidence-generating, and clinically actionable safety architecture. Drug safety can no longer be conceptualized as an intrinsic and immutable characteristic of an individual medicinal product; rather, it emerges dynamically from the interaction among pharmacological properties, dose and realized exposure, treatment duration, patient-specific biological susceptibility, comorbidities,

concomitant therapies, disease trajectories, healthcare-system characteristics, and patterns of therapeutic utilization. Consequently, meaningful safety evaluation requires continuous integration of molecular, mechanistic, clinical, epidemiological, computational, regulatory, and population-health evidence across the entire medicinal-product lifecycle.

- The analysis further establishes that pharmacovigilance and pharmacology constitute mutually reinforcing scientific domains. Molecular and clinical pharmacology provide mechanistic explanations for adverse reactions, pharmacokinetic variability, pharmacodynamic interactions, exposure–response relationships, pharmacogenomic susceptibility, and therapeutic vulnerabilities, whereas pharmacovigilance generates real-world observations capable of identifying previously unrecognized or incompletely characterized safety phenomena. Pharmacotherapy provides the clinical decision-making context in which these signals acquire therapeutic significance, particularly when clinicians must balance efficacy, toxicity, competing risks, polypharmacy, patient preferences, and disease-specific therapeutic objectives. Contemporary signal management accordingly requires structured detection, validation, prioritization, assessment, and translation into proportionate action rather than equating statistical signals with established causality.
- The synthesis also indicates that spontaneous reporting systems, electronic health records, claims databases, registries, prescription and dispensing datasets, clinical studies, literature surveillance, and patient-generated information should be regarded as complementary components of an evidence ecosystem rather than interchangeable sources. Their integration permits triangulation of signal strength, temporal relationships, biological plausibility, exposure patterns, absolute and relative risks, vulnerable subpopulations, and clinical consequences. Nevertheless, evidence abundance does not inherently establish evidence certainty; confounding, selection bias, exposure and outcome misclassification, underreporting, stimulated reporting, missingness, indication bias, channeling, monitoring intensity, and residual uncertainty must remain explicit components of pharmacovigilance interpretation.
- The future of drug safety depends on the development of intelligent and adaptive pharmacovigilance systems capable of combining quantitative signal detection, causal inference, real-world evidence, computational analytics, artificial intelligence, precision pharmacology, clinical expertise, and regulatory judgment. Current international pharmacovigilance strategies increasingly emphasize risk-based prioritization, integration with health and regulatory systems, digital tools, real-world data, workforce development, and equitable access to safe medical products.
- The therapeutic safety should be understood as a continuous evidence-to-action process: mechanistic pharmacology → exposure characterization → clinical pharmacotherapy → adverse-event observation → safety-signal intelligence → causal inference → pharmacoepidemiological risk stratification → real-world evidence integration → benefit–risk optimization → medication-harm mitigation → regulatory adaptation → population-health protection → continuous evidence generation. Such an architecture transforms pharmacovigilance from a predominantly post hoc monitoring activity into an adaptive scientific infrastructure for rational therapeutics, individualized risk management, prevention of avoidable medication-related harm, and sustained protection of public health throughout the medicinal-product lifecycle.

RECOMMENDATIONS

- The contemporary advancement of drug safety, pharmacovigilance, pharmacology, and pharmacotherapy warrants a coordinated set of scientific, clinical, technological, regulatory, educational, and public-health recommendations. First, pharmacovigilance systems should be progressively transformed from predominantly reactive adverse-event reporting structures into integrated, lifecycle-oriented safety intelligence systems capable of continuously combining

spontaneous reports, active surveillance, electronic health records, registries, claims databases, prescription and dispensing information, clinical studies, scientific literature, and appropriately governed patient-generated data. Such integration should remain risk-based and proportionate to the seriousness, uncertainty, exposure characteristics, and potential population-health consequences of identified safety concerns.

- National and institutional pharmacovigilance infrastructures should strengthen standardized procedures for signal detection, validation, confirmation, analysis, prioritization, causal assessment, regulatory interpretation, and follow-up. Statistical disproportionality signals should be treated as hypothesis-generating evidence rather than automatically interpreted as causal relationships. Clinical judgment, pharmacological plausibility, epidemiological assessment, temporal relationships, alternative explanations, and independent evidence triangulation should remain integral to signal evaluation.
- Pharmacological characterization should become more systematically connected with pharmacovigilance and pharmacotherapeutic decision-making. Pharmacokinetic and pharmacodynamic determinants, dose–exposure relationships, drug–drug and drug–disease interactions, pharmacogenomic variability, immunological mechanisms, organ-function impairment, and patient-specific susceptibility should be incorporated into safety-risk characterization whenever scientifically justified. This approach can facilitate more precise identification of vulnerable populations and support individualized therapeutic risk management.
- The real-world data should be used through explicit fit-for-purpose methodological frameworks rather than through simple data aggregation. Study designs should prespecify target populations, exposures, comparators, outcomes, estimands, observation periods, confounding-control strategies, missing-data procedures, and sensitivity analyses. Particular attention should be directed toward indication bias, channeling, immortal-time bias, exposure misclassification, outcome misclassification, surveillance bias, residual confounding, and informative missingness.
- The artificial intelligence, machine learning, natural-language processing, and other computational pharmacovigilance technologies should be incorporated under rigorous human oversight. Algorithms should undergo validation, calibration, external testing, drift monitoring, documentation, reproducibility assessment, and appropriate explainability procedures. Computational outputs should augment rather than replace clinical pharmacological and regulatory expertise.
- Medication-safety programmes should expand beyond narrowly defined adverse drug reactions to encompass preventable medication-related harm, prescribing errors, administration errors, monitoring failures, contraindicated combinations, therapeutic duplication, adherence-related problems, and system-level contributors to unsafe medication use. Clinical pharmacists, physicians, nurses, epidemiologists, pharmacologists, data scientists, regulators, and patients should participate in multidisciplinary safety governance.
- Risk-minimization interventions should be evaluated for effectiveness rather than assumed to be effective following implementation. Safety communication, prescribing restrictions, monitoring requirements, educational interventions, clinical decision-support systems, and other measures should be assessed through measurable outcomes and subsequently modified according to observed performance. This aligns with contemporary good-pharmacovigilance practice, in which risk-minimization and safety-management activities are integral components of lifecycle surveillance.
- National pharmacovigilance capacity should be strengthened through sustained workforce development, standardized education, interoperable information systems, international collaboration, transparent safety communication, and equitable access to safety information. Particular emphasis should be placed on strengthening systems in resource-constrained settings and integrating pharmacovigilance into broader healthcare and regulatory infrastructures.

Continuous evaluation should ensure that emerging evidence is translated into proportionate clinical, regulatory, and public-health action, thereby establishing pharmacovigilance as a durable component of rational pharmacotherapy and population-health protection.

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Historical Sciences

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Аңдатпа. Мақалада Қасым ханның Қазақ хандығын ұлы державаға айналдыруға қосқан үлесі, шекаралас елдермен жүргізген соғыстары мен Дешті-Қыпшақтағы саяси оқиғаларға ықпалы бағамдалады. Қасым хан және оның ұрпақтары жүргізген саясат салдарынан аймақта Хиуа хандығы, Моғол хандығы, Ұлы Моғол империясы, Бұхар хандығы мен Сефевидтер мемлекеттерінің құрылуы және күшеюі орын алды. Қасым ханның Шайбани ұрпақтарымен күрделі қарым-қатынасына баға берілді. Әсіресе Қазақ хандығының сефевидтермен қарым-қатынасы жаңа қырынан талданды. Әртүрлі мемлекеттердің саяси құрылымдарын талдау үшін тарихи-салыстырмалы талдау, әр оқиғаны рет бойынша тізіп жазу үшін мәселелі хронологиялық әдіс және тақырып мазмұнын жүйелі түрде жеткізу үшін жүйелілік-құрылымдық талдау қолданылды.

Тірек сөздер: Дешті Қыпшақ, Қасым хан, Әбілқайыр хан, Шайбани хан, Сефевидтер, Түркістан

Қазақ хандығын негізін қалаушылардың бірі Жәнібек ханның 9 ұлдары болды. Олар: Қасым, Жәдік, Әдік, Жиренше, Таныш, Махмұт, Ұснақ, Қамбар және Жаныш. Бәрінің арасында Қасымның шоқтығы биік болды. Әскери өнердегі ерекше дарынымен және біліктілігімен көзге түсіп, талай шайқастарға қатысып, даңқы шартарапқа жайылды. Ол билікке 1511 жылы келді. Бұрындық хан билік еткен кезде ең негізгі әскери қолбасшы да Қасым хан болатын. Ол билік еткен кезде халықтың саны 1 млн-ға жетіп, 300 мың әскер болған еді. Елдің даңқы Орта Азия мен Шығыс Еуропаға таралды. Қасым хан тұсында астана жиі ауысып тұрды. Алғашқыда орталық Сығанақтан Түркістанға, кейін Түркістаннан Сарайшыққа ауысқан [1]. Ол Хиуа хандығы, Шайбани әулеті, Моғол хандығы, Мәскеу кінәздігі, Ноғай Ордасы, Сібір хандығы және Сефевид әулетімен саяси қарым-қатынас орнатқан. Бабыр «Бабырнама» еңбегінде: «Бұл халықты Қасым хан сияқты бұған дейін ешкім бағындырмаған. Оның қарамағындағы әскер саны 300 мыңға жеткен», – деп жазған [2]. М. Х. Дулати «Тарих-и Рашиди» еңбегінде: «Ол билік еткен кезде 1 млн адам болып, 300 мың әскер болды. Жошыдан кейінгі Дешті Қыпшақтың ұлы ханы атанды», – деп мәлімдеген [3]. Қадырғали Жалайыри: «Жәнібек хандарының ұлдарының арасында ең белгілісі Қасым болды. Ол туралы аңыздар әр жерде көп тараған», – деген дерекпен бөлісті. Қасым хан

кезінде атақты «Қасқа жол» заңдар жинағы шығады. Заңдар жинағы бес бөлімнен тұрды: мүлік заңы, қылмыс заңы, әскери заң, елшілік және жұртшылық. Әлкей Хақанұлы Марғұланның ойынша, бұл заңдар жинағы ең қиын аласапыран кезеңде пайда болған. Елдің ішінде іріткі тудырмай, ішкі және сыртқы саясатты реттеп, халықты бір шаңырақ астына жинау үшін заңда реформаларды енгізу үшін ойлап табылған.

Қасым хан елді Керей, Жәнібек және Бұрындық хандар билеген кезде де әскери қақтығыстардың бел ортасында жүрді. Жеке саяси күш ретінде ол 16 ғасырдың алғашқы жылдарында көріне бастайды. Қасым ханды атағанда оның бөлесі Мұхаммед Шайбаниді айтпай қою қиын. Мұхаммед Шайбани атақты Әбілқайыр ханның немересі, Шах-Будақтың ұлы еді. 1469 жылы Әбілқайыр өмірден өткен соң, билікке келген Шайх-Хайдарды Қазақ, Ноғай және Сібір хандығының біріккен күші талқандайды. Осы жеңілістен кейін Дешті Қыпшақтағы билік дағдарысқа ұшырап, көптеген сұлтандар жаңа одақтастар іздей бастады.

Ноғай мырзалары Мұхаммед Шайбани мен Махмұд-Сұлтанды Астраханьға(Қажы-Тарханға) жөнелтіп, онда олар біраз уақыт олардың бақылауында болады. Олар Астраханьға жөнелтіледі [4]. Астрахань билеушісі Қасым хан олардың тәрбиелеуші етіп Темірбекті бекітеді де, біраз уақыттан кейін оларды Мәуереннахрға жібереді. Астраханьнан қашып шыққан Мұхаммед Шайбани Мәуереннахрға келіп, онда әскер жинайды.

Бастапқы уақытта оны ноғайлар қолдаса, кейін Шайбани Моғолстанмен одақ құрайды. Ол бұрынғы Ақсақ Темір империясына тиесілі қалаларды бағындырғысы келді [5]. Сыр бойындағы қалалар үшін күрес 1470-1500 жылдары үздіксіз созылып, бұл аймақ Мәуереннахр билеушілері, Қазақ хандығы, Моғолстан мен Ноғай Ордасы арасындағы басты қақтығыс алаңына айналды. Түркістан өңірі саяси, экономикалық әрі діни орталық болғандықтан, оған иелік ету Орта Азиядағы үстемдікті айқындаушы факторға айналды.

Мұхаммед Шайбани Түркістан аймағын өзіне қаратуға талпынды. Ол үшін Қасым сұлтаннан 1499 жылы көмек сұрайды. Ақсақ Темір ұрпақтарын құлатып, төрелердің билігін орнатпақ еді. Қасымға жазған хатында ол Ақсақ Темір ұрпақтарының Мәуереннахрда үстемдік етуі Шыңғыс хан құрған мемлекеттілігіне қайшы екендігі, бұрынғы заманға сай әділеттік салтанат етуі тиіс деген саяси уәж ұсынды [6, 252 б.].

Бұл уақытта Шайбани әулеті мен Қазақ хандығы арасындағы қарым-қатынас жақсарғанға ұқсайды. Дегенмен екі жақтың да көздегені Сырдария өзені бойындағы қалаларды бақылауда ұстау еді. Ақыры Шайбани 1500-1501 жылдары Темір әулетінің астанасы Самарқандты алады. Мұхаммед Шайбани Орталық Азиядағы ең ықпалды билеушілердің біріне айналды.

1500-1508 жылдары Мұхаммед Шайбани бұрынғы Ақсақ Темір империясының жерлерін қосып алып, қазақ жерін қосып алуды мақсат етеді. Ол Бұхара, Хорезм, Самарқанд сияқты ірі орталықтарды иемденіп қана қоймай, қазақ даласына да көз тікті. Қазақ хандығы бұл уақытта Бұрындық хан мен Қасым сұлтанның басшылығымен күшейіп келе жатқан болатын. Шайбанидің қазақ жерін қосып алу жоспары екі мемлекеттің арасындағы жаңа әскери қақтығыстарға алып келді.

1503, 1505, 1506 жылдары Шайбани Қазақ хандығына жорықтар ұйымдастырғанын атап өту керек. Бірақ ол кезде Қазақ хандығының Түркістандағы ықпалын әлсіретуді көздеп, шабуылдаған еді. Осы уақытта өзін Орталық Азияның әміршісі санаған Мұхаммед Шайбани Дешті-Қыпшақты қосып алуды жөн көрді.

Бұл уақытта Қазақ хандығын Бұрындық хан басқарса да, халықтың бүйрегі Қасым ханға бұрылған еді. Ең негізгі шайқастарды Қасым хан бастайтын. 1508 жылы Қасым хан Ноғай Ордасын бағындырады. Бұл жорық қазақтардың Еділ-Жайық бойындағы ықпалын күшейтіп, олардың саяси беделін арттырды. Ашуланған Шайбани Түркістанда қазақ саудагерлерімен сауда жасауға тыйым салады. Бұл тыйым екі ел арасындағы экономикалық қатынастарға соққы беріп, халықтың тұрмыс-тіршілігіне де әсер етті.

1509 жылы Шайбани Жәнібектің ұлы Жанша сұлтанға шабуылдап, оны жеңеді. Сол жылы Жәнібектің басқа ұлы Таныш сұлтан жасағынан сатқын пайда болып, ол Шайбаниге Бұрындық ханды қалай жеңуге болатынын көрсетеді. Жеңілген Бұрындықтың беделі түседі. Қазақтың рубасылары мен сұлтандары Бұрындықтан теріс айналып, Қасымды қолдауға бет бұрады.

1510 жылы Шайбани Сығанақтан Ұлытауға шабуыл жасайды. Қасым хан Мойынсыз деген атақ алған Хасан батырдың арқасында Шайбаниды жеңеді [4]. Қазақ халқының әскери дайындығы мен ұйымдасуы Шайбани әскерінен басым түседі.

Аталған оқиғалардан бұрын Шайбани Қасым ханға тәуелділігін білдіру үшін Түркістан өңірінде Қасым ханның атына теңге соқтыруға да уәде берген еді. Бірақ сөзінде тұрмады. Теңге соғу – биліктің заңды танылуын білдіретін аса маңызды саяси қадам еді. Шайбанидың уәдесінде тұрмауы қазақ пен өзбек арасындағы сенімді одан әрі әлсіретті. Сол үшін Қасым хан баласы Әбілқайырды Ташкентке, кейін Самарқандқа жібереді. 80 мың әскерімен ол Шайбаниды Самарқандтан тықсырады [6, 286 б.].

Қашқан Шайбани Мәуереннахр жерінде Сефевид шахымен Хорасан жері үшін таласады. Ол қазіргі Иран жеріндегі иеліктерге төрелік етуге лайықты екенін білдіріп, Сефевид шахы Ысмайылдан сол жерлерді беруді талап етеді. Бірнеше рет елшілік алмасқан соң, екі жақ арасында шайқас өтеді. Шайбани ақыры шахиншах Ысмайылдан 1510 жылы қаза табады. Бұл шайқастың нәтижесінде бұрынғы Шайбани билеген өңірлерде Қасым ханның ықпалы арта түседі және сефевидтер әулеті де Түркістан өңіріне көз аларта бастайды.

Бұл жерде Шайбани әулетінің ықпалы азайған соң, Қасым ханның қолдауымен 1511 жылы Елбарыс хан Хиуа хандығын құрайды. Қасым ханның Бұхар хандығына қарсы одақтасы болады. Шайбаниды жеңген соң, халық Қасымды ақ киізге көтеріп, хан сайлайды. Бұл Қасым ханның билігін заңдастырып, оның билігін бүкіл далаға таралуына негіз болады.

Бұл уақытта Шайбаниды өлтірген Ысмайыл шах Мәуереннахр жерін толығымен қосып алуды ойлайды. Бұхар хандығы өте әлсіз елге айналды. Соны көрген Қасым хан 1512 жылы өз ұлын Әбілқайырды Сефевид шахы Ысмайылға қарсы соғысуға жібереді. Ол Шайбани ұрпақтарымен бірігіп, Ысмайылға қарсы соғысады. Біріккен қазақ-өзбек әскері қызылбастарды ел шекарасынан қуа алды [7, 117 б.].

1513 жылы Сайрамның әмірі, Әмір Темірдің ұрпағы Қаттыбек Қасым ханға қаланы өз еркімен береді. Қасым хан Түркістан өңірінде күш жинай бастайды. Бірақ 1513 жылы Қасым хан Ташкент түбінде Шайбани әулетінің билеушілерінің Сүйінші-Қожа ханнан жеңіледі [8, 132 б.]. Бұл жеңіліс Қасым ханның аймақтағы ықпалын аздап әлсіреткенімен, оның стратегиялық жоспарына айтарлықтай соққы бола қойған жоқ. Ол осы уақытта бар күшті Түркістан аймағын бағындыруға жұмсайды. Түркістан қаласын орталық етіп, әскери істерді өзі басқарып отырады.

1514 жылы Ысмайыл шахтан қашқан Әбілқайыр ұрпақтары қазақтарды мазалайды. Моғолстанның ханы Саид Қасымға әскери одақ ұсынады. Қасым одақтан бас тартып, өзі Әбілқайыр ұрпақтарын Ташкентте жеңеді.

1514 жылы жеңілген Әбілқайыр ұрпақтары Әмір Темірдің шөбересі Бабыр ханды қуады. Соңғысы Солтүстік Үндістанда Ұлы Моғол империясын 1526 жылы құрған болатын. Бұл оқиға қазақ-өзбек арасындағы текетірестің тек Дешті Қыпшақпен шектелмей, бүкіл аймақтың саяси картасын өзгерткенін көрсетеді. Әбілқайыр ұрпақтары Әндіжаннан Саид ханның өзін қуады. Соңғысы Қашқарияда Моғол хандығын құрайды [4]. Осыдан өзбек-қазақ текетіресінің салдарынан басқа билеушілер халқымен жер аударып, Дешті Қыпшақтан тыс өңірде ұлы мемлекеттер құрғанын аңғаруға болады.

1514 жылы Қасым хан Мұхаммед Шайбанидың інісі Махмұд-сұлтанның ұлы Ұбайдолла сұлтанға өз қызын беріп, соғысты тоқтатады. Бұл неке екі жақты татуластыруға бағытталған далалық дипломатия еді. Соғыс тоқтаған соң, Шайбани ұрпақтары Қасымнан Ысмайыл шахқа

қарсы шығып, көмек бергенін қалайды. Қасым өз ұлын Әбілқайырды жібереді. Қазақ әскерінің оң қанатын Байрам аталық, сол қанатын Сары Әділ, ол орталығын Әбілқайырдың өзі басқарды. Мұхаммед Шайбанидың ұлы Мұхаммед Темірдің әскері сол қанаттың артына жайғасты. Ал Ұбайдолла сұлтан әскерлердің соңында орналасты. Шайқаста Байрам аталық пен Әбілқайыр қаза тапты. Біріккен Әбілқайыр және Мұхаммед Шайбанидың ұлы Мұхаммед Темір ханның 160 мыңға жуық әскері Ысмайыл шахқа қарсы шығып, жеңіліске ұшырайды. Бұл шайқасқа атақты Қобыланды да қатысқан еді.

“Алам-ара-йи шах Исмайл” атты еңбекте Ысмайылдың Әбілқайырдың бассүйегін найзаның ұшына қадап, масаттана жеңісті тойлағаны сипатталады [7, 118 б.]. Ұбайдолла сұлтан бастаған 30 мыңға жуық әскер сефевидтердің жерінде қалып қояды. Осы әскердің ұрпақтары кейін қазіргі Әзірбайжан жерінде Қазақ ауданын құрып, Батыс әзірбайжан диалектісінде сөйлейтін этникалық топқа айналды. 1747-1801 жылдар аралығында осы жерде Қазақ сұлтандығы құрылды. Бұл шетелде қазақ диаспорасының қалыптасуының бір ғана мысалы.

Бұл қазақ-өзбек әскерінің үлкен жеңілісі еді. Қасым хан Әбілқайыр сұлтанға егер жауды жеңген жағдайда Түркістандағы билікті оған беретініне уәде берген еді. Жеңілістен соң, бұл уәде орындалмай қалды. “Алам-ара-йи шах Исмайл” еңбегінде Қасым ханда 700 мыңға жуық әскер бар екені айтылады. Бұл Қасым хан тұсында елде 300 мың әскер болды деген басқа деректерге қайшы келетін дерек. Қалай болса да, бұл Қасым хан кезінде Қазақ Ордасының ұшы-қиыры жоқ үлкен аймақтарды бағындырып, ірі мемлекет құрғандығының айқын белгісі. Қасым хан кезінде қазақтың жері шығыстан батысқа қарай Алтайдан Еділге дейін, солтүстіктен оңтүстікке қарай Сібір ормандарынан бастап Түркістан өңіріне дейін созылып жатты.

Қасым хан Сефевидтерді талқандай алмады. Бірақ ол ел Қазақ хандығының тұтастығына қауіп төндірбегендіктен, бұл ой оны мазалай қойған жоқ. Бұл уақытта Шайбани әулетінің оқта-текте шабуылымен қоса, ноғайлардың дүркін-дүркін жорықтары жиілеп кетті. 1516-1517 жылдары Шайбани ұрпақтары Қазақ хандығына шабуылдады. Ноғай мырзасы Алшағыр соны пайдаланып, Ноғай хандығына тиесілі болған Батыс Қазақстандағы жерлерді қайтарды. Қырғыздардың көмегімен Қасым хан бұхарлықтардың тас-талқанын шығарды. Қасым хан Ноғай Ордасына қарсы аттанған кезде, Моғол ханы Саид қырғыздарды бағындырады. Бұл қырғыздардың біраз уақыт бойы моғолдардың қол астында қалуына негіз болады. Қырғыздар аталған оқиғалардан кейін тек Тахир хан тұсында Қазақ хандығына қарайды.

Ноғай Ордасының біраз күшейгеніне қарамастан, 1519 жылы Қасым Ноғай хандығының біраз жерін қайта Қазақ хандығына қосты. Ноғайлар Қырым ханымен бірігіп, Қазақ хандығына соғыс ашқысы келді. Бірақ Астрахань ханы Жәнібек тосқауыл қойып, соғысты болдыртпады. Астрахань ханы соғыста жеңетініне сенбегендіктен, соғысты кейінге шегерді. Бірақ уақыт тым кеш еді. Астрахань ханының саяси мәселелерді шешудегі солқылдақтығы Қасымның көздеген мақсаттарына қол жеткізбеуіне алып келді. 1521 жылы Астрахань ханмен бірігіп, Ноғай мен Қырым хандығына қарсы соғыс бастағысы келген Қасым хан өмірден өтеді [4].

Қасым ханнан кейін оңтүстік-шығыс Қазақстанды Әдік сұлтанның ұлы Тахир 1523-1532 жылдары биледі. 1525 жылы ол Шайбани ұрпақтарына шабуылдады. Бірақ жеңіліске ұшыраған соң, халық тарапынан құғынға ұшырады. Тахир қатігездігімен көзге көрінгендіктен, наразылық білдіргендер Тоғым ханның иеліктеріне қарай көшіп кетті. Бірақ есесіне қырғыздар Тахир ханға бағына бастайды. 1528 жылы Тахир Сефевид еліне қарсы шығып, жеңіліске ұшырайды.

Орталық Қазақстанды Жәдіктің ұлы Тоғым биледі. Сол кезде ең беделді хан Тоғым болады. 1537 жылы Мәуереннахр, Ноғай Ордасы, моғол ханы Абд ар-Рашид бірігіп, Тоғым

ханды жеңеді. Батыс Қазақстанды Қасым ханның ұлы Мамаш хан биледі. Деректер оның Қасымнан кейін бірден билікке келгенін, бірақ бүкіл қазақ жерін біріктіре алмағанын жазады.

Жәнібектің тоғыз ұлының бірі Қожа-Ахмет Батыс Қазақстанды биледі. Хақназар Қасым ханның басқа ұлы Хақназар Ноғай Ордасының сол қанатының басшысы Шейх-Мамайға қызмет етті [1]. Қасым хан өлімінен кейін елде бытыраңқылық орнайды. Қазақ хандығына қарсы ноғайлар, бұхарлықтар және моғолдар тұзақ құрып, мемлекеттілікке үлкен қауіп төндіреді. Тек Қасым ханның ұлы Хақназар хан кезінде ғана қауіп бұлты сейіліп, Қазақ хандығы мемлекеттілігін нығайта алды.

Қорытындылай келе, Қасым хан елді біріктіріп, қазақ жерінің тұтастығы үшін күрескен атышулы хан екенін іс жүзінде көрсете алды. Ол Хиуа, Бұхар хандығы, Моғол хандығы, Қызылбастар елі және Ноғай Ордасымен байланыс орнатып, осы елдердің халықаралық аренада саяси беделін арттыра алды. Қасым хан кезінде қазіргі қазақ елінің шекарасы қалыптасты. Ол Хиуа хандығы, Моғол хандығы, Ұлы Моғол хандығы мен Бұхар хандығының құрылуына тікелей және ішінара септігін тигізді. Оның халықаралық қатынастардағы ықпалын, сірә, асыра бағалау мүмкін емес.

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Economic Sciences

BANKLARDA RİSK İŞTAHASI VƏ STRES TEST NƏTİCƏLƏRİNİN STRATEJİ QƏRARLARDA İSTİFADƏSİ

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Annotasiya. Məqalədə bankın risk iştahası, erkən xəbərdarlıq göstəriciləri və stres-test nəticələrinin strateji qərarlara çevrilməsi araşdırılır. Metod kimi Azərbaycan Mərkəzi Bankının 2025-ci il üzrə sektor məlumatlarının təsviri təhlili, qüvvədə olan normativ sənədlərin müqayisəsi və qərar mexanizminin məntiqi modelləşdirilməsi seçilmişdir. Sektorun kapital və likvidlik göstəriciləri bütövlükdə dayanıqlılığa işarə etsə də, kredit keyfiyyətindəki dəyişikliklər və ssenari üzrə mümkün kapital azalması ayrı-ayrı banklarda daha erkən tədbir görməyi tələb edə bilər. Məqalədə göstərici, dözümlülük zonası, məsul şəxs və cavab tədbiri arasında əlaqəni müəyyən edən tətbiqi çərçivə təklif olunur. Sektor üzrə nəticələrin fərdi banklara avtomatik şamil edilə bilməməsi təhlilin əsas məhdudiyyətidir.
Açar sözlər: bank riski, risk iştahası, stres-test, kapital planlaşdırılması, likvidlik, erkən xəbərdarlıq.

Giriş

Bankın inkişaf planı kredit portfelinin böyüməsini, yeni müştəri qruplarına çıxışı və gəlirliliyin artırılmasını nəzərdə tuta bilər. Həmin planın davamlılığı isə bankın mümkün itkiləri hansı həddə qədər daşıya bilməsindən asılıdır. Kapital və likvidlik göstəriciləri yalnız hesabat dövrünün nəticəsini təsvir etdikdə idarəetməyə məhdud kömək edir; qərar qəbul edən şəxslər planlaşdırılan artımın həmin göstəriciləri əlverişsiz şəraitdə necə dəyişdirəcəyini də bilməlidirlər. Risk iştahası bu sualı bankın məqsədləri ilə üzləşdiyi risklər arasında ölçülə bilən əlaqəyə çevirir. Stres-test isə münasibətin daha ağır şəraitdə qüvvədə qalıb-qalmadığını yoxlamağa imkan verir.

Məqalənin məqsədi Azərbaycan bank sektorunun son müşahidə olunan göstəricilərini nəzərə alaraq risk iştahası ilə stres-test arasındakı əlaqənin strateji qərar qaydasına necə çevrilə biləcəyini izah etməkdir. Təhlil fərdi bankların daxili məlumatlarına söykənən empirik qiymətləndirmə iddiası daşımır. Məqalənin töhfəsi rəsmi sektor göstəricilərini bank səviyyəsində tətbiq edilə biləcək qərar ardıcıllığı ilə əlaqələndirən və bu iki məlumat səviyyəsini aydın ayıran çərçivənin qurulmasıdır.

Tədqiqat materialı və yanaşması

Tədqiqatın əsas məlumat bazasını Azərbaycan Respublikasının Mərkəzi Bankının 2025-ci ilin sonuna aid Maliyyə Sabitliyi Hesabatı təşkil edir. Hüquqi və təşkilati tələblər 2023-cü ildə qəbul edilmiş, sonrakı dəyişiklikləri əks etdirən “Banklarda korporativ idarəetmə Standartları” və 2026-cı ildə təsdiqlənmiş “Banklarda stres-testlərin aparılması Qaydası” əsasında araşdırılmışdır. Müqayisə üçün Maliyyə Sabitliyi Şurasının risk iştahası prinsipləri və Bazel Komitəsinin bank idarəetməsi üzrə prinsipləri götürülmüşdür. Bu sənədlərin PDF mətnləri istinad siyahısında təqdim edilir (AMB, 2023; AMB, 2026a; AMB, 2026b; FSB, 2013; BCBS, 2015).

İlk mərhələdə risk iştahası, riskgötürmə qabiliyyəti və limit anlayışları fərqləndirilmişdir. Daha sonra sektorun kredit, kapital və likvidlik üzrə müşahidə edilən göstəriciləri seçilmiş, 2026–

2027-ci illər üçün stres ssenarisinin nəticələri isə ayrıca qrupda göstərilmişdir. Son mərhələdə göstəricidəki dəyişiklikdən idarəetmə qərarına aparan ardıcıllıq qurulmuşdur. Təklif olunan hədlər rəqəmlə doldurulmur: konkret səviyyə yalnız bankın portfeli, daxili kapital planı, öhdəliklərinin strukturu və prudensial tələblər əsasında müəyyən edilə bilər.

Risk iştahası və qərarların sərhədləri

Mərkəzi Bankın korporativ idarəetmə standartlarında riskgötürmə qabiliyyəti bankın kapital, likvidlik və digər prudensial tələbləri pozmadan daşıya biləcəyi maksimum risk, risk iştahası isə strateji hədəflər naminə həmin qabiliyyət daxilində qəbul etmək istədiyi risk kimi müəyyən edilir. Risk limiti ayrı-ayrı fəaliyyət növləri üzrə maksimal həddi konkretləşdirir (AMB, 2023, s. 3). Deməli, risk iştahası bankın imkanlarının hamısından istifadə etmək öhdəliyi deyil. Prudensial minimumla daxili limit arasında məsafə saxlanması bazar şəraitində dəyişikliklərə cavab vermək üçün yer yaradır.

Risk iştahası bəyannaməsinin təsdiqi özü-özlüyündə qərarların intizamını təmin etmir. Bəyannamə kredit, likvidlik və kapital kimi sahələr üzrə göstəriciləri, onların dözümlülük zonalarını və kənarlaşmaya veriləcək cavabı göstərməlidir. Qüvvədə olan standartlar əhəmiyyətli risklərin tam əhatəsini, biznes strategiyası ilə uyğunluğu və göstəricilərin zonalara uyğunluğunun aylıq monitorinqini nəzərdə tutur (AMB, 2023, s. 17–18). Bu tələblərin əməli mənası odur ki, artım hədəfi təsdiqlənərkən onun yaratdığı mümkün risk də eyni qərarda nəzərə alınmalıdır.

Maliyyə Sabitliyi Şurasının prinsipləri risk iştahasının ümumi bank səviyyəsindən biznes xətlərinə və uyğun hallarda hüquqi şəxslərə ötürülməsini vurğulayır (FSB, 2013, s. 7–9). Məsələn, ümumi kredit artımı hədəfi ayrı-ayrı portfellər üzrə eyni risk həddini əsaslandırmır. İstehlak krediti üzrə gecikmələr sürətləndikdə, bu seqmentin artım limiti yenidən qiymətləndirilə bilər, halbuki başqa seqmentdə keyfiyyət göstəriciləri daha sabit qala bilər. Limitlərin bölüşdürülməsi bir göstəricinin yaxşılaşması ilə başqa sahədə toplanan riskin gizlənməsinin qarşısını almağa xidmət edir.

Bazel Komitəsinin prinsiplərinə görə riskə nəzarət idarəetmə orqanlarının məsuliyyəti, müstəqil risk funksiyası və daxili nəzarətlə əlaqəli qurulmalıdır (BCBS, 2015, s. 8–10, 25). Azərbaycan standartlarında da birinci müdafiə xətti risk yaradan fəaliyyət bölmələrindən, ikinci xətt risk və komplayens funksiyalarından, üçüncü xətt daxili auditdən ibarətdir (AMB, 2023, s. 17). Bu bölgü qərar mexanizmində əhəmiyyətlidir: məhsulu satan bölmə göstəricini izləyir, müstəqil risk funksiyası kənarlaşmanı qiymətləndirir, idarəetmə orqanı isə fəaliyyətin dəyişməsi barədə qərar verir. Daxili audit prosesin işləyib-işləmədiyini ayrıca yoxlayır.

Azərbaycan bank sektorundan müşahidə edilən siqnallar

Mərkəzi Bankın hesabatına əsasən 2025-ci ilin sonunda bank sektorunun aktivləri 57,1 milyard manata çatmışdır. Sektor üzrə kapital adekvatlığı əmsalı 17,6 faiz olmuş, məcmu likvidliyin örtülmə əmsalı 154 faizə, milli valyutada həmin əmsal 127 faizə yüksəlmişdir. Bununla yanaşı, qeyri-işlək kreditlərin həcmi il ərzində artaraq 763 milyon manat, onların ümumi kredit portfelində payı isə 2,5 faiz olmuşdur (AMB, 2026b, s. 12, 17, 23, 37). Bir tərəfdə kapital və likvidlik ehtiyatının, digər tərəfdə kredit keyfiyyətinə dair dəyişən siqnalın görünməsi risk iştahasının bir əmsala endirilməməli olduğunu göstərir.

Cədvəl 1. Azərbaycan bank sektorunda seçilmiş göstəricilər, 2025-ci ilin sonu

Göstərici	Səviyyə	Təhlil üçün mənası
Sektor aktivləri	57,1 mlrd. manat	Balansın miqyasını göstərir; fərdi bankın risk həddi deyil.
Kapital adekvatlığı əmsalı	17,6%	Sektor üzrə müşahidə edilmiş kapital mövqeyidir.
Məcmu likvidliyin örtülmə əmsalı	154%	Qısamüddətli likvidlik mövqeyinə dair sektor göstəricisidir.
Qeyri-işlək kreditlərin payı	2,5%	Kredit keyfiyyətində izlənməli dəyişməni göstərir.

Mənbə: Azərbaycan Respublikasının Mərkəzi Bankı, Maliyyə Sabitliyi Hesabatı 2025 (2026, s. 12, 17, 23, 37).

Cədvəldəki göstəricilər müxtəlif funksiyanı yerinə yetirir. Kapital adekvatlığı əmsalı mümkün itkilərin qarşılanmasına, likvidliyin örtülmə əmsalı qısamüddətli pul çıxışlarına, qeyri-işlək kreditlərin payı isə aktiv keyfiyyətinə dair siqnal verir. Bank üzrə daxili hədd bu sektor rəqəmlərini mexaniki təkrarlamamalıdır. Məsələn, bir bankda depozitlərin az sayda iri müştəridə cəmlənməsi sektor üzrə əlverişli LCR göstəricisinə baxmayaraq əlavə likvidlik ehtiyatını əsaslandıra bilər. Eyni qayda portfelin konkret sahədə cəmlənməsinə və təminatın keyfiyyətinə də aiddir.

Rəsmi hesabatda 2025-ci il ərzində qeyri-işlək istehlak kreditlərinin 58 milyon manat artaraq 305 milyon manata çatdığı və həmin seqment üzrə əmsalın 3,3 faizə yüksəldiyi göstərilir (AMB, 2026b, s. 24). Bu məlumat bütün banklarda eyni riskin yarandığı anlamına gəlmir. Bununla belə, portfel artımını planlaşdıran bank üçün göstəricinin ümumi kredit portfeli ilə yanaşı məhsul və müştəri qrupu səviyyəsində izlənməsinin səbəbini izah edir. Vaxtı keçmiş kreditlərin həcmi, ehtiyatların yetərliliyi və yeni verilən kreditlərin keyfiyyəti birlikdə qiymətləndirilmədikdə tək əmsal gecikmiş xəbərdarlıq verə bilər.

Stres ssenarisindən fəaliyyət qərarına

Stres-test ağır şəraitin bankın kapitalına, likvidliyinə və gəlirinə mümkün təsirini ölçür; o, həmin şəraitin mütləq baş verəcəyini bildirmir. Mərkəzi Bankın 2026-cı il qaydası bankdan likvidlik, kredit, bazar və əməliyyat riskləri üzrə stres-test aparmağı, nəticələr əsasında tədbirlər planı hazırlamağı və nəticələri strateji planla, risk iştahası və limitlərlə əlaqələndirməyi tələb edir (AMB, 2026a, s. 3, 6–7). Qayda həmçinin məlumatın keyfiyyətini, modelin müstəqil yoxlanmasını və tərs stres-test imkanını nəzərdə tutur (AMB, 2026a, s. 3–4).

Sektor üzrə 2025-ci il hesabatının pessimist ssenarisində kapital adekvatlığı əmsalı 2026-cı il üçün 14,8 faiz, 2027-ci il üçün 13,6 faiz hesablanmışdır. Həmin hesabat pessimist ssenarinin rəsmi iqtisadi proqnoz olmadığını açıq bildirir. Hesablamada bankların dividend ödəmədiyi fərziyyəsi də tətbiq edilmişdir (AMB, 2026b, s. 45–46). Bu rəqəmlər 2025-ci ilin müşahidə edilmiş 17,6 faizlik sektor göstəricisi ilə eyni tip məlumat deyil: biri faktiki hesabat göstəricisi, digərləri şərti ssenarinin nəticəsidir. Buradakı fikir sektor əmsalının hansı səviyyədə qalacağını əvvəlcədən söyləmək deyil, kapital ehtiyatının planlaşdırılmasında şokun mümkün təsirini nəzərə almaqdır.

İdarəetmə baxımından stres-test nəticəsi üç sualı cavablandırmalıdır. Birincisi, mənfi dəyişiklik ən çox hansı portfel və ya maliyyələşmə mənbəyindən yaranır? İkincisi, təsir baş verdikdə daxili dözümlülük zonasına və prudensial tələblərə qədər nə qədər ehtiyat qalır? Üçüncüsü, hansı tədbir risk profilini ölçülə bilən vaxt ərzində qəbul olunan zonaya qaytara bilər? Cavabın yalnız proqnoz əmsalından ibarət olması büdcə, kredit siyasəti və maliyyələşmə planı haqqında qərar vermək üçün kifayət etmir.

Qərar mexanizmi üçün əvvəlcə hər göstərici üzrə normal zona, xəbərdarlıq zonası və limit pozuntusu zonası müəyyənləşdirilir. Daxili hədlər riskgötürmə qabiliyyətindən aşağı seçilir və

bankın balansına uyğun sənədləşdirilir. Xəbərdarlıq zonasında yeni kreditlərin keyfiyyəti və depozitlərin davranışı daha sıx yoxlanır; limit pozuntusunda isə əvvəlcədən təsdiqlənmiş səlahiyyət qaydasına uyğun portfel artımı, qiymət siyasəti və likvidlik ehtiyatı nəzərdən keçirilir. Ssenari nəticəsi bankın mövcud limiti pozmasa belə, gələcək dövrdə pozuntu göstərəndə büdcə və kapital planına düzəliş edilməsi əsaslıdır. Bu təklif standartlarda nəzərdə tutulan dözümlülük zonası və kənarlaşmaya cavab məntiqinin əməli tətbiqidir (AMB, 2023, s. 18; AMB, 2026a, s. 3–4).

Cədvəl 2. Risk göstəricisindən qərara keçid üçün təklif olunan sxem

İzlənən siqnal	Yoxlanacaq əlaqə	Mümkün idarəetmə addımı
Kredit keyfiyyətinin pisləşməsi	Yeni kreditlərin keyfiyyəti, sektor cəmləşməsi, ehtiyatlar	Riskli seqmentdə artım planını və qiymət şərtlərini yenidən qiymətləndirmək
Likvidlik ehtiyatının azalması	Depozit axınları, iri müştəri asılılığı, yüksək keyfiyyətli likvid aktivlər	Maliyyələşmə mənbələrini genişləndirmək və ehtiyat səviyyəsini artırmaq
Stres altında kapitalın azalması	Zərər kanalları, risk üzrə ölçülmüş aktivlər, kapital buferi	Kapital planına və dividend barədə fərziyyələrə yenidən baxmaq
Limitin pozulması	Səbəb, davamlılıq və məsul bölmə	Komitəyə çatdırmaq və tədbirin icrasını izləmək

Mənbə: Müəllifin AMB-nin korporativ idarəetmə standartları və stres-test qaydası əsasında hazırladığı tətbiqi sxem (AMB, 2023, s. 17–18; AMB, 2026a, s. 3–4). Cədvəldə göstərilən addımlar bütün banklar üçün eyni məcburi limitləri ifadə etmir.

Bu sxemin işləməsi üçün bankda risk idarəetmə bölməsinin çıxardığı nəticə qərar verən orqana vaxtında çatmalıdır. Risk göstəricisi dəyişdikdən bir neçə ay sonra hazırlanan geniş hesabat erkən xəbərdarlıq funksiyasını itirə bilər. Ona görə qısa aylıq monitorinq, ayrıca dərin ssenari təhlili və qərarın icrası üzrə sonrakı yoxlama bir-birini tamamlamalıdır. Mövcud standartlarda bəyannamənin göstəriciləri üzrə aylıq monitorinq tələbi və risk limitlərinin davamlı izlənməsi bu əlaqə üçün normativ əsas yaradır (AMB, 2023, s. 18).

Qərar mexanizminin tətbiq nümunəsi

Tətbiq ardıcıllığını istehlak kreditləri üzrə artım planı nümunəsində izləmək olar. Bank növbəti il üçün yeni kredit həcmini müəyyənləşdirərkən əvvəlcə öz portfelində ilkin gecikmə əlamətlərini, kredit alanların borc yükünü və müəyyən məhsullarda cəmləşməni təhlil etməlidir. Sektor üzrə 2025-ci ildə istehlak kreditlərinin qeyri-işlək hissəsinin artması ayrıca yoxlama aparmaq üçün səbəbdir; bunun konkret bankda eyni tendensiyanın mövcud olduğunu göstərdiyi iddia edilmir. Bankın daxili məlumatları riskin artdığını təsdiqləyirsə, artım hədəfinin hesablanması yalnız keçmiş gəlirliliyə əsaslana bilməz. Təxmini itkilər, ehtiyatlara ehtiyac və həmin portfelin kapital istifadəsi də qərara daxil edilir.

Növbəti addımda bank öz portfelinə uyğun əlverişsiz ssenari qurur: gəlirlərin zəifləməsi borcalanların ödəniş intizamına, gecikmələrin artması isə mümkün itkilərə və kapitala təsir edir. Eyni vaxtda depozitlərin azalması fərz edilərsə, kredit artımı ilə likvidlik ehtiyatı arasında ziddiyyət yarana bilər. Bu əlaqələr modelləşdirildikdən sonra rəhbərlik başlanğıc planı, daha yavaş artım və kredit şərtlərinin dəyişdirilməsi kimi variantları müqayisə edir. Variantların hər biri üzrə risk iştahası zonasına uyğunluq ayrıca göstərilir. Seçilmiş addımın icra müddəti və yenidən baxılma şərti əvvəlcədən qeydə alındıqda stres-test real qərarın yoxlanıla bilən hissəsinə çevrilir.

Bu nümunədə qərarın nəticəsi barədə rəqəm verilməməsi qəsdəndir: bankın daxili məlumatları olmadıqda konkret itki, həddvə ya gəlirlilik göstəricisi hesablamaq əsaslı olmazdı. Nümunə metodun məntiqini göstərir. Onun faydası ssenaridə nəzərdə tutulan şokun həmin bank üçün mümkünlüyü, məlumatların keyfiyyəti və sonradan görülmüş tədbirin ölçülməsi ilə yoxlanmalıdır.

Məlumat keyfiyyəti və təhlilin sərhədləri

Düzgün qərar yalnız giriş məlumatları etibarlı olduqda mümkündür. Bank bir müştərinin müxtəlif məhsullar üzrə öhdəliklərini birləşdirə bilmədikdə, kreditin təminatı vaxtında yenilənmədikdə və ya öhdəliklərin müddət strukturu natamam olduqda stres-test nəticəsinin dəqiqliyi azalır. Mərkəzi Bankın yeni qaydası məlumat mənbələrinin uzlaşdırılmasını, uyğunsuzluqların təhlilini, qeyri-dəqiq müşahidələrin aşkar edilməsini və mənbələrin etibarlılığının sənədləşdirilməsini nəzərdə tutur (AMB, 2026a, s. 4). Bu tələblər rəqəmsal infrastrukturun keyfiyyəti ilə maliyyə qərarının keyfiyyəti arasındakı birbaşa əlaqəni göstərir.

Məlumatların çoxluğu özlüyündə daha yaxşı proqnoz yaratmır. Keçmişdə müşahidə edilməmiş şokları yalnız tarixi itkilərə əsaslanan model zəif əhatə edə bilər. Modelin qurulmasına cəlb olunmayan şəxslər tərəfindən validasiya və ssenarilərin müntəzəm yenilənməsi bu zəifliyi azaltmağa yönəlir (AMB, 2026a, s. 3–4, 6). Eyni zamanda kredit, bazar və likvidlik şoklarını tamamilə ayrı qiymətləndirmək ümumi təsiri aşağı göstərə bilər: kredit itkisi kapitalı azaldarkən, etimadın zəifləməsi likvidliyə də təzyiq göstərə bilər. Qayda likvidlik stres-testində digər risklər üzrə nəticələrin nəzərə alınmasını da tələb edir (AMB, 2026a, s. 6).

Bu tədqiqatın başlıca məhdudiyyəti banklar üzrə mikro məlumatların, daxili limitlərin və fərdi stres-test modellərinin açıq olmamasıdır. Buna görə təqdim olunan qərar sxeminin müəyyən bir bankda maliyyə itkisini nə qədər azaltdığı hesablanmamışdır. Sektor üzrə kapital və likvidlik göstəriciləri banklar arasındakı fərqləri gizlədə bilər; makro ssenarinin nəticəsi də konkret bankın balansına köçürülə bilməz. Çərçivənin sonrakı tətbiqi üçün bank səviyyəsində portfel və pul axını məlumatları ilə ölçülən nəticələri müqayisə edən ayrıca empirik tədqiqat tələb olunur.

Nəticə

Təhlil göstərir ki, risk iştahası bankın strateji məqsədlərini ölçülə bilən risk sərhədlərinə bağlayanda idarəetmə alətinə çevrilir. Stres-test həmin sərhədlərin əlverişsiz şəraitdə nə qədər davamlı qalacağını yoxlayır. Rəsmi sektor məlumatlarında 2025-ci ilin sonunda kapital və likvidlik mövqeyi güclü görünsə də, qeyri-işlək kreditlərin artımı bütün göstəricilərə eyni istiqamətdə baxmağın doğru olmadığını göstərir. Sektorun dayanıqlığı barədə ümumi nəticə fərdi bankın risk profilini əvəz etmir.

Təklif edilən tətbiq ardıcıllığı bankın risk iştahası üzrə göstəriciləri və dözümlülük zonalarını müəyyən etməsi, portfel səviyyəsində erkən siqnalları izləməsi, stres-testdən sonra kapital və likvidlik ehtiyatını yenidən hesablaması, limitə yaxınlaşmanı səlahiyyətli orqana çıxarması və qəbul edilmiş tədbirin nəticəsini yoxlamasıdır. Bu ardıcıllıq normativ tələbləri bankın real büdcə və məhsul qərarları ilə əlaqələndirir. Müxtəlif ölçülü banklar üçün konkret hədlər ayrıca əsaslandırılmalıdır; məqalədə göstərilən sektor rəqəmləri belə hədlərin hazır norması kimi istifadə edilə bilməz.

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МАРКЕТИНГОВАЯ ЛОГИСТИКА В СИСТЕМЕ ПРОДВИЖЕНИЯ И РАСПРЕДЕЛЕНИЯ ПРОДУКЦИИ ПРОМЫШЛЕННОГО ПРЕДПРИЯТИЯ

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Аннотация

В статье рассматривается роль маркетинговой логистики в продвижении и распределении продукции промышленного предприятия на примере ТОО «QazTehna» — казахстанского производителя автобусной и коммерческой техники. Актуальность исследования обусловлена тем, что в промышленном маркетинге конкурентоспособность определяется не только характеристиками продукции и ценой, но и способностью предприятия своевременно доводить продукцию до корпоративного потребителя, обеспечивать необходимый уровень сервиса и поддерживать устойчивые информационные связи. Систематизированы теоретические подходы к маркетинговой логистике как результату интеграции маркетинговых и логистических функций. На основе открытых данных QazTehna и материалов предприятия проанализированы ассортимент, производственные возможности, развитие локализации, каналы взаимодействия с корпоративными заказчиками и особенности распределения продукции. Предложены направления совершенствования маркетингово-логистического взаимодействия и система показателей его оценки.

Ключевые слова

Маркетинговая логистика, промышленный маркетинг, распределение, продвижение, каналы сбыта, логистический сервис, коммерческий транспорт, B2B-маркетинг, qaztehna, Казахстан.

Введение

Современная деятельность промышленного предприятия предполагает одновременное решение нескольких взаимосвязанных задач: изучение рынка, формирование востребованного продуктового предложения, продвижение продукции, организация ее распределения и обеспечение необходимого уровня обслуживания потребителей. Особенно ярко данная взаимосвязь проявляется на рынке транспортного машиностроения, где продукция отличается высокой стоимостью, технической сложностью, длительным сроком эксплуатации и зависимостью потребителя от своевременности поставки техники, запасных частей и сервисных услуг.

В традиционном подходе маркетинг и логистика нередко рассматриваются как самостоятельные функциональные области. Однако исследования показывают, что их координация непосредственно связана с качеством обслуживания клиентов и эффективностью распределения. Интеграция маркетинговых и логистических функций позволяет согласовывать рыночный спрос с производственными и распределительными возможностями предприятия [1; 2].

Для промышленного предприятия недостаточно определить, какой товар необходим потребителю. Необходимо обеспечить его наличие в нужное время и в нужном месте, согласовать характеристики заказа с производственными возможностями, организовать поставку и последующее обслуживание. Поэтому маркетинговая логистика становится связующим звеном между рынком и производством.

Практический интерес представляет деятельность ТОО «QazTehna», расположенного в индустриальной зоне города Сарани Карагандинской области. Предприятие производит автобусную и коммерческую технику; его портфель включает автобусы Yutong, а также коммерческую технику Sinotruk и Scania [3; 4].

Цель статьи — обобщить теоретические подходы к маркетинговой логистике и на их основе проанализировать особенности продвижения и распределения продукции ТОО «QazTehna», а также определить направления совершенствования маркетингово-логистического взаимодействия предприятия.

Маркетинговая логистика сформировалась на пересечении маркетинга и логистики. Маркетинг ориентирован на выявление и удовлетворение потребностей рынка, формирование ценностного предложения и управление отношениями с потребителями. Логистика обеспечивает управление материальными, информационными и связанными с ними потоками, необходимыми для физического доведения продукции до потребителя.

В учебной и научной литературе маркетинговая логистика рассматривается как планирование, реализация и контроль физического движения материалов и готовой продукции от места происхождения к месту использования с учетом требований клиентов и затрат предприятия [5]. В системном понимании она охватывает также координацию материальных, информационных и финансовых потоков между поставщиками, предприятием, посредниками и конечными пользователями.

Исследования интеграции маркетинга и логистики показывают, что обе функции имеют общую ориентацию на потребительский сервис. Маркетинг формирует понимание того, что необходимо клиенту, а логистика определяет, каким образом обеспечить выполнение этого требования с приемлемыми затратами. Поэтому качество обслуживания становится одним из ключевых элементов их интеграции [1; 2].

Важен переход от функционального к интегрированному пониманию маркетинговой логистики. При функциональном подходе транспортировка, складирование, управление запасами, продажи и продвижение могут оцениваться отдельно. При интегрированном подходе анализируется вся цепочка создания ценности: от возникновения потребности до исполнения заказа и послепродажного обслуживания.

Для промышленного предприятия эта цепочка может быть представлена так: исследование рынка → сегментация клиентов → формирование продуктового предложения → продвижение → получение и обработка заказа → планирование производства и комплектации → распределение и доставка → сервисное сопровождение → обратная связь → повторное взаимодействие с клиентом.

Потребительский сервис может выступать объединяющим элементом маркетинга и логистики [2]. Для промышленного клиента он включает доступность продукции, качество и точность поставки, соответствие количества и комплектации заказу, информационное сопровождение и способность поставщика реагировать на проблемы.

Следовательно, маркетинговая логистика должна оцениваться не только через логистические затраты. Снижение затрат не является положительным результатом, если оно приводит к ухудшению уровня обслуживания. Целевым является такое соотношение затрат и сервиса, при котором предприятие выполняет требования сегмента и сохраняет экономическую эффективность.

Современные исследования развивают данный подход, рассматривая маркетинговую логистику как интегрированную систему управления, ориентированную на создание потребительской ценности, устойчивость цепей поставок и цифровизацию процессов [6; 7].

Маркетинг и логистика в системе промышленного B2B-рынка. На B2B-рынках решение о приобретении промышленной продукции обычно принимается организацией и может включать формирование технического задания, сравнение предложений, оценку стоимости владения, согласование условий поставки, заключение договора и контроль исполнения.

Поэтому продвижение промышленной продукции не ограничивается рекламой. Для потенциального заказчика важны техническая документация, характеристики модели, сроки изготовления и поставки, возможность адаптации продукции, сервисная поддержка и запасные части. Логистическая информация становится частью маркетингового предложения.

Потребности различных категорий покупателей неодинаковы. Транспортная организация может уделять особое внимание пассажировместимости, экономичности, надежности и сервису, тогда как промышленное или горнодобывающее предприятие может быть заинтересовано в специализированной коммерческой технике, грузоподъемности и эксплуатационной приспособленности.

Следовательно, единая модель распределения не всегда обеспечивает одинаковую ценность для всех клиентов. Сегментация должна распространяться не только на рекламные сообщения, но и на условия заказа, логистический сервис, сроки поставки и последующее обслуживание. Различия в требованиях к сервису могут использоваться как основа сегментации промышленных клиентов [8].

Для дорогостоящей техники момент продажи не завершает взаимодействие. После поставки возникают сервисные, гарантийные, ремонтные и снабженческие процессы. Поэтому устойчивость клиентских отношений зависит от совокупного опыта взаимодействия с поставщиком.

Производственный и рыночный потенциал ТОО «QazTehna». ТОО «QazTehna» расположено в индустриальной зоне города Сарани Карагандинской области. Строительство предприятия началось в 2019 году; были восстановлены и модернизированы 40,5 тыс. кв. м производственных и складских помещений. В декабре 2020 года запущен цех крупноузловой сборки автобусов, а в июне 2021 года — мелкоузловое производство [3; 4].

Согласно официальному сайту QazTehna, площадь предприятия составляет 40 500 кв. м, численность персонала — 840 человек, заявленная рыночная доля за 2024 год — 68%. Производственная мощность указана на уровне 1 200 автобусов и 10 000 единиц коммерческой техники в год [3].

Производственный портфель включает городские, туристические, междугородние и специальные автобусы Yutong, а также коммерческую технику Sinotruk и Scania. На сайте отдельно представлены электрические автобусы [4].

Динамика выпуска показывает расширение деятельности: 165 единиц техники в 2021 году, 568 — в 2022 году, 1 579 — в 2023 году и 1 576 — в 2024 году. На сайте также указан план на 2025 год: 1 560 единиц автобусной техники и 2 139 единиц коммерческой техники [3].

Развитие производства сопровождается локализацией. По данным предприятия, фактический уровень локализации составляет 36,08%, при этом поставлена задача увеличить долю казахстанского содержания до 50% [3]. В 2025 году реализовывался инвестиционный проект стоимостью 4 млрд тенге по созданию цеха изготовления и штамповки деталей обшивки автобусов и коммерческой техники [9].

Для маркетинговой логистики локализация имеет двойное значение: она может выступать характеристикой отечественного продукта и одновременно способствовать большей управляемости отдельных участков цепи поставок.

Продвижение промышленной техники имеет информационно-консультационный характер. На официальном сайте QazTehna представлены модели автобусов и коммерческой техники, технические характеристики, категории продукции и контакты отдела продаж [4]. Цифровой канал выполняет функцию не только повышения узнаваемости, но и первичного контакта потенциального клиента с продуктовым предложением.

Для промышленного покупателя важна информация, необходимая для принятия решения. Поэтому цифровое представление продукции следует рассматривать как часть маркетинговой логистики: данные о модели, технических параметрах и возможностях предприятия снижают неопределенность на стадии формирования заказа.

Расширение продуктового предложения позволяет ориентировать коммуникации на различные сценарии эксплуатации. На сайте выделены городские, туристические, междугородние, электрические и специальные автобусы, а также коммерческая техника [4].

В материалах предприятия отмечается наличие в автобусах навигации, видеонаблюдения, бесконтактной оплаты проезда, кондиционирования и оборудования для посадки и высадки маломобильных пассажиров [3]. Для маркетинга это возможность формировать предложение вокруг конкретных выгод для эксплуатирующей организации.

Эффективность продвижения целесообразно связывать с коммерческими и логистическими результатами: количество обращений - с коммерческими предложениями, договорами, поставками и повторными заказами.

Для QazTehna характерен преимущественно B2B-характер распределения. Основными потребителями продукции, согласно предоставленной справке, являются транспортные, промышленные и горнодобывающие предприятия Казахстана; автобусы производства предприятия эксплуатируются во всех регионах страны [10]. Это предполагает прямые договорные отношения и институциональные каналы закупок.

Реальным подтверждением участия предприятия в крупных закупках являются данные Портала государственных закупок Республики Казахстан. В одном из опубликованных договоров поставщиком автобусов указано ТОО «QazTehna»; плановая сумма лота составила 14,994 млрд тенге, сумма предмета договора без НДС — 14,943 млрд тенге [11].

Другой пример относится к корпоративному сектору. В документах электронного портала закупок АО «Самрук-Қазына» QazTehna указано поставщиком автобуса для ТОО «ОЙЛ ТРАНСПОРТ КОРПОРЕЙШЭН»; техническая спецификация предусматривает пригородный автобус класса 3 вместимостью до 40 мест [12].

Таким образом, распределительную систему QazTehna можно рассматривать как сочетание государственных закупок, корпоративных закупок и прямых договоров с организациями. Каждый канал предъявляет собственные требования к документальному сопровождению, техническому соответствию, срокам и процедуре согласования.

В условиях расширения ассортимента коммерческой техники значение B2B-каналов возрастает. Для грузовых автомобилей и специализированной техники важны не только характеристики машины, но и возможность обеспечить поставку, комплектность, сервис и запасные части.

В промышленном маркетинге логистический сервис является частью потребительской ценности. Для клиента важен не только факт приобретения техники, но и возможность эксплуатировать ее с минимальными простоями. Поэтому маркетинговая логистика должна включать процессы после передачи продукции заказчику.

К ним относятся гарантийное и сервисное обслуживание, поставка запасных частей, консультационная поддержка, обработка обращений и обратная связь. С позиции маркетинга они формируют опыт взаимодействия клиента с брендом, а с позиции логистики требуют управления запасами, информацией и сервисными ресурсами.

Для QazTehna это особенно актуально из-за территориального охвата рынка. Если техника эксплуатируется в разных регионах Казахстана, организация сервиса требует учета географии клиентов, времени доставки запасных частей и доступности специалистов.

Целесообразно сегментировать сервисное предложение: для крупных корпоративных клиентов могут использоваться индивидуальные условия сопровождения, для региональных заказчиков — стандартизированные сервисные пакеты, а для крупных автопарков — планирование технического обслуживания с учетом эксплуатации.

При этом следует различать показатели физического исполнения логистического процесса и маркетинговые результаты. Поставка в согласованный срок является логистическим показателем, а готовность клиента продолжить сотрудничество — маркетинговым результатом. Их совместный анализ позволяет оценивать влияние сервиса на отношения с клиентом.

Локализация как фактор маркетингово-логистической эффективности. Развитие локализации QazTehna имеет значение не только для промышленной политики, но и для маркетинговой логистики. Фактический уровень локализации, по данным предприятия, составляет 36,08%, а целью является увеличение доли казахстанского содержания до 50% [3].

В июне 2025 года QazTehna сообщил о реализации инвестиционного проекта стоимостью 4 млрд тенге по созданию цеха изготовления и штамповки деталей обшивки автобусов и коммерческой техники; проект направлен на увеличение доли местного содержания [9].

Локализация может влиять на маркетинговое предложение: отечественное производство может быть значимо для организаций, ориентированных на приобретение казахстанской продукции, а развитие местной компонентной базы потенциально повышает управляемость цепи поставок.

Одновременно рост локализации требует развития закупочной и складской логистики. Расширение сети отечественных поставщиков означает необходимость координации качества, сроков, объемов партий и надежности контрагентов.

Отметим направления совершенствования маркетинговой логистики QazTehna.

Первое направление - углубление сегментации корпоративных клиентов. Для транспортных предприятий, промышленных компаний, горнодобывающих организаций и государственных заказчиков могут формироваться отдельные продуктовые и сервисные предложения.

Второе направление - интеграция данных маркетинга и производства. Информация о спросе, обращениях и перспективных заказах должна сопоставляться с мощностями, доступностью комплектующих и графиками выпуска.

Третье направление - цифровизация клиентского взаимодействия. Сайт предприятия уже выполняет функцию презентации продукции и первичного контакта. Его дальнейшее развитие может включать электронный запрос коммерческого предложения, фильтрацию моделей по назначению, отслеживание статуса обращения и электронное сервисное обращение.

Четвертое направление - развитие сервисной логистики. Для ключевых сегментов целесообразно определить нормативы времени реакции на обращение, сроки поставки основных запасных частей и порядок обработки гарантийных случаев.

Пятое направление — единая система KPI маркетинга и логистики. Подразделения должны оцениваться не только по собственным показателям, но и по совместному результату - качеству выполнения заказа и сохранению клиента.

Рассмотрим систему показателей маркетинговой логистики. Для практической оценки предлагаемой системы можно использовать следующие показатели: количество квалифицированных обращений корпоративных клиентов; конверсия коммерческих предложений в договоры; средний срок выполнения заказа; доля поставок в согласованный срок; среднее время реакции на сервисное обращение; доступность ключевых запасных частей; доля повторных заказов; доля обращений через цифровые каналы; доля отечественных компонентов.

Такая система позволяет оценивать маркетинговую логистику как единую цепочку. Рост количества обращений сам по себе не свидетельствует о повышении эффективности, если он не сопровождается ростом заключенных договоров и качественным исполнением поставок. Аналогично снижение логистических затрат не должно оцениваться отдельно от сроков и качества обслуживания.

На основе теоретических положений и анализа практики предприятия предлагается рассматривать маркетинговую логистику QazTehna как последовательность: изучение потребностей целевого сегмента → формирование продуктового предложения → продвижение и коммуникация → получение заказа → согласование технических параметров → планирование производства и комплектации → доставка → ввод техники в эксплуатацию → сервисное сопровождение → обратная связь → повторное взаимодействие.

Такая модель отличается от узкого понимания распределительной логистики тем, что начинается на этапе формирования рыночного предложения. Это позволяет учитывать влияние требований клиентов на ассортимент и характеристики продукции.

Для QazTehna обратная связь от клиентов имеет значение в связи с расширением продуктового портфеля и развитием локализации. Информация об эксплуатационных проблемах, востребованных характеристиках, требованиях к сервису и запасным частям может использоваться при планировании производства и развитии продуктовой линейки.

Таким образом, маркетинговая логистика выступает механизмом двусторонней связи: маркетинг передает в производственно-логистическую систему информацию о спросе, а логистика обеспечивает маркетинг данными о реальных возможностях производства, запасах, сроках и исполнении заказов.

Заключение

Теоретический анализ показывает, что маркетинговая логистика представляет собой систему координации маркетинга и логистики вокруг потребительской ценности и качества обслуживания. Для промышленного предприятия это особенно важно, поскольку решение о покупке определяется не только характеристиками товара, но и условиями поставки, надежностью поставщика, сервисным сопровождением и совокупными затратами эксплуатации.

На примере ТОО «QazTehna» установлено, что предприятие располагает значительным производственным и ассортиментным потенциалом: развивает выпуск автобусной и коммерческой техники, расширяет продуктовый портфель, развивает локализацию и работает с различными категориями корпоративных заказчиков. Открытые данные предприятия указывают на выпуск 1 576 единиц техники в 2024 году, заявленную рыночную долю 68% за 2024 год и фактический уровень локализации 36,08% [3].

Практический анализ показывает, что распределение продукции QazTehna осуществляется преимущественно в B2B-среде. Реальные документы государственных и корпоративных закупок подтверждают участие предприятия в поставках автобусов различным организациям [11; 12]. Поэтому актуальны вопросы точности коммерческих предложений, сроков поставки, технического соответствия продукции и последующего сервиса.

В качестве основных направлений совершенствования предложены сегментация корпоративных клиентов, интеграция маркетинговой и производственной информации, цифровизация взаимодействия, развитие сервисной логистики и внедрение единой системы KPI.

Дальнейшее исследование может включать эмпирический анализ клиентов QazTehna: изучение критериев выбора поставщика, значимости цены, технических характеристик, сроков поставки, локализации, сервисного обслуживания и цифровой коммуникации. Это позволит количественно определить факторы, наиболее значимые для корпоративных заказчиков, и перейти к обоснованию конкретного механизма совершенствования маркетинговой логистики предприятия.

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Biological Sciences

Drug Synergy and Antagonism: Molecular and Cellular Mechanisms of Drug Combination Effects

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Abstract
The combined administration of therapeutic agents is a foundational strategy of modern pharmacology, yet the distinction between a clinically successful drug combination and a harmful or ineffective one rests on complex molecular and cellular phenomena. This review synthesizes current understanding of drug synergy and antagonism, beginning with the quantitative frameworks, including Loewe additivity, Bliss independence, the combination index method, and isobolographic analysis, that allow synergism and antagonism to be defined and measured in a scientifically rigorous manner. The molecular and cellular mechanisms that generate supra-additive or sub-additive effects are then examined across therapeutic domains. In oncology, synergy arises from parallel pathway blockade, synthetic lethality, DNA damage response manipulation, apoptotic priming, and reversal of multidrug resistance; in infectious disease, it emerges from sequential blockade of biosynthetic pathways, enhanced intracellular drug accumulation, and drug-induced sensitization. Pharmacokinetic mechanisms, including cytochrome P450 inhibition and induction, transporter-mediated interactions, and altered distribution, are distinguished from true pharmacodynamic interactions at target level. Antagonism, long considered a purely undesirable outcome, is analyzed mechanistically and reinterpreted in light of evolutionary studies showing that antagonistic interactions can restrain the emergence of resistance. Systems-level perspectives, including network pharmacology and higher-order interaction analysis, are integrated throughout. Finally, the methodological pitfalls that afflict combination studies, the challenges of clinical translation, and emerging strategies for rational combination design are critically appraised. A central conclusion is that synergy is not a property of two molecules alone but of a drug pair acting within a defined biological, genetic, and physiological context.

Keywords
drug synergy; antagonism; combination therapy; combination index; Loewe additivity; Bliss independence; synthetic lethality; pharmacokinetic interactions; network pharmacology; drug resistance

Introduction: The Rationale for Drug Combination Therapy

Monotherapy with a single pharmacological agent is rarely sufficient to cure complex, heterogeneous, or adaptable diseases. Infectious pathogens mutate under drug pressure, tumors rewire their signaling networks, and chronic diseases such as hypertension involve multiple, partially redundant physiological control systems. Combination therapy addresses these limitations simultaneously: it widens the spectrum of vulnerable targets, retards the evolution of resistance, permits dose reduction of toxic individual components, and can produce therapeutic effects that no constituent drug achieves alone (Mokhtari et al., 2017). The clinical record of combination chemotherapy in testicular cancer and childhood leukemia, triple antiretroviral therapy in HIV infection, and multi-drug regimens in tuberculosis testifies to the transformative power of well-designed combinations.

At the same time, combining drugs is far from universally beneficial. Combinations add toxicity, complicate dosing, and can interact in ways that reduce the efficacy of each agent. An interaction that appears synergistic in one cellular background may be antagonistic in another, and several widely used combinations owe their clinical benefit not to true synergy but to simpler properties such as independent drug action or passive additivity (Plana et al., 2022). Understanding when and why two drugs synergize or antagonize therefore requires both rigorous quantitative definitions and a mechanistic account of what happens inside cells and organisms when two perturbations co-occur.

The aim of this review is to provide such an integrated account. The first sections define the quantitative frameworks on which all claims of synergy or antagonism must rest, since without a reference model of no interaction the very concepts are meaningless (Foucquier & Guedj, 2015). The middle sections examine molecular and cellular mechanisms, first pharmacokinetic and then pharmacodynamic, that produce synergy in oncology, microbiology, and chronic disease management. Subsequent sections analyze the mechanisms and consequences of antagonism, including the counterintuitive evolutionary advantages that antagonistic interactions can confer. The review closes with systems-level perspectives, translational challenges, and methodological recommendations (Fig. 1).

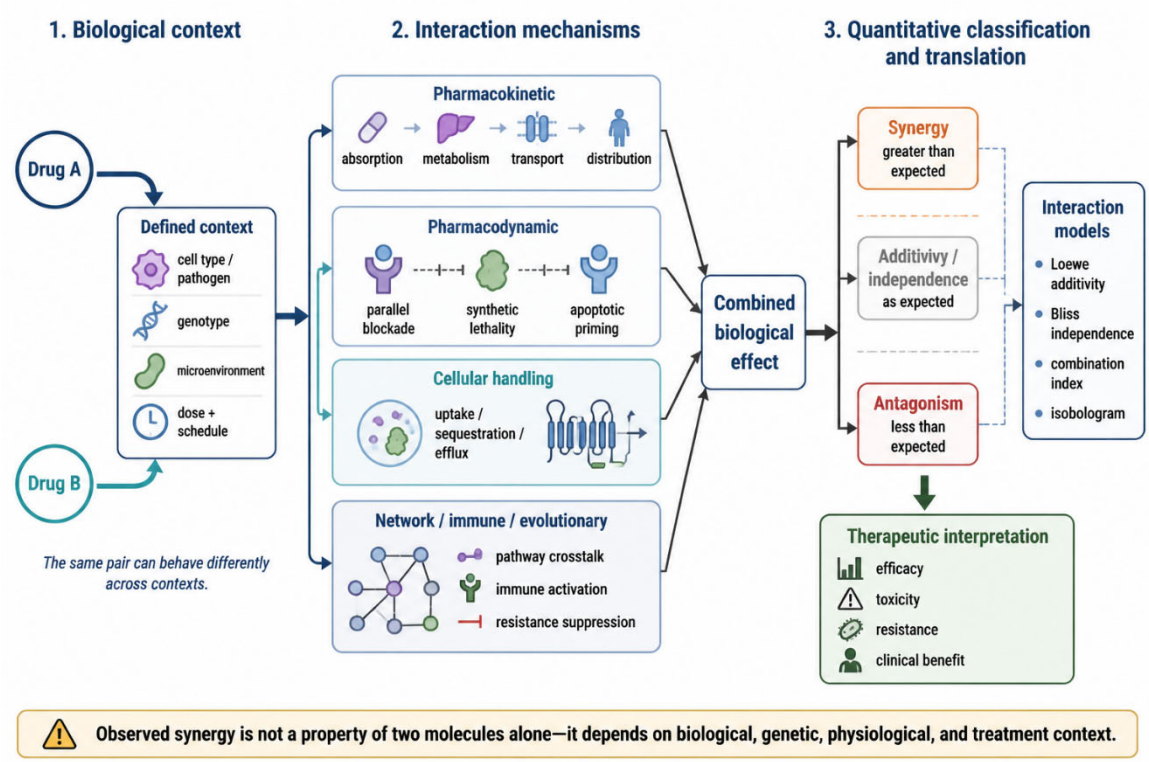

Figure 1. Context-dependent framework for drug combination effects. Drug A and Drug B act within a defined biological context that includes the cell type or pathogen, genetic background, microenvironment, and dosing schedule. Their combined effect may arise through pharmacokinetic mechanisms, pharmacodynamic interactions at receptors and signaling pathways, altered cellular drug uptake or efflux, and broader network, immune, or evolutionary processes. These mechanisms converge to produce the observed combined biological effect. Quantitative approaches—including Loewe additivity, Bliss independence, the combination index, and isobolographic analysis—classify the interaction as synergistic, additive or independent, or antagonistic. The therapeutic meaning of the interaction must then be evaluated in relation to efficacy, toxicity, resistance, and clinical benefit. Thus, synergy or antagonism is not an intrinsic property of two molecules alone, but an emergent feature of their action within a specific biological and treatment context.

Historical and Conceptual Foundations of Drug Interaction Analysis

The formal study of drug interactions predates modern molecular pharmacology by more than a century. In the nineteenth century, Fraser observed that the mydriatic effects of atropine and calabar bean were not additive, initiating a debate about how combined drug effects should be interpreted. The central conceptual problem, articulated repeatedly since then, is that observed combined effects must be compared against an expected effect calculated under some null hypothesis of no interaction. Different null hypotheses are defensible, and this plurality of reference models remains the single largest source of confusion and contradiction in the synergy literature (Foucquier & Guedj, 2015).

Two null hypotheses dominate. The first, Loewe additivity, asks what effect two drugs would produce if they were, in effect, two doses of the same drug scaled to their individual potencies. The second, Bliss independence, asks what effect two drugs would produce if they acted through entirely independent probabilistic mechanisms, so that the probability of the combined response equals one minus the probability that neither drug achieves its individual effect. Loewe additivity is the more stringent model and is generally preferred when both agents act on the same target or pathway, whereas Bliss independence is more natural when agents act through distinct mechanisms (Tallarida, 2012). Because the two reference surfaces differ, the same data set can be judged synergistic under Bliss independence and approximately additive under Loewe

additivity; accordingly, any claim of synergy is incomplete without a statement of the reference model, the effect level, and the dose ratio at which it was demonstrated (Foucquier & Guedj, 2015).

A third tradition, the method of isoboles, approaches the problem geometrically. An isobole is a contour of constant effect, typically the fifty percent effective dose, plotted in a dose space whose axes are the doses of the two constituent drugs. For strictly additive interactions, the isobole is a straight line connecting the individual doses that produce the chosen effect alone; observed dose pairs falling below this line indicate synergy, while dose pairs above it indicate sub-additivity or antagonism (Tallarida, 2012). The isobologram remains one of the most transparent and widely used tools in interaction analysis, and its statistical machinery for confidence intervals and variable slope relationships has been progressively refined (Huang et al., 2019). The practical consequences of choosing an appropriate analytical framework are considerable. In cell culture studies of cytotoxic drugs, analyses that ignore the steepness of individual dose-response curves, the choice of the fixed-dose ratio, or the effect level at which interaction is assessed can invert the qualitative conclusion of an experiment entirely (Chou, 2010). For this reason, contemporary reviews emphasize that synergy quantification requires standardized experimental design, including full dose-response matrices for each drug alone and in constant or varying ratios, and transparent reporting of the reference model used (Bijnsdorp et al., 2011).

Quantitative Frameworks I: Loewe Additivity and the Dose-Effect Basis of Interaction

Loewe additivity derives from the concept of dose equivalence. If drug A produces a given effect at concentration a and drug B produces the same effect at concentration b, then the combination of dose a' of A plus dose b' of B is additive when the fractional contributions sum to one: a'/a plus b'/b equals unity. Values below one indicate that less of each drug is needed than predicted, that is, synergy; values above one indicate antagonism. This formulation, sometimes called the similarity principle, presupposes that the two drugs act on the same biological target or produce their effects through congruent dose-response relationships. When the assumption holds, Loewe additivity is the most defensible reference model, because two preparations of the same drug in different concentrations must, trivially, combine additively in this manner (Tallarida, 2012).

Mathematical treatment of additivity has continued to mature. Explicit formulations of additive dose-response models have been developed that satisfy formal consistency conditions, clarifying when Loewe additivity yields well-defined predictions and when, for example, dissimilar dose-response slopes make the additive surface ambiguous (Lederer et al., 2018). Mechanistic multi-hit models have provided a biological justification for these statistical reference models in microbiology. If two antibiotics each kill bacteria through independent stochastic hits, Bliss independence follows naturally; if the antibiotics act on the same target and their doses are interchangeable, Loewe additivity follows. Simulations of multi-hit models reproduce both reference surfaces and clarify the intermediate conditions under which observed interactions lie between the two references (Baeder et al., 2016). This mechanistic grounding is valuable because it converts a purely statistical dispute into an empirical question about the underlying mode of action of each agent.

In experimental practice, Loewe additivity underlies the most widely applied quantitative method in pharmacology, the combination index method described below, and it also anchors modern high-throughput synergy scoring. Experimental design deserves particular emphasis, because the same pair of drugs can display different interaction strengths at different dose ratios and at different effect levels. Full dose matrix designs, in which every combination of several concentrations of each drug is tested, are now considered the standard for preclinical combination studies, since they allow the interaction to be mapped across the entire exposure space rather than at a single arbitrary point (Bijnsdorp et al., 2011). Fixed-ratio designs, in which the two drugs are combined in constant proportions based on their individual potencies, remain popular

because they mirror the fixed-dose formulations used in clinical practice, but they capture only one slice of the interaction surface and can miss ratio-dependent synergy or antagonism (Chou, 2010). The central lesson from six decades of refinement is that additivity is model-dependent, and that the choice among additivity models should be dictated by knowledge of mechanism wherever such knowledge exists (Foucquier & Guedj, 2015).

Quantitative Frameworks II: Bliss Independence, Higher-Order Additivity, and Software Tools

The Bliss independence model treats the fractional effect of each drug as an independent probability and defines the expected combined effect as the sum of the individual effects minus their product. Bliss independence is the natural reference when drugs act through genuinely separate mechanisms, and it is especially convenient for quantal endpoints such as cell death, infection, or cure, where probabilities combine naturally (Foucquier & Guedj, 2015). A revised Bliss model that accounts for the curvature of individual dose-response relationships has been shown to reduce false positive synergy calls in high-throughput screening, an important correction because naive Bliss scoring of raw viability percentages systematically overstates synergy for potent drugs (Di Veroli et al., 2016).

The extension of interaction analysis beyond two drugs raises further conceptual issues. For combinations of three or more agents, the intuitive reference models of pairwise analysis must be generalized, and the expected effect of the full combination can be computed in more than one way from the pairwise and single-drug responses. Comparative analyses of increasingly large drug mixtures in bacteria demonstrated that the two canonical reference models, Bliss independence and Loewe additivity, agree remarkably well for large numbers of constituents even though they diverge for pairs, supporting their joint use as convergent null hypotheses in multidrug studies (Russ & Kishony, 2018).

Practical implementation of these frameworks depends on open and standardized software. Interactive platforms that fit individual dose-response curves, compute expected additive surfaces, and visualize interaction maps across full dose matrices have made quantitative analysis accessible to non-specialist laboratories and have improved comparability between studies (Di Veroli et al., 2016). Nonetheless, software cannot resolve the interpretive choices described above; the reference model, the effect level, and the experimental design must be specified by the investigator, and divergent synergy calls for the same data across tools almost always trace to differing default assumptions rather than to computational error (Foucquier & Guedj, 2015) (Fig. 2).

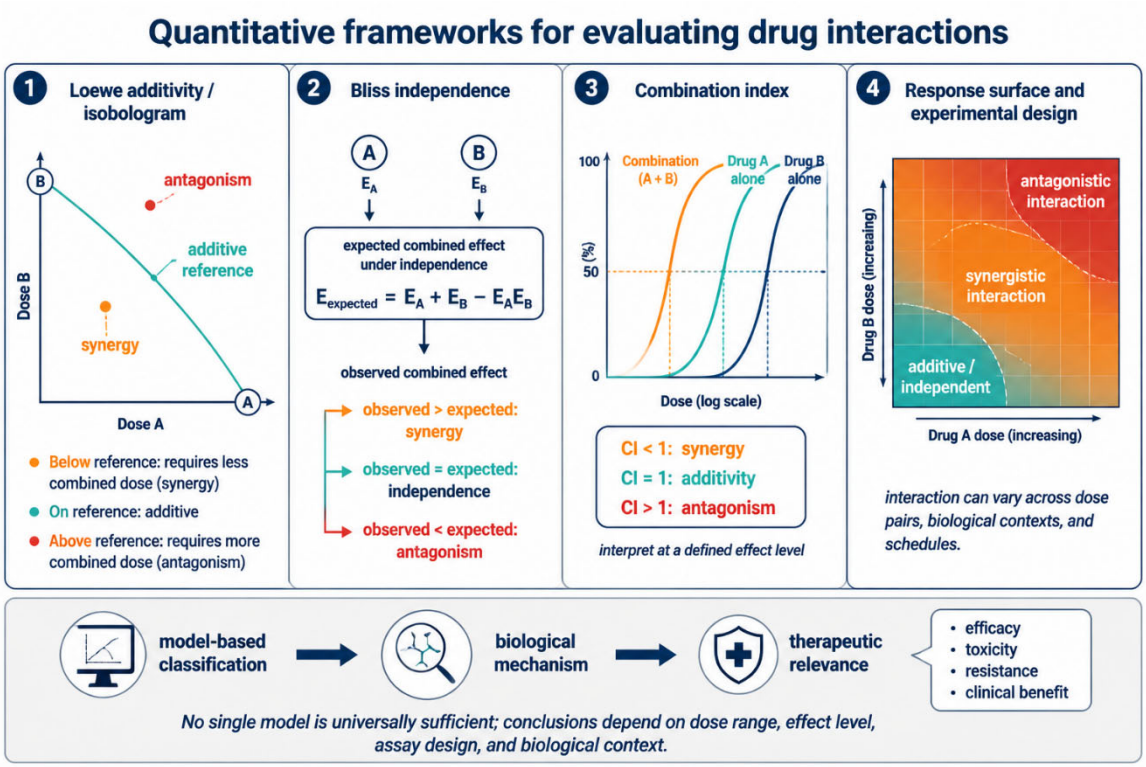

Figure 2. Quantitative frameworks for evaluating drug interactions. The figure compares complementary approaches used to classify drug combinations as synergistic, additive or independent, or antagonistic. **(A)** Loewe additivity and isobolographic analysis compare the observed combination dose with an additive reference line; combinations below the reference indicate synergy, whereas combinations above it indicate antagonism. **(B)** Bliss independence estimates the expected combined effect from the individual effects of Drug A and Drug B using the relationship (E_{\mathrm{expected}} = E_A + E_B - E_AE_B). Differences between the observed and expected effects identify synergy, independence, or antagonism. **(C)** The combination-index approach compares dose–effect relationships for individual drugs and their combination; a combination index below 1 indicates synergy, a value equal to 1 indicates additivity, and a value above 1 indicates antagonism. **(D)** Response-surface analysis evaluates interaction patterns across multiple dose pairs, illustrating that a single combination may contain synergistic, additive, and antagonistic regions. The interpretation pathway emphasizes that model-based classifications must ultimately be related to biological mechanisms and therapeutic outcomes, including efficacy, toxicity, resistance, and clinical benefit. Conclusions depend on the selected dose range, effect level, assay design, treatment schedule, and biological context.

Quantitative Frameworks III: The Combination Index Method and Isobolographic Analysis

The method of Chou and Talalay unified the mass-action analysis of enzyme inhibition with the median-effect equation, deriving a general expression for the combination index that quantifies the degree of interaction at any effect level. A combination index below one indicates synergism, one indicates additivity, and above one indicates antagonism, with the magnitude of deviation providing a graded, interpretable measure of interaction strength (Chou & Talalay, 1984). Because the method incorporates the slopes of individual dose-response curves through the median-effect plot, it remains valid for agents whose dose-response relationships are shallow or steep, and it supports the analysis of combinations at fixed dose ratios, the design most relevant to clinical formulations. The combination index method rapidly became the dominant quantitative approach in cancer pharmacology and has since accumulated tens of thousands of applications across pharmacology (Chou, 2010).

Applications of the method illustrate its utility in protocol design. Computerized quantitation of interactions among cytotoxic agents has repeatedly identified synergistic sequences and ratios

that informed clinical combination schedules, demonstrating how quantitative interaction analysis can move directly from in vitro dose matrices to treatment design (Chou, 2008). Comparative analyses of preclinical and clinical combination studies have emphasized, however, that synergy demonstrated in cell culture does not guarantee clinical benefit, and that translational studies must consider drug exposure, scheduling, and toxicity when extrapolating from combination indices to patients (Chou, 2008).

Isobolographic analysis remains the principal graphical alternative and complement to the combination index. Modern treatments of the isobole provide rigorous statistical confidence regions for additive predictions, handle drugs with dissimilar dose-response slopes, and extend to combinations of three agents through isobolar surfaces (Tallarida, 2012). Comprehensive methodological reviews summarize the conditions under which isoboles and combination indices agree, and both converge on the same qualitative conclusions when individual dose-response curves are well characterized (Huang et al., 2019). In practice, contemporary studies increasingly report both: combination indices across a range of effect levels and isobolograms at fixed effect levels, providing complementary quantitative and visual evidence (Chou, 2010; Huang et al., 2019).

Pharmacokinetic Mechanisms of Interaction: Absorption, Metabolism, and Distribution

Not all drug interactions arise at the level of molecular targets. A large class of interactions operates on the movement of drugs through the body, changing the concentration that reaches the target tissue. Because the magnitude of any pharmacodynamic interaction is assessed on the observed dose-response relationship, unrecognized pharmacokinetic interaction can masquerade as synergy or antagonism at the target level. Distinguishing the two is essential for correct mechanistic interpretation (Bibi, 2008).

The cytochrome P450 enzyme system is the principal site of pharmacokinetic interaction. Inhibition of a metabolic enzyme by one drug increases the exposure of another drug that depends on that enzyme for clearance, effectively raising the dose of the victim drug; induction of the same enzyme lowers exposure and can abolish therapeutic activity. Classic and clinically consequential examples include the inhibition of CYP3A4 by macrolide antibiotics or azole antifungals, which elevates concentrations of statins, calcineurin inhibitors, and many targeted anticancer agents, and the induction of CYP enzymes by rifampicin, phenytoin, and St John's wort, which accelerates the clearance of co-administered drugs (Hakkola et al., 2020). Mechanistically, inhibition may be competitive, reversible, or mechanism-based and irreversible, the latter producing prolonged effects that persist until new enzyme is synthesized. Systematic compilations of human CYP inhibitors and inducers now permit prospective prediction of many such interactions before they are encountered clinically (Hakkola et al., 2020). Historically, the recognition that P450 inhibition and induction underlie the majority of clinically significant interactions dates to the earliest systematic characterizations of the enzyme family in drug metabolism (Bibi, 2008).

The same pharmacokinetic logic can be exploited deliberately. Ritonavir, a potent CYP3A4 inhibitor, is co-formulated with other antiretrovirals and with newer anticancer agents not to act at a viral or tumor target but to boost exposure of the active partner, a pharmacokinetic enhancer in the strict sense. Similarly, the combination of a non-steroidal anti-inflammatory drug with a proton pump inhibitor is not synergistic at any molecular target but is mechanistically complementary at the organ level, preventing the gastric toxicity that anti-inflammatory drugs would otherwise produce. Whether such interactions are labeled synergistic depends on the endpoint chosen; at the level of the therapeutic index, they are genuinely beneficial combinations (Bibi, 2008).

Drug transporters constitute the second major locus of pharmacokinetic interaction. P-glycoprotein, the product of the ABCB1 gene, is expressed at the apical surface of intestinal enterocytes, the blood-brain barrier, hepatocytes, and renal tubular cells, where it actively exports

an enormous range of structurally diverse substrates back into the lumen, blood, or urine. Inhibition of P-glycoprotein by one drug increases the absorption and tissue penetration of another, while induction decreases both. Clinically important examples include the elevation of digoxin concentrations by P-glycoprotein inhibitors such as verapamil, quinidine, and clarithromycin, and the reduction of oral anticoagulant exposure by strong P-glycoprotein inducers (Finch & Pillans, 2014). Because P-glycoprotein also determines central nervous system penetration, transporter-mediated interactions can change drug distribution in a compartment-specific manner, increasing systemic exposure without increasing brain exposure, or the reverse (Finch & Pillans, 2014). The ABCB1 transporter has been implicated in interactions involving hundreds of drug pairs, and review of its clinical relevance concludes that transporter-mediated interactions are among the most frequent and most predictable classes of pharmacokinetic interaction (Marchetti et al., 2007). Protein binding displacement, once considered a major mechanism, is now understood to be clinically important only for drugs with narrow therapeutic indices, high extraction ratios, or both, since the increased free fraction is rapidly cleared in most cases.

A further layer of pharmacokinetic interaction operates below the level of systemic exposure, within the microenvironment of the target tissue. Solid tumors characteristically exhibit regions of low extracellular pH, elevated interstitial pressure, and abnormal vascularization, all of which alter the intracellular partitioning of weakly basic and weakly acidic drugs. Agents that raise lysosomal pH, such as the antimalarial chloroquine and related lysosomotropic compounds, can release weakly basic cytotoxics that had been sequestered in acidic organelles, thereby restoring nuclear drug access and converting an apparently resistant cell into a sensitive one. Conversely, co-administration of drugs that compete for the same intracellular compartment can produce antagonism of distribution without any change in plasma concentrations. Such compartment-level interactions are invisible to conventional plasma pharmacokinetic monitoring and are increasingly recognized as a source of the discrepancy between measured exposure and observed response, particularly in oncology where intratumoral heterogeneity of perfusion and acidity is the rule rather than the exception (Bibi, 2008; Hakkola et al., 2020).

Pharmacokinetic interactions therefore generate genuine, clinically meaningful synergy and antagonism, but of a fundamentally different kind from pharmacodynamic interactions. The distinction matters practically: pharmacokinetic synergy is generally dose-form independent, predictable from enzyme and transporter phenotyping, and manageable through dose adjustment, whereas pharmacodynamic interactions require mechanistic knowledge of target biology (Hakkola et al., 2020).

Pharmacodynamic Mechanisms I: Receptor-Level and Signaling Pathway Interactions

Pharmacodynamic interactions arise when two drugs influence one another's downstream biological response, either at the level of the same molecular target or through the architecture of cellular signaling networks. The simplest form is direct target-level interaction: two ligands acting on the same receptor, two inhibitors acting on the same enzyme, or two drugs whose binding to distinct sites on a single protein alters one another's affinity or efficacy. Such interactions are predictable from receptor theory and generally produce Loewe-additive or mildly non-additive effects, with the direction of deviation determined by the type of binding competition and the presence or absence of spare receptors (Tallarida, 2012).

More interesting are interactions that arise from the topology of cellular signaling networks. Physiological signaling pathways are organized into cascades and feedback loops in which inhibition of one node produces compensatory activation of parallel nodes, a phenomenon observed across cancer, inflammation, and metabolism. When two drugs inhibit two nodes that lie in parallel but converge on a shared downstream effector, their combination produces greater suppression than either alone, a mechanism exemplified by the combination of BRAF and MEK

inhibitors in melanoma. Inhibition of mutant BRAF produces near-complete initial tumor regression but the pathway rapidly reactivates through upstream signaling, receptor tyrosine kinase activation, and bypass signaling, effects that a downstream MEK inhibitor suppresses, producing deeper and more durable responses in combination than either drug achieves alone (Eroglu & Ribas, 2016). The combination delays the emergence of resistance, reduces paradoxical MAPK activation in normal tissues, and has now become a standard of care in BRAF-mutant melanoma, illustrating how rational pathway-level understanding translates directly into clinical synergy (Subbiah et al., 2020).

The concept of pathway crosstalk generalizes this example. Jia and colleagues classified drug combinations by the relationship between their targets and identified that combinations of agents acting on different but functionally connected pathways, rather than on the same target, are most often synergistic in cancer models (Jia et al., 2009). Their analysis of a large number of characterized combinations showed that synergistic pairs frequently target separate proteins within the same pathway or in parallel pathways converging on a shared phenotype, whereas pairs that target the same protein tend to be simply additive. Subsequent systems pharmacology analyses confirmed this pattern broadly, framing drug action at the level of network perturbation rather than single-target binding and predicting synergistic pairs from the position of their targets in protein interaction networks (Van Hasselt & Iyengar, 2019). This network perspective has practical consequences: rather than searching blindly among all possible drug pairs, one can prioritize combinations whose targets occupy complementary or convergent positions in the disease-relevant interaction network (Hopkins, 2008).

Signaling network interactions also explain a large fraction of antagonism. Two drugs whose target nodes feed into a shared signaling module in a non-convergent manner may trigger compensatory feedback that partially negates the effect of the other. Similarly, one drug that reduces the transcriptional activity of a pathway may blunt the expression of the target that the second drug inhibits, producing apparent antagonism. Such network-mediated antagonism has been documented across antimicrobial combinations and is reviewed below in the context of bacterial physiology. Beyond oncology and infection, pharmacodynamic synergy is routinely exploited in chronic disease management. Fixed-dose antihypertensive combinations act on distinct control axes of blood pressure, and fixed-dose triple regimens achieve control rates that exceed the simple sum of monotherapy effects, consistent with genuine interaction at the level of integrated cardiovascular regulation. In analgesia and anesthesia, combinations of opioids with non-opioid agents, or of hypnotics with neuromuscular blockers, are designed around additive or synergistic pharmacodynamic interactions that permit dose reduction of each component and a corresponding reduction in dose-dependent toxicity. These examples illustrate that supra-additive benefit at the level of a physiological endpoint does not always require interaction at a single molecular target; convergence at the level of an organ system or a regulatory axis can suffice (Fig. 3).

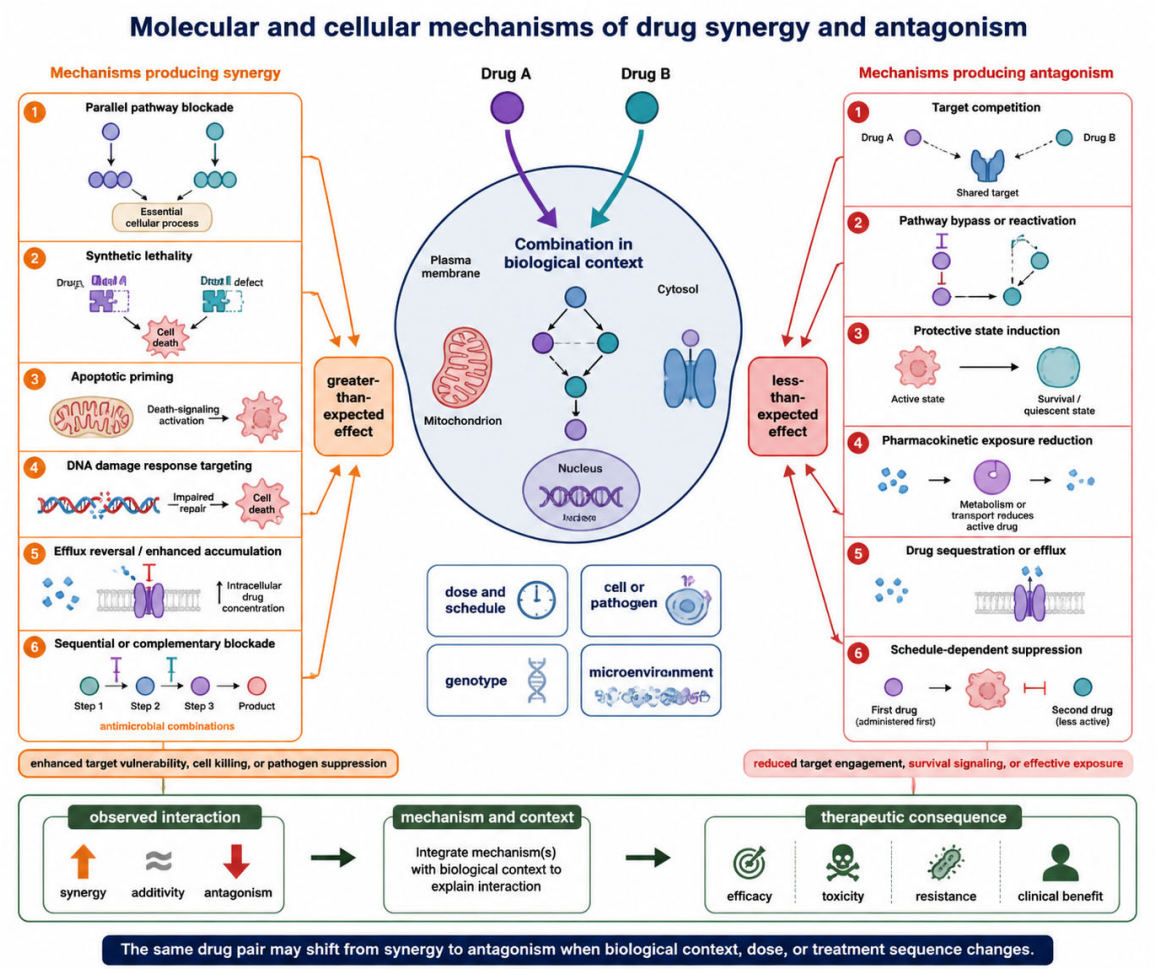

Figure 3. Molecular and cellular mechanisms of drug synergy and antagonism. The central schematic emphasizes that the effect of a drug combination is determined by its biological context, including dose and treatment schedule, cell or pathogen state, genotype, and microenvironment. Mechanisms producing synergy (left) include parallel pathway blockade, synthetic lethality, apoptotic priming, DNA damage-response targeting, reversal of drug efflux or enhanced intracellular accumulation, and sequential or complementary pathway blockade. These mechanisms increase target vulnerability, cell killing, or pathogen suppression, resulting in a greater-than-expected combined effect. In contrast, antagonism (right) may arise through competition for a shared target, pathway bypass or reactivation, induction of a protective or quiescent state, reduced pharmacokinetic exposure, drug sequestration or efflux, and schedule-dependent suppression. These mechanisms decrease target engagement, survival signaling, or effective drug exposure, producing a less-than-expected effect. The lower panel shows that the observed interaction—synergy, additivity, or antagonism—should be interpreted together with its underlying mechanism and biological context to anticipate therapeutic consequences for efficacy, toxicity, resistance, and clinical benefit. Thus, the same drug pair may shift from synergy to antagonism when the biological context, dose, or treatment sequence changes.

Pharmacodynamic Mechanisms II: Synthetic Lethality and DNA Damage Response Targeting

Among the most biologically elegant mechanisms of drug synergy is synthetic lethality, the situation in which a loss of function in either of two genes is tolerated but simultaneous inactivation of both is lethal. Synthetic lethal interactions arise from the organization of cellular processes into parallel, partially redundant systems; when one branch is disabled, the other compensates, but simultaneous loss of both branches collapses an essential cellular function. Synthetic lethality provides a theoretical framework for designing combinations that exploit

tumor-specific vulnerabilities: a drug inhibiting one branch of a redundant pair is selectively lethal in cells already carrying an inactivating mutation in the other branch (Lord & Ashworth, 2017).

The paradigmatic example is the clinical success of PARP inhibitors in BRCA1- and BRCA2-mutated breast, ovarian, and prostate cancer. PARP enzymes are central to single-strand break repair and base excision repair; their inhibition leads to the accumulation of single-strand lesions that collapse replication forks and convert into double-strand breaks. Homologous recombination, the pathway that repairs double-strand breaks, is already non-functional in BRCA-mutated tumors, so the two lesions are individually tolerable but jointly lethal. Because normal cells retain one intact repair pathway, the therapeutic index is unusually wide. Preclinical and clinical studies have confirmed the synthetic lethal interaction between PARP inhibition and BRCA deficiency in a variety of contexts and have extended the concept to combinations of PARP inhibitors with platinum chemotherapy, which itself generates lesions repaired by homologous recombination, further widening the range of tumors in which the strategy can be applied (Lord & Ashworth, 2017).

The synthetic lethal framework has also been refined conceptually. Some combinations produce synthetic lethality that does not depend on the underlying genetics of the tumor, the so-called drug-driven synthetic lethality, in which two drugs jointly disable a process that either drug alone only partially inhibits. For example, combination of a DNA-PK inhibitor with a PARP inhibitor can produce tumor-selective lethality across a range of genetic backgrounds, effectively manufacturing a synthetic lethal interaction pharmacologically rather than relying on the prior genetic lesion (Jdey et al., 2017). This expansion of the concept substantially widens the applicability of synthetic lethal strategies beyond the relatively small set of tumors carrying homologous recombination deficiency.

Importantly, synthetic lethality is not limited to DNA repair. Synthetic lethal interactions have been documented in RNA splicing, proteasomal degradation, metabolic flux, chromatin regulation, and RAS pathway signaling, and genome-wide CRISPR screens now permit systematic discovery of such interactions at scale. The clinical development of synthetic lethal combinations nonetheless faces significant obstacles, including acquired resistance, bone marrow toxicity when both branches of a redundant pair operate in normal hematopoietic cells, and the difficulty of identifying patient populations whose tumors carry the relevant sensitizing lesion (Lord & Ashworth, 2017).

Pharmacodynamic Mechanisms III: Apoptotic Pathway Sensitization and Mitochondrial Priming

A mechanistically distinct form of synergy arises at the level of the apoptosis machinery. Many cytotoxic therapies ultimately converge on the activation of caspases, the proteolytic enzymes that execute cell death, but tumor cells often resist this step through overexpression of anti-apoptotic Bcl-2 family proteins or through defects in death receptor signaling. Combining a drug that increases the damage signal, for example a DNA-damaging agent, with a drug that lowers the threshold for apoptosis, for example a BH3 mimetic that neutralizes anti-apoptotic proteins, produces more complete cell killing than either agent alone, a phenomenon sometimes called apoptotic priming (Mokhtari et al., 2017).

An especially well-characterized example involves TRAIL, a death receptor ligand that selectively induces apoptosis in transformed cells. While TRAIL alone can trigger apoptosis in sensitive cells, many tumor cell lines are resistant, and this resistance can be overcome by concurrent or sequential chemotherapy. Studies in breast cancer cell lines demonstrated that doxorubicin and 5-fluorouracil synergize with TRAIL to induce apoptosis through caspase-8 recruitment to the death-inducing signaling complex and mitochondrial amplification of the signal (Keane et al., 1999). Similar mechanisms of death-inducing signaling complex potentiation and mitochondrial amplification have been documented for TRAIL combined with a broad range of chemotherapeutic drugs across tumor types, establishing apoptotic sensitization as a general rather than agent-specific phenomenon (Keane et al., 1999; Sullivan et al., 2020).

The general principle of apoptotic sensitization extends well beyond TRAIL. The intrinsic and extrinsic apoptotic pathways converge on mitochondrial outer membrane permeabilization, and the relative activation of pro-apoptotic and anti-apoptotic Bcl-2 family members, sometimes summarized as mitochondrial priming, determines whether a given damage signal succeeds in committing the cell to death. Agents that increase priming, including BH3 mimetics, glucocorticoids in lymphoid malignancies, and myeloid differentiation therapies, therefore synergize broadly with DNA-damaging agents, kinase inhibitors, and immunotherapies whose lethal signals would otherwise be buffered by anti-apoptotic reserve. Conversely, tumors that overexpress anti-apoptotic proteins convert what would be synergistic pairs into antagonistic ones, since the second drug fails to lower the apoptotic threshold and may instead induce protective cell cycle arrest. This dependence of the interaction sign on the apoptotic state of the cell illustrates a broader theme of this review: drug interaction is a property of the cellular context as much as of the molecules involved (Mokhtari et al., 2017) (Fig. 4).

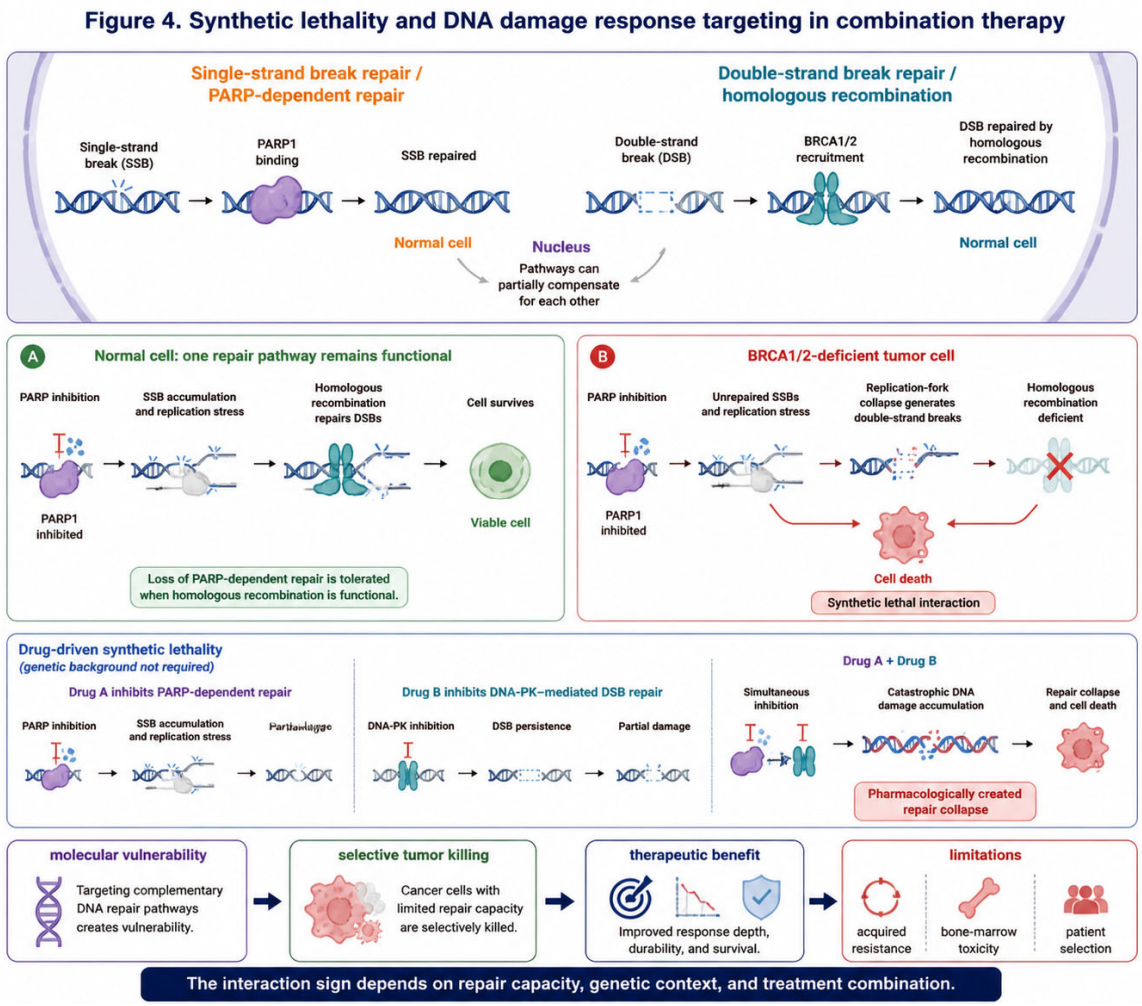

Figure 4. Synthetic lethality and DNA damage response targeting in combination therapy. The upper panel illustrates the complementary relationship between PARP1-dependent repair of single-strand DNA breaks and BRCA1/2-mediated homologous recombination repair of double-strand breaks. In normal cells, loss of one repair route can be partially tolerated because the alternative pathway remains functional. In contrast, PARP inhibition in BRCA1/2-deficient tumor cells promotes the accumulation of unrepaired single-strand lesions, replication stress, and replication-fork collapse, generating double-strand breaks that cannot be effectively repaired by homologous recombination. The resulting repair failure produces a synthetic lethal interaction and selective tumor-cell death, whereas normal cells with intact homologous recombination remain viable. The lower mechanistic panel depicts drug-driven synthetic lethality, in which

combined inhibition of PARP-dependent repair and DNA-PK-mediated double-strand-break repair produces pharmacologically induced repair collapse without requiring a pre-existing genetic defect. The translational sequence summarizes how complementary DNA-repair vulnerabilities can produce selective tumor killing and therapeutic benefit, while also highlighting acquired resistance, bone-marrow toxicity, and the need for appropriate patient selection as major limitations. Overall, the figure emphasizes that combination efficacy depends on repair capacity, genetic context, and treatment design.

Pharmacodynamic Mechanisms IV: Transporters, Metabolism, and Drug Efflux as Drivers of Interaction

Cellular drug handling, including uptake, sequestration, and efflux, is a major determinant of apparent pharmacodynamic interaction. Overexpression of ATP-binding cassette transporters, particularly P-glycoprotein, confers multidrug resistance by actively exporting a broad range of structurally unrelated cytotoxic agents from tumor cells, and this single alteration can convert a synergistic drug pair into a weak or antagonistic one by lowering intracellular concentrations below the threshold for interaction (Sharom, 2008). Conversely, combining a cytotoxic agent with an inhibitor of its efflux transporter can restore or enhance intracellular exposure and generate clinically useful synergy.

The concept of chemosensitization, in which a non-cytotoxic or weakly cytotoxic agent reverses resistance and thereby potentiates the effect of a second drug, has a long history in cancer pharmacology. Chemosensitizers have been developed against several ABC transporters, including P-glycoprotein, multidrug resistance-associated protein, and breast cancer resistance protein, and systematic surveys have catalogued their potential to reverse multidrug resistance in cell culture (Choi & Yu, 2014). Early first-generation inhibitors failed in clinical trials largely because of systemic toxicity at the concentrations required for effective transporter blockade, reflecting the physiological role of these pumps in protecting normal tissues; subsequent generations with improved selectivity, together with mechanistically novel approaches such as transcriptional silencing of transporter genes, continue to be evaluated. More recent summaries of ABC transporter pharmacology have emphasized the central role these proteins play not only in multidrug resistance but also in normal pharmacokinetics, and have argued that transporter-targeted combination therapy requires careful consideration of tissue-specific expression and physiological function (Choi & Yu, 2014).

Transporter-mediated interactions extend far beyond cancer. In bacteria, efflux pumps of the resistance-nodulation-division family expel multiple antibiotic classes, and inhibition of these pumps can synergize with antibiotics to which the bacteria would otherwise be resistant. In parasitic disease, reversal of chloroquine resistance by agents that block parasite digestive vacuole function or drug export has been explored for decades. In all these cases, the underlying mechanism is shared: lowering the rate of drug export raises the steady-state intracellular concentration of the partner drug, effectively increasing its dose without increasing its administered dose. At the whole-organism level, the same principle underlies the deliberate use of transporter inhibition to enhance oral bioavailability or central nervous system penetration, so that a single transporter interaction can be either a hazardous adverse interaction or a designed therapeutic strategy depending on intent and context (Sharom, 2008; Marchetti et al., 2007).

Drug delivery technology has added a further dimension to transporter- and distribution-mediated interaction. Nanoparticulate co-formulation allows two drugs with incompatible pharmacokinetic profiles to be delivered in a fixed stoichiometric ratio, synchronizing their pharmacokinetics so that the intracellular concentration ratio required for a synergistic interaction is maintained over time rather than achieved only transiently. Co-encapsulation of a cytotoxic agent with a transporter inhibitor, or of two agents whose synergy is ratio-dependent, can convert an interaction that is weak or variable with free drug administration into a reproducible one, and

preclinical studies have demonstrated that the synergistic ratio identified in vitro can be preserved in vivo by appropriate carrier design. This synchronization of exposure is a pharmacokinetic strategy for preserving a pharmacodynamic interaction, and it illustrates how formulation science can be used to enforce the conditions under which a molecular mechanism of synergy can actually operate in a living organism (Sharom, 2008; Marchetti et al., 2007).

Pharmacodynamic Mechanisms V: Antimicrobial Combinations, Sequential Pathway Blockade, and Resistance Evolution

Infectious disease offers some of the clearest examples of molecularly defined drug synergy, largely because bacterial targets are biochemically discrete and their pathways well mapped. The classic paradigm is sequential blockade, in which two drugs inhibit successive steps of a single biosynthetic pathway. Sulfonamides and trimethoprim, which act on dihydropteroate synthase and dihydrofolate reductase respectively, synergize because the depletion of tetrahydrofolate produced by the second drug cannot be compensated once the first drug has blocked the upstream step, an example of genuine mechanism-based synergy that underlies a widely used fixed-dose combination.

Beyond this classic example, systematic functional screens in bacteria have revealed patterns of antibiotic interaction that correlate with target pathway. A foundational study categorized antibiotic pairs in Escherichia coli on the basis of the growth properties of strains lacking individual drug targets, showing that drugs acting on the same pathway tend to be synergistic while drugs acting on different pathways more often produce additive or antagonistic interactions (Yeh et al., 2006). This observation has since been generalized: large-scale studies of pairwise antibiotic interactions confirm that a large fraction of strongly synergistic pairs act on the same pathway or on convergent pathways, whereas strongly antagonistic pairs frequently act on pathways that counteract one another.

The mechanism of synergy in antibiotic combinations is not limited to target level interaction. Some combinations exploit drug-induced physiological changes that sensitize the bacterium to a second drug: for example, inhibition of cell wall synthesis can increase the permeability of the bacterial envelope to a second drug whose target lies in the cytoplasm, producing a positive feedback on drug accumulation. The synergy between cell wall active beta-lactams and aminoglycosides in enterococcal endocarditis is conventionally explained in this way, as is the cooperation between membrane-disrupting agents and intracellularly targeted antibiotics. Other combinations exploit the differential growth rates that one drug imposes on the population, effectively shifting the bacterium into a physiological state in which the second drug is more potent. A comprehensive review of such mechanisms in molecular detail concludes that antibiotic synergy is generally explainable by reference to three broad classes, namely direct target-level interaction, drug-induced sensitization, and passive additivity of independent killing mechanisms (Sullivan et al., 2020). The same review emphasizes that most antibiotic combinations in clinical use were discovered empirically rather than by design, and that a molecular understanding of synergy is only now catching up with clinical practice.

Analogous logic applies beyond antibacterial therapy. In antifungal treatment, azoles that inhibit ergosterol biosynthesis synergize with polyenes that bind the resulting sterol-depleted membrane, and with echinocandins that weaken the cell wall, so that membrane and wall damage compound one another. In antiviral therapy, the combination of agents acting at different stages of the viral life cycle, from entry through reverse transcription to proteolytic maturation, produces suppression of viral replication that exceeds the sum of monotherapy effects and, critically, suppresses the emergence of resistant quasispecies by reducing the population of replicating virus. In antitubercular therapy, multidrug regimens are built on the same principles of sequential pathway blockade and independent mutation prevention, with each additional agent reducing the probability that a doubly resistant mutant arises during treatment. Across all these domains, the

interaction of the drugs at the level of the pathogen population, suppressing the expansion of resistant lineages, is as important therapeutically as the interaction at the level of the individual cell, and the two are not always congruent (Sullivan et al., 2020; Yeh et al., 2009).

Biofilms, which are aggregated bacterial communities embedded in a self-produced matrix, represent a separate biological context in which drug synergy and antagonism can emerge. The biofilm matrix physically limits drug penetration, and bacteria within biofilms exhibit metabolic heterogeneity that confers tolerance to a wide range of antibiotics. Combinations that address distinct aspects of biofilm physiology, for example by disrupting the matrix while killing metabolically active cells, often succeed where single agents fail, and the interaction type observed in planktonic culture is frequently altered, in either direction, when the same drug pair is tested against biofilm-grown bacteria.

Pharmacodynamic Mechanisms VI: Antagonism and Its Mechanistic Basis

Antagonism, defined quantitatively as a combined effect smaller than expected from a chosen reference model, is as mechanistically diverse as synergy. At the molecular level, antagonism arises when two drugs bind to the same receptor in a manner that reduces the effect of the combination below that achievable by either alone, when two drugs produce opposite downstream effects on a shared second messenger, or when two drugs target pathways whose joint inhibition is biochemically impossible or cytostatic rather than cytotoxic. The systematic analysis of drug interaction mechanisms has documented such patterns across many therapeutic areas and provides a useful taxonomy of negative interactions (Jia et al., 2009).

In bacteria, a particularly interesting class of antagonism involves suppressive interactions, in which one drug partially or completely negates the growth inhibitory effect of another so that the combination produces less inhibition than one of the constituents alone. Suppressive interactions were first systematically characterized in E. coli, where they arise when two drugs that inhibit the same essential process through different mechanisms reduce one another's effective target engagement, and they have since been documented across multiple bacterial species (Singh & Yeh, 2017). Mechanistically, suppression often reflects drugs acting on opposing arms of a homeostatic system, so that joint inhibition partially restores rather than further disrupts the regulated process. Suppressive interactions also influence the evolution of resistance: in a classic experiment, the combination of trimethoprim and a beta-lactam antibiotic produced a fitness landscape in which resistance to one drug was selected against because the resistant strain grew more poorly in the presence of the combination than the wild type did, suggesting that appropriately chosen antagonistic combinations can retard resistance evolution (Chait et al., 2007).

The evolutionary consequences of drug interaction have been explored systematically in microbial systems. A theoretical and experimental review of the effect of drug interaction on the evolution of resistance concluded that antagonistic combinations can slow the evolution of resistance by narrowing the selective advantage of resistance mutations and by generating fitness trade-offs in which resistance to one drug imposes a cost in the presence of the other (Yeh et al., 2009). Conversely, synergistic combinations, while more efficacious in the short term, can generate a larger selective differential for resistance and therefore accelerate resistance evolution once resistance appears. The net effect of a combination on resistance evolution therefore depends on both its interaction type and the frequency of resistance mechanisms that alter interaction strength, a nuance that is increasingly relevant as combination therapies are used more widely.

In cancer, antagonistic interactions are usually unwanted, but their mechanistic basis is nevertheless important to understand. Two drugs that target the same pathway at different levels can produce mutual antagonism if the upstream inhibitor blunts expression of the downstream target, or if compensatory feedback loops are activated by one drug and inhibit the effect of the other. A second mechanism involves scheduling: two cytotoxic drugs whose cytotoxicity depends

on cell cycle phase may antagonize one another if the first drug arrests cells in a phase in which they are insensitive to the second. Such antagonism is schedule-dependent and disappears when the drugs are given in sequence rather than concurrently. Finally, pharmacodynamic antagonism can arise from toxicity-directed protective interactions, in which one drug protects normal tissues from the toxicity of another but in doing so reduces the exposure of tumor tissue to the active drug. Understanding these mechanisms is essential for the correct interpretation of clinical interaction data.

Antagonism as a Therapeutic Opportunity: Reversing the Negative Perspective

The view of antagonism as inherently undesirable has been significantly revised in the last two decades, particularly in the context of antimicrobial therapy. Because the efficacy of a drug combination over time depends on whether it selects for or against resistant mutants, an interaction that is mildly antagonistic in terms of immediate efficacy may nevertheless be strongly advantageous in terms of long-term resistance management. The systematic analysis of suppressive interactions in bacteria showed that antagonistic combinations can generate negative cross-resistance in which resistance to one drug increases sensitivity to the other, and can thereby be used to channel bacterial evolution in directions that are clinically useful (Singh & Yeh, 2017). In the context of antibiotic resistance, where the pace of resistance emergence continues to outstrip the introduction of new agents, such evolutionary considerations are of great practical importance.

Theoretical models have explored the conditions under which antagonistic combinations are therapeutically optimal. A study of optimal drug synergy in antimicrobial treatment concluded that the most effective combination depends on the timescale of treatment, the genetic background of the pathogen, and the cross-resistance profile of the population, and that the interaction type that maximizes short-term efficacy does not necessarily maximize long-term success (Torella et al., 2010). Related experimental work has shown that the evolutionary trajectory of a bacterial population under drug treatment is shaped by the interaction type of the drug combination, with antagonistic combinations generally imposing weaker selection for resistance and thereby slowing its spread (Baym et al., 2016).

In oncology, a similarly counterintuitive strategy is embodied in sequential rather than concurrent combinations, in which a first drug is used to select for or induce a vulnerability that a second drug exploits. This is not antagonism in the strict pharmacodynamic sense, but it is a related strategy of shaping the biological system rather than simply combining two independent attacks. Such strategies, broadly termed adaptive therapy or evolutionary herding, are being explored in both cancer and infectious disease and represent an important future direction for combination design (Baym et al., 2016).

Systems-Level and Network Pharmacology Perspectives

The molecular mechanisms described above can be organized into a broader framework in which drug combinations are understood as perturbations of disease-relevant molecular networks. In this view, the interaction of two drugs is determined by the relationship between their targets and by the topology of the network that connects those targets to the disease phenotype. Network pharmacology, a term popularized by Hopkins, proposes that drugs do not act on single targets but on networks, and that rational combination design should therefore take account of network structure rather than target identity alone (Hopkins, 2008).

Computational systems biology has developed a range of approaches to exploit this perspective. Mathematical models of signaling networks have been used to predict synergy from network topology, identifying combinations that target pathways in a convergent or parallel manner. Bayesian and machine learning models trained on existing combination data have been used to predict new synergistic pairs from drug structural features, target profiles, and gene expression signatures, achieving useful accuracy in prospective validation studies. Comprehensive reviews of

such systems biology approaches summarize the methodology and highlight both the strengths and limitations of computational prediction, in particular the dependence of predictive performance on the quality and coverage of the underlying training data (Van Hasselt & Iyengar, 2019).

Network-based reasoning also clarifies why the same combination can produce opposite interaction signs in different cellular contexts. Because the position of a drug target in a signaling network varies with the mutation profile of a cell, two drugs whose targets converge on a shared effector in one genetic background may occupy disconnected modules in another, so that the interaction sign follows the network state rather than the drug pair itself. This context dependence is increasingly visible in large pan-cancer combination screens and argues for interaction assessment as an integral part of molecular tumor characterization rather than a one-time preclinical determination (Jia et al., 2009; Van Hasselt & Iyengar, 2019).

An additional layer of complexity arises from the fact that drug combinations in vivo operate in a multi-scale environment involving tissues, organs, and the whole organism, rather than in isolated cell culture. Systems pharmacology, which integrates pharmacokinetic and pharmacodynamic models at multiple scales, has been applied to combination therapy in order to predict how interactions observed at the cellular level translate into therapeutic effects at the organismal level. This integrated approach is still maturing, but it represents a natural convergence of pharmacokinetic and pharmacodynamic interaction analysis (Hopkins, 2008; Van Hasselt & Iyengar, 2019).

Higher-Order Interactions and Multi-Drug Combinations

Most combination studies analyze drug pairs, but therapeutic regimens frequently comprise three or more agents. The interaction of three drugs cannot in general be predicted from pairwise interactions alone, since the combined effect depends on the way in which all three perturbations jointly influence the biological system. Empirical studies in bacteria have shown that higher-order interactions are common, that they increase in frequency and magnitude with the number of drugs in the combination, and that they are biased toward antagonism on average. Emergent suppressive interactions, in which a three-drug combination produces greater bacterial growth than one of the constituent drugs alone, have been documented in pathogenic isolates and represent a biologically counterintuitive outcome that cannot be anticipated from pairwise data (Tekin et al., 2016).

On the other hand, the systematic exploration of higher-order combinations has also revealed unexpected opportunities. An analysis of all possible combinations of ten antibiotics concluded that, based on the properties of the pairwise interaction landscape, ultra-high-order combinations containing many drugs can be predicted to be highly effective, and that the fraction of drug pairs that are antagonistic is a useful predictor of the performance of the full combination (Katzir et al., 2019). The mechanistic basis of such high-order interactions is not yet well understood, but it is thought to reflect the combined effects of pairwise interactions propagating through biological networks and to involve shared, pathway-level downstream effects. As more therapeutic regimens move beyond three drugs, understanding higher-order interactions will become increasingly important for the rational design of polypharmacy (Russ & Kishony, 2018).

Immunological Mechanisms of Combination Synergy

The success of immune checkpoint inhibitors has added a new dimension to drug combination therapy, in which the interacting agents modulate host immunity rather than acting directly on tumor cells. The combination of CTLA-4 and PD-1 blockade, which is now standard in metastatic melanoma, was designed on the basis of complementary immunological mechanisms: CTLA-4 regulates the priming phase of T cell activation in lymphoid organs, whereas PD-1 regulates effector function in peripheral tissues, so the two inhibitors act on distinct regulatory circuits rather than on the same target. Mechanistic dissection in murine models demonstrated that anti-

CTLA-4 and anti-PD-1 operate through distinct cellular mechanisms, with anti-CTLA-4 expanding a broadly reactive T cell population and anti-PD-1 reinvigorating exhausted effector cells, and that combination therapy recruits additional T cell clonotypes not expanded by either monotherapy (Wei et al., 2017). Clinical reviews of the combined CTLA-4 and PD-1 blockade approach document the greater durability of response relative to either monotherapy, together with greater toxicity, and discuss the mechanistic basis of both (Buchbinder & Desai, 2016).

A complementary immunological mechanism underlies the synergy between cytotoxic chemotherapy and checkpoint blockade. Certain chemotherapeutic agents, notably anthracyclines, oxaliplatin, and cyclophosphamide, induce immunogenic cell death, a form of tumor cell death that releases damage-associated molecular patterns and thereby recruits and activates dendritic cells, leading to cross-presentation of tumor antigens and expansion of a T cell response (Galluzzi et al., 2015). In the context of checkpoint blockade, such immunogenic cell death converts a tumor that is immunologically silent into one that is immunologically active, so that the T cell response expanded by checkpoint inhibitors has a target to act upon. In general, immunological synergy is a good example of a mechanism in which the two drugs do not act on the same cell or the same pathway at all, so that a purely cell-autonomous analysis of synergy is inadequate. It also illustrates a recurring trade-off in combination therapy: the same immunological mechanisms that deepen and prolong tumor control, namely broader T cell expansion and breakdown of peripheral tolerance, also account for the increased immune-related toxicity of combined checkpoint blockade, so that the therapeutic index of the combination must be established clinically rather than assumed from efficacy alone (Buchbinder & Desai, 2016; Wei et al., 2017).

Beyond checkpoint blockade, the immunological dimension of combination therapy extends to the modulation of myeloid and stromal cells within the tumor microenvironment. Agents that deplete immunosuppressive myeloid cells, inhibit transforming growth factor beta signaling, or repolarize tumor-associated macrophages can convert a tumor that rejects T cell infiltration into one that supports it, thereby multiplying the effect of a T cell directed therapy given concurrently. Radiotherapy and some targeted agents contribute to the same endpoint by increasing antigen release and upregulating major histocompatibility complex expression on tumor cells. Conversely, some cytotoxic and targeted agents deplete effector lymphocytes or induce compensatory upregulation of alternative checkpoint receptors, producing immunological antagonism in which each agent undermines the other. These observations reinforce the central point that the sign of a drug interaction in immunotherapy is determined by the configuration of the host immune system as much as by the tumor, and that the same combination can behave very differently in immunologically hot and cold tumors (Galluzzi et al., 2015; Buchbinder & Desai, 2016).

The Mechanistic Basis of Combination Efficacy Beyond True Synergy

A growing body of clinical and preclinical evidence suggests that many drug combinations in successful clinical use are not in fact synergistic by any strict quantitative definition. An analysis of combination therapies in precision oncology concluded that a large fraction of approved combinations owe their clinical benefit to independent drug action, in which two drugs each achieve partial tumor control in different subpopulations of tumor cells, rather than to a synergistic interaction at the level of individual cells (Plana et al., 2022). Independent drug action is a conceptually important alternative to true pharmacodynamic synergy, because it does not require any special molecular interaction between the two agents and is therefore much more likely to be observed in randomized clinical trials. The distinction matters clinically because independent drug action predicts that the combination will be effective as long as each drug is effective in some tumor cells, whereas true synergy predicts that the combination will be effective only in tumors whose molecular profile matches the mechanism of interaction.

Clinical experience with some combinations suggests that the same apparent clinical outcome, namely a greater therapeutic effect than either drug alone, can arise from several mechanisms that are conceptually distinct. Clarifying which mechanism underlies the observed clinical benefit matters because the different mechanisms carry different predictions about patient selection, scheduling, and the likelihood of success in different tumor types. A further review of combinatorial drug therapy in the post-genomic era emphasizes that understanding the molecular basis of each combination is essential for the rational selection of patients and for the design of second-generation combinations that overcome resistance (Al-Lazikani et al., 2012).

The implication for translational research is that demonstrating true pharmacodynamic synergy in cell culture is neither necessary nor sufficient for clinical success, and that combination strategies based on independent action, pathway complementarity, pharmacokinetic boosting, or immunological recruitment may be at least as important. Indeed, some of the most successful combinations in clinical oncology appear to combine elements of all of these mechanisms (Subbiah et al., 2020; Plana et al., 2022).

Clinical Translation: From In Vitro Interaction to Therapeutic Benefit

The translation of preclinical synergy into clinical benefit is fraught with difficulty. Combination clinical trials face logistic and regulatory challenges that monotherapy trials do not, including the need to establish the safety and pharmacokinetics of each agent individually before combining them, the difficulty of attributing toxicity to one agent or the other, and the intellectual property constraints that discourage collaboration between the pharmaceutical companies that own the individual agents. Combination trials have historically been slow to enroll, difficult to design, and vulnerable to attrition at higher failure rates than monotherapy trials. Regulatory considerations are particularly complex when two investigational agents are combined, since each agent requires its own safety database and the combined regimen requires evidence of benefit over either monotherapy (Al-Lazikani et al., 2012).

Methodological standards in combination trial design have nevertheless advanced. Novel designs, including adaptive platform trials and Bayesian model-based designs, have been proposed to accelerate the evaluation of combinations and to allow multiple agents to be tested in multiple combinations simultaneously. Seamless phase I/II designs have the potential to shorten the development path for combinations and to make better use of the large number of mechanistically plausible pairs generated by preclinical screening. In the specific context of drug-radiotherapy combinations, dedicated methodological and regulatory frameworks have been developed that may generalize to other modalities of combined treatment.

The single greatest obstacle to clinical translation remains the discordance between preclinical and clinical measures of interaction. A combination that produces a combination index of one half in cell culture may produce no clinical benefit, either because the preclinical effect reflects a mechanism absent in the patient, because the scheduling and pharmacokinetics of the clinical regimen do not reproduce the preclinical exposure, or because the tumor microenvironment modifies the interaction. Systematic analysis of preclinical and clinical combination studies has shown that concordance between preclinical synergy and clinical efficacy is modest at best (Chou, 2008). Addressing this discordance will require better preclinical models, including patient-derived organoids and xenografts, careful attention to drug exposure and scheduling in the design of preclinical studies, and clinical trial designs that incorporate biomarkers of the mechanism of interaction (Al-Lazikani et al., 2012; Plana et al., 2022).

The translational problem is compounded in practice by polypharmacy outside the trial setting. Patients receiving combination anticancer or antimicrobial therapy are frequently elderly and receive multiple drugs for comorbid conditions, so that the pharmacokinetic and pharmacodynamic interactions studied in a controlled trial are superimposed on an uncontrolled background of interacting comedications. Drug interaction screening tools and comprehensive

interaction checkers have improved the detection of high-risk pairs in routine care, but their predictive value is limited by context dependence and by the paucity of pharmacodynamic interaction data for most drug pairs. Regulatory frameworks for fixed-dose combinations, which require demonstration of the contribution of each component to the claimed effect, have in effect institutionalized the demand for interaction evidence at the population level, and the same standards are progressively being applied to combination regimens in oncology and infectious disease (Hakkola et al., 2020; Al-Lazikani et al., 2012).

Methodologically, the field is also moving from pairwise, static assessment toward dynamic and adaptive characterization of interactions. Machine learning models trained on large pan-cancer combination screens can now predict interaction sign and magnitude from genomic and pharmacological features with useful accuracy, and can be interrogated to identify the molecular features that drive predicted synergy, closing the loop between prediction and mechanism. Patient-derived organoids and microphysiological systems offer preclinical platforms in which drug exposure, metabolism, and multicellular architecture are reproduced more faithfully than in conventional two-dimensional culture, addressing at least part of the discordance that has historically separated in vitro interaction analysis from clinical outcome. Prospective testing of model-predicted combinations in such systems, followed by biomarker-stratified clinical evaluation, represents the most credible path from computational prediction to therapeutic practice (Plana et al., 2022; Van Hasselt & Iyengar, 2019).

Methodological Limitations and Future Directions

The second structural direction concerns the formal integration of interaction analysis with pharmacokinetics. Classical combination indices are computed on nominal concentrations, yet the concentration actually experienced by the target tissue is shaped by absorption, distribution, metabolism, and elimination, all of which can differ between the combination and monotherapy conditions. Dose-response matrices measured in the presence of realistic pharmacokinetic profiles, or analyzed with pharmacokinetic-pharmacodynamic linking models, would allow interaction to be attributed to its true locus rather than to the administered dose. Similarly, the development of sensitive assays for unbound intracellular drug concentration promises to separate transporter- and metabolism-driven effects from genuine target-level interactions, a separation that most current studies cannot achieve. Until such methods are routine, the combination index and its graphical analogs remain the best available summary of interaction, provided that their model dependence and their insensitivity to exposure dynamics are kept clearly in view (Chou, 2010; Foucquier & Guedj, 2015).

Several methodological limitations affect current practice in combination research. First, as discussed above, the definition of synergy is model-dependent, and different reference models produce different conclusions from the same data. Second, synergy is context-dependent: the same combination may be synergistic in one cell line, antagonistic in another, and inert in a third, so that extrapolation from a single model system is rarely justified. Third, many combination studies report only a single dose pair or a single effect level, which is insufficient to characterize the interaction surface and may produce misleading conclusions. Fourth, the intracellular concentrations of the two drugs are rarely measured, so that pharmacokinetic interactions at the cellular level, including competition for uptake transporters or efflux pumps, may be misinterpreted as pharmacodynamic interactions. Finally, most preclinical studies are conducted under cell culture conditions that do not reproduce the tumor microenvironment, the immune system, or the pharmacokinetics of intact organisms, all of which can profoundly modify the interaction of two drugs.

Future progress will depend on several developments. Quantitative systems pharmacology models that integrate drug pharmacokinetics, target engagement, network dynamics, and host physiology are needed to predict how cellular interactions translate into organismal effects.

Single-cell technologies and spatially resolved transcriptomics will allow interaction to be mapped at the level of individual cells within a heterogeneous population, providing a much more complete picture than population-averaged assays. Genome-wide perturbation screens will identify the genetic determinants of synergy and antagonism for each drug pair, enabling rational patient stratification. Evolutionary models that integrate drug interaction with resistance evolution will guide the design of combinations that are not only efficacious at the outset but remain efficacious over time (Baym et al., 2016; Yeh et al., 2009). Finally, the network pharmacology paradigm will continue to mature into a predictive framework that identifies new combinations from the topological and dynamic properties of disease-relevant molecular networks (Hopkins, 2008).

Conclusion

Drug synergy and antagonism are not unitary phenomena but the emergent consequences of multiple molecular and cellular mechanisms acting at the level of targets, pathways, transporters, metabolism, and the broader biological system in which the drugs act. Quantitative frameworks built on Loewe additivity, Bliss independence, the combination index, and isobolographic analysis provide the essential foundation on which claims of interaction must rest, while the mechanistic interpretation of interaction requires an understanding of everything from cytochrome P450 metabolism to apoptotic signaling to immunological recruitment. The distinction between pharmacokinetic and pharmacodynamic interaction is fundamental to correct interpretation, and the recent recognition that many clinically successful combinations are not synergistic by strict definitions has clarified the relationship between preclinical interaction analysis and therapeutic benefit. Antagonism, long regarded as an unwanted outcome, is now understood in some contexts to offer therapeutic opportunities through its effects on resistance evolution. The future of combination therapy lies in the integration of quantitative interaction analysis with systems-level models, evolutionary principles, and mechanistic biomarkers, so that combinations are designed from first principles rather than discovered empirically and translated rationally rather than opportunistically.

In practical terms, the lessons of this synthesis can be summarized as a set of working principles for combination research. Define the interaction against an explicit reference model and report the model, the effect level, and the dose ratio, because synergy claimed without these parameters is not interpretable. Separate pharmacokinetic from pharmacodynamic mechanisms before attributing an effect to target biology, since the two demand entirely different interventions. Characterize the interaction across the full dose matrix and in more than one cellular background before drawing conclusions about the drug pair, because context dependence is the norm rather than the exception. Consider resistance evolution from the outset, since a combination that selects strongly for resistance may be inferior in the long run to a mildly antagonistic one that constrains it. Test higher-order interactions empirically whenever a regimen contains more than two agents, because pairwise data do not predict them. Finally, remember that the clinical objective is the therapeutic index rather than the combination index, and that a regimen wins not by maximizing interaction in a cell culture dish but by integrating efficacy, toxicity, pharmacokinetic feasibility, and resistance management in the patient. These principles do not diminish the excitement of the molecular mechanisms described in this review; on the contrary, they are the conditions under which those mechanisms can be converted reliably into clinical benefit.

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СЫРДАРИЯ ӨЗЕНІ ӨСІМДІКТЕРІНІҢ ТАРАЛУ ЕРЕКШІЛІГІ

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Аңдатпа. *Бұл мақалада Түркістан облысы аумағында орналасқан Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің Сырдария өзені жайылмасындағы өсімдік жамылғысының таралу ерекшеліктері қарастырылды. Зерттеу барысында парктың ресми материалдары, флористикалық зерттеулер, ғылыми жарияланымдар және Сырдария өзені аңғарының өсімдік жамылғысына қатысты әдеби деректер талданды.*

Өсімдіктердің таралуына өзен суының режимі, топырақтың ылғалдылығы мен тұздылығы, жер бедері, грунт суларының орналасуы және антропогендік әсер негізгі факторлар ретінде ықпал етеді. Өзенге жақын ылғалды учаскелерде қамыс, тал, тораңғы, жиде және түрлі шалғындық өсімдіктер басым болса, өзеннен алыстаған сайын жыңғыл, шеңгел, жусан, сораң және басқа да құрғақшылық пен тұздануға төзімді өсімдіктердің үлесі артады. Ерекше назар тораңғы ормандарына аударылады, себебі олар Сырдария аңғарының табиғи экожүйелерін тұрақтандыруда және биоалуантүрлілікті сақтауда маңызды рөл атқарады. Зерттеу нәтижелері Сырдария жайылмасындағы өсімдіктердің кеңістіктік таралуы гидрологиялық жағдайлармен тығыз байланысты екенін көрсетті.

Түйін сөздер: *Сырдария өзені, өсімдік жамылғысы, флора, жайылма, атырау, тораңғы, қамыс, жыңғыл, Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі, биоалуантүрлілік, өсімдіктердің таралуы.*

Кіріспе. Өсімдік жамылғысы кез келген табиғи аумақтың экологиялық тұрақтылығын қамтамасыз ететін маңызды компоненттердің бірі болып табылады. Өсімдіктер топырақ түзілу процесіне, су айналымына, жануарлар дүниесінің тіршілік ету ортасын қалыптастыруға және атмосфералық көмірқышқыл газын сіңіруге қатысады. Әсіресе өзен аңғарларындағы өсімдік қауымдастықтарының маңызы жоғары. Себебі өзен аңғары қоршаған шөл және шөлейт ландшафттарымен салыстырғанда ылғал мөлшері жоғары, микроклиматы салыстырмалы түрде жұмсақ және өсімдік жамылғысы түрлік жағынан бай экологиялық дәліз қызметін атқарады.

Қазақстанның оңтүстік бөлігіндегі ірі өзендердің бірі – Сырдария. Оның аңғары шөлдік және шөлейттік табиғи жағдайлардың арасында орналасқан ерекше экологиялық жүйе болып саналады. Өзеннің суы мен грунт суларының әсерінен мұнда тоғайлы ормандар, шалғындар, қамысты қауымдастықтар, бұталы өсімдіктер және галофиттік өсімдік топтары қалыптасқан.

Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі Түркістан облысының маңызды ерекше қорғалатын табиғи аумақтарының бірі болып табылады. Парктың негізгі міндеттерінің бірі – Сырдария және Арыс өзендерінің жағалауларындағы табиғи кешендерді, өсімдіктер мен жануарлар дүниесін сақтау. Парктың қазіргі ресми мәліметтері бойынша оның жалпы жер көлемі 119 978,418 га, оның ішінде Түркістан филиалы – 37 656 га, Сырдария филиалы – 46 068 га, Боралдай филиалы – 36 255 га аумақты қамтиды.

Зерттеудің мақсаты – Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі аумағындағы Сырдария өзені аңғары өсімдіктерінің түрлік құрамын және олардың кеңістіктік таралу ерекшеліктерін әдеби деректер негізінде талдау.

Зерттеу міндеттері:

1. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің табиғи-географиялық ерекшеліктерін сипаттау;
2. Сырдария аңғары флорасының түрлік құрамына талдау жасау;
3. Өсімдіктердің өзен арнасына қатысты таралу заңдылықтарын анықтау;
4. Негізгі өсімдік қауымдастықтарын сипаттау;
5. Сирек және қорғауды қажет ететін өсімдік түрлерін анықтау;
6. Өсімдік жамылғысына әсер ететін негізгі экологиялық және антропогендік факторларды бағалау.

1. Зерттеу нысаны және әдістері

Зерттеу нысаны ретінде Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің Сырдария өзені жайылмасы мен оған іргелес табиғи кешендері алынды.

Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі Түркістан облысында орналасқан. Парк 2012 жылы Арыс, Боралдай және Түркістан орман және жануарлар әлемін қорғау жөніндегі мемлекеттік мекемелерді біріктіру арқылы құрылған. Ал Сырдария өзенінің жайылмасындағы жергілікті маңызы бар табиғи кешенді қаумал 2010 жылы құрылып, оның негізгі мақсаттарының бірі Сырдария аңғары экожүйелерін сақтау және қалпына келтіру болған.

Зерттеу барысында салыстырмалы-географиялық, флористикалық, экологиялық-географиялық және әдеби-талдамалық әдістер пайдаланылды. Парктың ресми сайтындағы флора жөніндегі мәліметтер, ғылыми-зерттеу жұмыстарының нәтижелері және Сырдария аңғарының өсімдік жамылғысына арналған ғылыми жарияланымдар салыстырылды.

Өсімдіктердің таралу ерекшеліктерін анықтау кезінде олардың суға және топырақ ылғалына қатынасы, тұздануға төзімділігі, тіршілік формасы және өзен арнасына қатысты орналасу жағдайы ескерілді.

Бұл мақала жаңа далалық экспедициялық материалдарды ұсынбайды, сондықтан келтірілген сандық көрсеткіштер жарияланған және парктың ресми деректерінен алынған мәліметтер ретінде қарастырылады.

2. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің табиғи жағдайы

Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің табиғи кешендері біркелкі емес. Парк аумағында екі негізгі табиғи тип ерекшеленеді: Сырдария мен Арыс өзендерінің жайылмалық-аңғарлық ландшафттары және Боралдай жотасының таулы табиғи кешендері.

Сырдария филиалы негізінен жазық, жайылмалық және өзен аңғарының табиғи кешендерін қамтиды. Сондықтан бұл аймақта өсімдіктердің таралуын анықтайтын басты фактор – су режимі.

Сырдария өзені аңғары шөлдік климат жағдайында орналасқандықтан, өзенге жақын аумақтарда өсімдіктердің өсуіне қолайлы жағдай қалыптасады. Өзен суы мен грунт сулары топырақтағы ылғал мөлшерін арттырады. Соның нәтижесінде өзен жағалауында ағаштар мен бұталардан құралған тоғайлар, қамыс және шалғындық өсімдіктер таралады.

Өзеннен қашықтаған сайын топырақ ылғалы азайып, тұздану деңгейі жоғарылауы мүмкін. Мұндай жағдайда гидрофиттер мен мезофиттердің орнына ксерофиттік және галофиттік өсімдіктер басымдық ала бастайды.

Осылайша Сырдария аңғарындағы өсімдіктердің таралуын шартты түрде «су айдыны – жағалау – жайылма – жайылма үсті терраса – шөлдік ландшафт» бағытында қарастыруға болады.

3. Сырдария өзені жайылмасындағы флораның түрлік құрамы

Флораның жетекші тұқымдастарының ішінде:

Тұқымдас	Түрлік құрамдағы үлесі
Алабұталар	18 %
Күрделігүлділер	16 %
Астық тұқымдастар	12 %
Бұршақ тұқымдастар	6 %
Крестгүлділер	4 %
Тарандар	3 %
Басқа тұқымдастар	Қалған бөлігі

Алабұталар тұқымдасының жоғары үлесі Сырдария аңғарының шөлдік және сортаңданған орталарымен байланысты. Бұл тұқымдастың көптеген өкілдері құрғақшылыққа және топырақтағы тұз мөлшерінің жоғары болуына бейімделген.

Астық тұқымдастарының едәуір үлесі өзен жағалауларындағы ылғалды шалғындықтар мен қамысты қауымдастықтарға байланысты. Олардың құрамына қамыс, бидайық, ажырық және басқа шөптесін өсімдіктер кіреді.

Бұршақ тұқымдастарының өкілдері де өзен аңғарында кездеседі. Олардың ішінде мия сияқты түрлер шалғындық және жайылмалық экожүйелер үшін маңызды.

Сырдария аңғары флорасының тағы бір ерекшелігі – оның экологиялық топтарға жіктелуінің айқын байқалуы. Су маңында ылғал сүйгіш түрлер, жайылманың құрғақтау бөліктерінде шалғындық және бұталы өсімдіктер, ал тұзданған учаскелерде галофиттер таралады.

4. Өсімдіктердің өзен арнасына қатысты таралуы

Сырдария өзені бойындағы өсімдіктердің таралуын олардың суға қажеттілігіне қарай бірнеше экологиялық белдеуге бөлуге болады.

4.1 Су маңы және жағалау белдеуі

Өзен арнасына ең жақын учаскелерде су деңгейінің маусымдық өзгеруіне төзімді өсімдіктер қалыптасады. Мұнда қамыс, әртүрлі қияқөлеңдер, шөптесін өсімдіктер және жағалық бұталар кездеседі.

Қамыс – Сырдария аңғарының ең тән өсімдіктерінің бірі. Ол өзен жағалауларында, ескі арналарда, көлтабанды ойыстарда және ылғалдылығы жоғары жерлерде қалың қауымдастық түзеді.

Қамысты алқаптар тек өсімдік жамылғысының элементі емес, көптеген жануарлар үшін мекен ету және қоректену ортасы болып табылады. Сондықтан оның экожүйелік маңызы жоғары.

4.2 Тоғайлы белдеу

Сырдария аңғарының маңызды өсімдік қауымдастықтарының бірі – **тоғай**лар. Тоғай құрамында талдар, теректер, жиде, тораңғы және басқа да ағаш-бұта түрлері кездеседі.

Сурет 1. Сырдария филиалы, Арыс орманшылығы

Сырдария өзені жағалауындағы тоғайлы өсімдіктердің таралуы грунт суларының тереңдігімен тығыз байланысты. Грунт сулары жер бетіне жақын орналасқан учаскелерде ағаш және бұта өсімдіктері жақсы дамиды.

Сырдария аңғарында жиде, тал және тораңғыдан тұратын тоғайлар ерекше экологиялық маңызға ие. Ғылыми және ресми материалдарда тораңғы ормандарын сақтау мәселесіне арнайы көңіл бөлінетіні көрсетілген.

Парктың 2024–2028 жылдарға арналған ғылыми-зерттеу бағыттарының бірі – Сырдария өзені сағасындағы тораңғы ормандарын сақтау, олардың флорасын түгендеу және мониторинг жүргізу.

4.3 Шалғындық белдеу

Жайылманың салыстырмалы түрде биіктеу және уақытша ғана су басатын бөліктерінде шалғындық өсімдіктер таралады.

Бұл жерде бидайық, ажырық, әртүрлі астық тұқымдастар, мия және басқа шөптесін түрлер кездеседі.

Шалғындық өсімдіктердің дамуына көктемгі су тасуы мен грунт суларының деңгейі әсер етеді. Су тасқыны кезінде ылғалданған топырақ кейін біртіндеп құрғаған кезде шалғындық өсімдіктердің өсуіне қолайлы жағдай қалыптасады.

4.4 Бұталы белдеу

Өзеннен алыстаған сайын ылғал мөлшері азаяды. Мұндай жағдайда жыңғыл, шеңгел және басқа құрғақшылыққа төзімді бұталар таралады.

Жыңғыл (Tamarix) тұзды топырақтарға бейімделген өсімдіктердің бірі. Оның тамыр жүйесі грунт суларына жетіп, құрғақ климат жағдайында өмір сүруге мүмкіндік береді.

Шеңгел тәрізді бұталар да өзен жайылмасының құрғақтау және тұзданған бөліктерінде кездеседі.

4.5 Галофиттік өсімдіктер белдеуі

Сырдария аңғарында топырақтың тұзденуы өсімдіктердің таралуына елеулі әсер етеді. Сортаң және сор топырақтарда тұзға төзімді өсімдіктер – галофиттер басым болады.

Оларға алабұталар тұқымдасының көптеген өкілдері жатады. Бұл топтың жоғары түрлік үлесі Сырдария жайылмасының экологиялық жағдайын сипаттайтын маңызды көрсеткіштердің бірі болып табылады.

5. Тораңғы тоғайларының экологиялық маңызы

Сурет 2. Сырдария филиалы, Байырқұм орманшылығы

Сырдария аңғарындағы ерекше назар аударуды қажет ететін өсімдік қауымдастықтарының бірі – тораңғы тоғайлары.

Тораңғы – шөлдік өзен аңғарларында қалыптасатын тоғай экожүйелеріне тән ағаш. Оның тамыр жүйесі жер асты суымен байланысты болғандықтан, өзен аңғарындағы гидрологиялық режимге тәуелді.

Тораңғы тоғайлары бірнеше маңызды экологиялық қызмет атқарады:

* өзен жағалауын бекітеді;
* топырақ эрозиясын азайтады;
* желдің әсерін әлсіретеді;
* микроклимат қалыптастырады;
* жануарларға мекен және қорек береді;
* биоалуантүрлілікті сақтайды;
* өзен аңғарының табиғи ландшафтық келбетін қалыптастырады.

Сырдария өзенінің жайылмасында тораңғының екі түрі – түрліжапырақты тораңғыл және тораңғы кездесетіні көрсетілген. Сонымен қатар тораңғының Қазақстанның Қызыл кітабына енгізілген түрлері бар екені атап көрсетіледі.

Сондықтан тораңғы популяцияларының жағдайын тұрақты бақылау Сырдария аңғары экожүйесін қорғаудың негізгі бағыттарының бірі болуы тиіс.

6. Сирек және қорғауды қажет ететін өсімдіктер

Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің флоралық маңызы оның тек түр санының көптігімен емес, сирек және қорғауды қажет ететін өсімдіктердің болуымен де анықталады.

Парктың аумағында Қазақстанның Қызыл кітабына енгізілген 52 астам өсімдік түрі кездеседі. Олардың қатарында Зеравшан аршасы, Грейг қызғалдағы, кәдімгі пісте, Сиверс алмасы және басқа сирек өсімдіктер бар.

Бұлардың басым бөлігі Боралдай таулы аймағымен байланысты болғанымен, Сырдария филиалының да өзіндік қорғауды қажет ететін флорасы бар.

Сырдария аңғарында сирек өсімдік түрлерін сақтауда табиғи су режимін сақтау ерекше маңызды. Өйткені өзен суының азаюы және грунт сулары деңгейінің төмендеуі бірінші кезекте ылғалға тәуелді өсімдіктердің жағдайына әсер етеді.

7. Өсімдік жамылғысының таралуына әсер ететін факторлар

Сырдария аңғарындағы өсімдіктердің таралуы табиғи және антропогендік факторлардың бірлескен әсерімен анықталады.

7.1 Гидрологиялық фактор

Су – Сырдария жайылмасы өсімдіктерінің таралуын анықтайтын негізгі фактор. Өзен деңгейінің маусымдық өзгеруі жайылманың белгілі бөліктерін су басуына әкеледі.

Су режимінің өзгеруі өсімдік қауымдастықтарының құрамына тікелей әсер етеді. Ылғалдың азаюы қамыс пен басқа гидрофиттердің таралу аумағын қысқартуы мүмкін.

7.2 Топырақ факторы

Сырдария жайылмасында аллювиалды-шалғынды, шалғынды-батпақты және тұзданған топырақтар кездеседі. Әр топырақ типіне белгілі бір өсімдік қауымдастығы бейімделеді.

Мысалы, ылғалды аллювиалды топырақтарда қамыс пен шалғындық өсімдіктер жақсы дамыса, тұзданған топырақтарда галофиттік түрлер басым болады.

7.3 Климаттық фактор

Түркістан өңірінің климаты құрғақ және ыстық. Жазғы температураның жоғары болуы булануды күшейтеді. Сондықтан өзеннен алыстаған сайын табиғи ылғалдың азаюы өсімдіктердің таралуына шектеу қояды.

7.4 Антропогендік фактор

Сырдария аңғарының өсімдік жамылғысына мал жаю, ауыл шаруашылығы, суару жүйелері, жол және елді мекендердің кеңеюі әсер етеді.

Сырдария аңғарының басқа бөліктеріне жүргізілген зерттеулерде қарқынды мал жаю, ауыл шаруашылығы, көлік және техногендік әсер өсімдік жамылғысының деградациясына әкелетіні көрсетілген. Бұзылған учаскелерде түрлік байлық төмендеп, арамшөптік және экологиялық құндылығы төмен түрлердің үлесі артуы мүмкін.

Бұл заңдылық Сырдарияның Түркістан облысы аумағындағы бөліктері үшін де мониторинг жүргізу қажеттігін көрсетеді.

8. Өсімдіктерді қорғау және мониторинг

Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің басты міндеттерінің бірі – табиғи кешендерді және ерекше құндылығы бар өсімдіктер дүниесін сақтау.

Өсімдіктерді қорғаудың тиімді жүйесі бірнеше бағыттан тұруы қажет:

1. Флораны тұрақты түгендеу.

Түрлердің қазіргі таралу аймақтарын анықтап, бұрынғы деректермен салыстыру қажет.

2. Тұрақты мониторинг алаңдарын ұйымдастыру.

Тораңғы, жиде, тал және қамыс қауымдастықтарының динамикасын бақылау маңызды.

3. Су режимін бақылау.

Өзен деңгейінің және грунт суларының өзгеруі өсімдіктердің жағдайымен бірге қарастырылуы тиіс.

4. Сирек түрлердің популяциялық мониторингі.

Қызыл кітапқа енгізілген және жергілікті сирек түрлердің саны, таралу аумағы және табиғи жаңаруы анықталуы қажет.

5. Антропогендік жүктемені реттеу.

Мал жаю, ағаш кесу, өсімдіктерді жинау және рекреациялық қысым шектелуі тиіс.

6. Қашықтан зондтау және ГАЖ технологияларын пайдалану.

Спутниктік суреттер арқылы тоғайлардың, қамысты алқаптардың және деградацияланған аумақтардың өзгерісін бақылауға болады.

7. Экологиялық ағарту жұмыстарын жүргізу.

Жергілікті тұрғындар мен туристер арасында сирек өсімдіктерді қорғау туралы ақпараттық жұмыстар жүргізудің маңызы зор.

Қорытынды. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі аумағы Қазақстанның оңтүстігіндегі флоралық әртүрлілігі жоғары ерекше қорғалатын табиғи аумақтардың бірі болып табылады.

Өсімдіктердің кеңістіктік таралуында негізгі заңдылық – олардың суға және топырақ ылғалына тәуелділігі. Өзен арнасына жақын аймақтарда қамыс және басқа ылғал сүйгіш өсімдіктер, жайылманың ағашты бөліктерінде тал, жиде және тораңғы тоғайлары, ал құрғақтау және тұзданған учаскелерде жыңғыл, шеңгел және галофиттік өсімдіктер таралады.

Тораңғы тоғайлары Сырдария аңғарының табиғи экожүйесін сақтауда ерекше орын алады. Олар топырақты бекітіп, микроклиматты қалыптастырады, жануарлар үшін мекен ету ортасын қамтамасыз етеді және биоалуантүрліліктің сақталуына ықпал етеді. Сондықтан тораңғы ормандарын қорғау, олардың табиғи жаңаруын бақылау және тұрақты мониторинг жүргізу қажет.

Қазіргі жағдайда Сырдария аңғарындағы өсімдіктердің сақталуы өзеннің табиғи гидрологиялық режимін, топырақтың ылғалдылығы мен тұздылығын және антропогендік жүктемені бақылаумен тығыз байланысты.

Алдағы уақытта Сырдария–Түркістан өңірлік табиғи паркінің өсімдік жамылғысын зерттеу барысында тұрақты мониторинг алаңдарын ұйымдастырып, ГАЖ және қашықтан зондтау әдістерін пайдалану, сирек түрлердің популяциялық жағдайын анықтау және өсімдік қауымдастықтарының маусымдық динамикасын зерттеу ұсынылады.

Осы шаралар Сырдария аңғарының табиғи өсімдік жамылғысын сақтап қана қоймай, өңірдің экологиялық тұрақтылығын қамтамасыз етуге мүмкіндік береді.

Пайдаланылған әдебиеттер тізімі:

1. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі. 10 жылдығына арналған.
2. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі. Флоралық әртүрлілігі. Сырдария өзенінің жайылмасы мен атырауының флорасы жөніндегі мәліметтер.
3. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркі. 2020-2025 жылдардағы ғылым, ақпарат және мониторинг бөлімінің атқарған жұмыстары.
4. Төлеміс Е.Х. Сырдария-Түркістан мемлекеттік өңірлік табиғи паркінің табиғи кешендері және флорасы. Биологиялық бағыттағы ғылыми материалдар.
5. Сырдария–Түркістан өңірлік табиғи паркі аумағындағы Боралдай тауының ағашты өсімдіктерін зерттеу. Букетов атындағы Қарағанды университетінің репозиторийі.
6. Веселова П.В., Кудабаева Г.М., Абдилданов Д.Ш., Үсен С. Сырдария өзені аңғарының шөлейт бөлігіндегі өсімдіктердің құрамы мен құрылымына бұзылу факторларының әсері. ҚазҰУ Хабаршысы. Биология сериясы. 2025. №3. 125–138. DOI: 10.26577/bb2025104310.
7. Қазақстан Республикасының ерекше қорғалатын табиғи аумақтары туралы нормативтік материалдар. Сырдария–Түркістан мемлекеттік өңірлік табиғи паркінің қорғау аймағының режимі.
8. Сырдария өзенінің аңғары мен жайылма өсімдіктері туралы материалдар. Өзен аңғарындағы тоғай, шалғын және галофиттік өсімдіктердің таралу ерекшеліктері.
9. Қызылорда облысының табиғи-географиялық және өсімдік жамылғысы туралы материалдар. Сырдария жайылмасындағы тоғайлы және шөлдік өсімдіктер қауымдастықтары.

Philological Sciences

The Missing Middle- Why AI in Education Needs Guardrails, Not Hype or Panic

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Artificial intelligence is being sold to schools, parents, and students as a near-universal good — a tool that personalizes learning, saves teachers time, and helps struggling students catch up. The marketing is confident. The evidence, so far, is not. That gap between promise and proof is the real story here, and it matters more than a simple "AI good" or "AI bad" verdict.

A 2026 case study examining AI tool use in an asynchronous university course found no statistically significant difference in final grades between students who used AI tools and those who didn't [1]. What did predict performance, across both groups, was active engagement with the course, not which tools students used [1]. In other words, the technology itself was not the variable that mattered, which is an uncomfortable finding for an industry whose pitch rests almost entirely on the technology being the variable that matters. This is not an isolated result; it is a symptom of a wider pattern that researchers inside the field of educational technology, not outside critics, have been naming for several years. Neil Selwyn, a leading scholar of education technology, has spent much of the last few years cataloguing the ways AI's educational benefits get overstated. In 2022 he outlined several concerns with the trajectory of AI in schools, warning against uncritical acceptance of industry claims and pointing to the social harms, ideological assumptions, and environmental costs that tend to be left out of the pitch [2]. In a 2024 follow-up, Selwyn argued that the sheer volume of hyperbole surrounding AI has made it harder to think clearly about its actual, lasting educational implications, and cautioned that uncontrolled reliance on these tools risks reducing authentic learning experiences and genuine cognitive engagement [3]. A separate 2024 study built and validated a model of AI's underdiscussed downsides in education, drawing on 56 reviewed studies and a survey of 260 university participants; it confirmed concerns spanning reduced human connection, data privacy and security risks, algorithmic bias, weakened critical thinking, and unequal access, and found these problems tend to compound each other rather than occur in isolation [4]. None of this is fringe skepticism. It is coming from the people who study education technology for a living.

If one wants to see what happens when screen-based engagement scales without dosage limits, autism research offers one of the clearest, and most concerning, data sets available, precisely because autistic children are already documented to spend more time on screens than their neurotypical peers. A study of Iranian toddlers with autism spectrum disorder found a clear dose-response relationship: every additional hour of foreground screen media was associated with a measurable increase in ASD symptom severity scores, while every additional hour of social interaction was associated with a decrease [5]. A separate longitudinal study following children at high familial likelihood for autism found that greater screen exposure at 18 months predicted both higher rates of autism and ADHD symptoms and lower developmental achievement by preschool age, and that children who went on to receive an autism or ADHD diagnosis had already been exposed to significantly more screen time earlier in development than their peers [6]. This tracks with the American Academy of Pediatrics' existing recommendation to avoid screens entirely under age two and cap them at one hour daily between ages two and five, guidance that most children in the relevant studies already exceed [7]. The term researchers have started using for this pattern

is "virtual autism," first proposed by psychologist Marius Zamfir in 2018 to describe autism-like symptoms, including delayed language, reduced social engagement, and sensory difficulties, appearing in children under three after prolonged screen exposure (8, pg. 447). It is a useful term for naming a real correlation, but it deserves a caveat: a comprehensive 2026 review of this literature notes that the association between screen exposure and autism-related outcomes is generally small in magnitude and marked by considerable heterogeneity across studies, and stresses that virtual autism is not a formal diagnosis recognized in the DSM-5 or ICD-11, remaining a proposed descriptive concept rather than an established clinical category [9]. The risk is real enough to take seriously. It is not yet settled science, and an article, or an industry, that treats it as either nonexistent or definitively proven would be overstating its case in opposite directions.

This is not a story about one population, however. It is what tends to happen whenever engagement-optimized technology scales without limits, across children generally. A broader review of the cognitive effects of digital technology found that every additional hour of daily television at ages one and three increased the risk of measurable attentional problems at age seven by 9%, and that preschoolers watching more than two hours of screens daily were nearly eight times more likely to meet criteria for ADHD, though notably, entertainment content, not educational content, drove these effects [10]. That distinction matters for any AI-education pitch built on "educational" screen time, since it suggests the content type, not just the presence of a screen, does real work in these outcomes. The backlash is visible in sentiment data too. A 2026 survey found Gen Z's enthusiasm for AI dropped 14 percentage points in a single year, with reported anger toward the technology rising nine points, even among people who use it daily [11]. The same reporting found a majority of educators now believe ed-tech is actively hindering students' social and emotional development, behavior, mental health, and overall well-being [11]. Whatever AI in education eventually becomes, the people currently living through its rollout are growing less convinced by the pitch, not more.

None of this means AI has no place in education, and a fair account has to give real weight to where it works. Assistive applications aimed at neurodivergent students show genuine, practical value: digital calendars, task reminders, and structured routines that support independence and daily functioning, tools that are narrow in scope and do not ask a child to simply spend more time looking at a screen for its own sake [12]. The same 2026 survey cited above found 71% of teachers believe AI specifically helps students learn in ways suited to them, and 90% of respondents agreed digital tools, AI included, have a legitimate place in education [11]. The earlier finding that active engagement, not tool use, predicted academic outcomes cuts both ways: it suggests AI can support learning when it is paired with genuine engagement rather than substituted for it [1]. The pattern that emerges is consistent. Scoped, purposeful tools with a clear function tend to hold up under scrutiny, while open-ended, engagement-maximizing tools marketed as general-purpose learning solutions tend not to.

Taken together, this evidence points toward regulation, not rejection. It suggests a need for dosage limits by age, modeled on existing screen-time guidance, rather than open-ended use marketed as inherently beneficial [7]. It also suggests a need for outcome verification before marketing claims are allowed to shape purchasing decisions or parental expectations. An investigative teardown of a 2019 New York Times feature on the ed-tech product Bakpax found the article was sourced almost entirely from company spokespeople and borrowed heavily from the company's own PR material to inflate AI's actual role, while downplaying the teacher labor that kept the system running; the product shut down in 2022 [13]. Beyond verification, there is a case for drawing a clear line between scoped assistive tools and general-purpose engagement tools, since reminder systems and structured routines are a fundamentally different category of product from AI systems designed to maximize time-on-screen, and arguably warrant different regulation. Finally, the risks researchers have already identified, including data privacy, algorithmic bias, and

reliability, point toward a need for genuine transparency requirements rather than voluntary disclosure [4].

It is worth ending with a caveat aimed at critics as much as advocates. Some scholars have warned that backlash against digital technology in education can be hijacked by a broader "back to basics" political movement, one that opposes progressive, socially oriented pedagogy for reasons that have little to do with the actual evidence on AI or screens, and everything to do with reframing learning as a narrowly individual, cognitive activity [14]. That is a real risk too. The goal of this article is not to romanticize a screen-free classroom or to treat every skeptical voice as automatically correct; it is to insist that claims in either direction be held to the same evidentiary standard the technology itself is supposedly built on.

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The role of artificial intelligence technologies in the educational environment

Роль технологий искусственного интеллекта в образовательной среде

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Annotation. The article is devoted to understanding the digital transformation of higher education in the context of the rapid spread of artificial intelligence technologies. It examines changes in the organization of the educational process, the role of the teacher, the nature of learning tasks, approaches to assessment, and the development of academic integrity. Special attention is paid to students' language training, since it is working with text, argumentation, translation, and oral and written speech that simultaneously unlocks the productive potential of generative artificial intelligence and fosters a critical attitude towards its results. The article analyses UNESCO's international guidelines and the regulatory documents of the Republic of Kazakhstan in the field of artificial intelligence development. A pedagogical model "AI as a tool — human as an author" is proposed, based on step-by-step interaction: task definition, generation, verification, editing, argumentation, and reflection. It has been shown that digital transformation should not be limited to the technical equipment of the educational environment: it involves changing the content of competencies, teaching methods, and the culture of scientific and educational activities.

Keywords: digital transformation, artificial intelligence, generative artificial intelligence, higher education, language competence, academic integrity, digital literacy, critical thinking, Kazakhstan, educational technologies.

Introduction.

In recent years, the digital transformation of education has moved from the realm of individual innovative projects to the sphere of systemic changes. The emergence of generative artificial intelligence models capable of creating coherent texts, images, presentations, software code, and other products has significantly expanded the understanding of what operations can be delegated to digital tools. For higher education, this means a change not only in the set of technologies used but also in the very logic of organizing educational activities. If previously digitalization was primarily associated with electronic educational platforms, distance learning courses, digital libraries, and the automation of individual procedures, today the central issue is the distribution of intellectual work between a person and an algorithmic system.

UNESCO views generative artificial intelligence as a technology that simultaneously creates new opportunities and raises issues for education regarding regulation, data protection, pedagogical appropriateness, equality of access, and the preservation of human subjectivity [1, pp. 8–12]. The document emphasizes the need for a human-centered approach, in which artificial intelligence does not replace educational goals but is used to achieve them. This position is particularly important for universities, since higher education is responsible not only for transmitting knowledge but also for developing independent thinking, research skills, professional communication, and the ability to make informed decisions.

For Kazakhstan, the issue takes on additional significance in connection with the development of national policy in the field of artificial intelligence. The concept for the development of artificial intelligence for 2024–2029 establishes the need to develop human capital, digital competencies, and the conditions for the implementation of AI in various spheres of public life [2, pp. 6–15]. In 2026, the digital agenda was further developed in the nationwide strategy “Digital Qazaqstan” until 2029, which is focused on systemic digitalization and large-scale implementation of artificial intelligence technologies [3]. Consequently, the university becomes one of the spaces where professionals are formed who are not only capable of using AI but also of critically evaluating its results.

The aim of this article is to identify the main pedagogical changes associated with the use of artificial intelligence in higher education and to substantiate the possibilities of its use in developing students’ language competence. To achieve this aim, the following tasks are considered: to identify the main directions for transforming the educational process; to determine the role of the teacher in the environment of generative AI; to analyze the possibilities of using AI in language training; to identify risks and limitations; to propose a practical model for organizing learning activities.

Artificial intelligence as a factor changing the educational paradigm.

However, the system’s ability to quickly generate text does not automatically mean that the result will be of high quality. Generative models can reproduce factual errors, inaccurate references, oversimplified explanations, and stylistic inconsistencies. Therefore, the nature of the learning competence fundamentally changes. It is not enough for a student to know how to get an answer; they must be able to verify the answer, compare it with reliable sources, determine the limits of applicability, and rework the material they have obtained. In this sense, digital transformation enhances the importance of critical thinking.

In the traditional model, a learning task is often structured according to the “read — understand — reproduce” scheme. Given the availability of generative AI, the scheme “define the task — get options — check — compare — justify — create your own product” becomes more productive. This sequence shifts the focus from reproducing a ready-made result to managing the intellectual process. The student must demonstrate not only the final text but also the ability to explain why they chose a particular solution.

This approach aligns with the modern understanding of digital competence. It encompasses not only technical skills but also information literacy, security, responsible behavior, and the ability to use digital resources meaningfully. For the university environment, these are supplemented by a research culture, academic integrity, and professional responsibility.

The new role of the teacher in the generative AI environment

Consequently, the pedagogical design is also changing. Instead of focusing on a single final product, it is more appropriate to evaluate the process: the initial task formulation, the request to the AI, the selection of the result, the fact-checking, the editing, and the final authorial position.

This format makes learning activities more transparent and at the same time fosters metacognitive skills.

For language teachers, this opens up broad opportunities. AI can act as a dialogue partner, a draft editor, a language example generator, a professional situation simulator, or a comparative analysis tool. However, the final decision regarding the normativity, accuracy, and appropriateness of a linguistic variant should be made by the student, based on the rules they have studied and reference sources.

Thus, the professional competence of a teacher in a digital environment includes two interrelated components: subject-methodological and digital. The first allows you to determine what the student needs to be taught; the second enables you to choose a technology and integrate it into the learning process in such a way that it enhances, rather than replaces, the educational goal.

Language training as a space for productive interaction with AI.

Language education has its own specific features: its outcome is manifested not only in knowledge of the rules but also in the ability to independently create and understand texts, participate in dialogue, argue a position, and take into account the communicative situation. Therefore, generative AI can be particularly useful as a training environment.

The first area is working with written speech. A student can prepare their own text and then request comments from the AI regarding its structure, logic, and language. At the same time, it is important that the system does not rewrite the text completely. From a pedagogical perspective, it is more valuable to receive a list of problems and correct them independently. After that, the student can compare the original and edited versions and explain each significant change.

The second area of focus is the development of dialogic speech. Generative AI makes it possible to model professional situations: telephone conversations, tourist service, hotel check-in, conflict resolution, customer consultation, and business correspondence. A student can engage in a dialogue in a given role and then analyze the speech formulas used, the level of politeness, the accuracy of the vocabulary, and the relevance to the professional situation.

The third area of focus is working with the level of difficulty. For students with different levels of language proficiency, the same material can be adapted into several versions: B1, B2, or C1. However, the result must undergo pedagogical review. Simplifying the text may lead to a loss of semantic nuances, while artificially complicating it may result in unnatural vocabulary. Therefore, the teacher uses AI as a tool for preparing options, not as a final editor.

The model “AI as a tool — human as the author.”

For the practical organization of classes, it is advisable to use a model in which generative AI is considered not as the author of the educational product, but as a tool at certain stages of its creation. The model includes six sequential stages.

The first stage is task definition. The student independently determines the goal, the audience, the genre, and the main requirements for the product. For example: “Prepare a brief informational message for a foreign tourist about the rules of conduct at the historical and cultural site in Turkestan.” Already at this stage, independent thinking work is being formed.

The second stage is generating options. The student contacts the AI with a request and receives one or more options. It is important to save the request itself, as it becomes part of the learning portfolio. The student learns to clarify instructions and set limits on the scope, style, and level of language.

The third stage is verification. The obtained text is compared with a textbook, a regulatory reference book, an official website, or another reliable source. Special attention is paid to facts, dates, names, terms, and references. It is at this stage that information literacy is formed.

The fourth stage is editing. The student corrects the identified errors, rearranges the sentences, replaces imprecise wording, and adapts the text to the actual addressee. It is important that the final version is not a mechanical copy of the AI's response.

The fifth stage is argumentation. The student explains why they changed certain elements of the text. For example: why a specific lexeme was replaced, why one fact was omitted, why a certain form of address was chosen. This stage transforms editing into a meaningful linguistic activity.

The sixth stage is reflection. The student answers the following questions: what did the AI do; what did I do; what errors were detected; what sources were used for verification; what did I learn in the process.

This reflection allows us to assess not only the product but also the level of independence.

Academic integrity and changes to the grading system

One of the most challenging issues in digital transformation is academic integrity. A simple attempt to ban the use of AI does not solve the problem, as technologies continue to evolve, and the boundaries of permissible use vary across different educational contexts. It seems more productive to establish transparent rules: a student should know when the use of AI is permitted, to what extent, how it is recorded, and what responsibility they bear for the final result.

In the context of generative AI, process-based assessment becomes particularly important. If a teacher evaluates only the final text, it is difficult for them to determine the student's contribution. However, if the assessment includes drafts, versions of the text, comments, oral defense, and reflection, it becomes possible to see the dynamics of the work.

For example, a written assignment can be divided into four components: an independent initial version; a request to the AI; a critical analysis of the response; and the final author's version. Content, linguistic accuracy, the quality of information verification, argumentation, and independence can be assessed. This format does not exclude AI, but it does not reduce academic work to mere copying.

The issue of the reliability of references requires special attention. Generative models are capable of creating plausible but non-existent bibliographic data. Therefore, students need to be systematically taught the rule: a reference is considered used only after verifying the existence of the source, the correspondence of the author, title, year, and content. In a scientific paper, the author is responsible for bibliographic accuracy.

Risks of digital transformation

Despite the significant pedagogical potential, the use of AI is accompanied by risks. The first of these is a decline in independence due to the uncritical use of ready-made answers. If a student systematically submits the formulation of their thoughts to the system, they may reduce their own practice of writing and argumentation. Therefore, the technology should be used in such a way that the person's intellectual work does not disappear.

The second risk is related to the accuracy of the information. AI is not a universal reference and can generate convincing but incorrect data. The higher the academic and professional cost of an error, the more important independent verification becomes. For students in the tourism field, this is especially relevant when working with historical information, geographical data, regulatory requirements, descriptions of facilities, and information for tourists.

The fourth risk is digital inequality. Access to modern tools may vary depending on the device, the quality of the internet connection, the language of the interface, and the functionality of specific services. Therefore, the mandatory use of a single commercial tool may create additional barriers. University practice should provide alternative ways to complete the assignment.

The fifth risk is linguistic and cultural homogeneity. For Kazakh and other languages with fewer digital resources, the quality of generation may be less stable, especially when working with culturally specific vocabulary, proper names, and historical realities. Consequently, language training becomes not only a field for the application of AI but also a field where verification and preservation of cultural specificity are particularly necessary.

Prospects for higher education in Kazakhstan

The National Concept for the Development of Artificial Intelligence for 2024–2029 considers the development of human resources and competencies as a necessary condition for the formation of an AI ecosystem [2, pp. 24–29]. In this context, universities perform a dual function. On the one hand, they train specialists for the digital economy. On the other hand, they must themselves transform educational processes and become platforms for the responsible implementation of AI.

For humanities and language disciplines, a promising direction could be the development of local teaching scenarios that take into account the national, professional, and regional context. For example, students in tourism-related fields could be given assignments to create multilingual informational materials about tourist sites in Kazakhstan, prepare dialogues with foreign visitors, edit machine translations, and analyze professional terminology.

Another direction is the development of research competencies. AI can assist students at the stages of identifying key concepts, structuring material, language editing, and generating research questions. However, the search for scientific sources, verification of their reliability, interpretation of the results, and formulation of scientific conclusions should remain human-controlled stages. This approach aligns with the human-centered logic promoted by UNESCO [1, pp. 28–34].

1. A practical scenario for a Russian language lesson using AI.

Let's consider an example of a lesson for students of the tourism profile at the B1–B2 level on the topic "Telephone conversations". The goal of the lesson is to develop skills in concise, informative, and polite professional communication. In a digital model, the lesson can be structured so that AI is used as a tool for creating and subsequently verifying language material.

At the first stage, students are asked to independently compose five key formulas: greeting, clarification of information, request, apology, and ending the conversation. In the second stage, they formulate a request to the AI: to create a dialogue between an employee of a travel company and a client who wants to change the booking terms. In the third stage, the groups analyze the response: they note successful formulas, identify overly long lines, and check for politeness and suitability for a professional situation. In the fourth stage, students rewrite the dialogue. They must shorten unnecessary phrases, replace unnatural expressions, add necessary clarifications, and maintain a businesslike tone. In the fifth stage, a role-playing game is conducted without showing the text: one student is an employee of the company, the other is a client. After completing the task, the participants compare the spoken language with the written version and discuss which formulas turned out to be the most useful.

In the final stage, the student fills out a short reflective form: "What did the AI suggest?", "What did I change?", "What error did I find in the AI's response?", "What language formula was new to me?". Thus, a single digital task combines grammar, vocabulary, speaking, writing, critical thinking, and reflection.

Conclusion

The digital transformation of higher education in the era of artificial intelligence primarily involves a change in educational logic. It is not enough for a university to provide students with

access to modern digital services. It is necessary to foster a culture of their meaningful, safe, and responsible use.

Generative AI can expand teaching opportunities: personalize learning materials, simulate professional situations, provide language practice, assist in editing, and create additional assignment options. At the same time, it raises the requirements for critical thinking, information literacy, academic integrity, and the ability to make independent decisions.

For language training, the "AI as a tool — human as an author" model is particularly productive. Its key principle is that the student retains responsibility for setting the task, verifying the information, selecting language tools, editing, and the final result. In this model, digital technology does not replace the traditional goals of language education but creates additional conditions for achieving them.

In the long term, the development of AI competencies among teachers and students should be considered as part of the overall culture of a modern university. Kazakhstani universities, by implementing national digital development guidelines, can simultaneously develop their own pedagogical practices that take into account the country's linguistic and cultural diversity. Local educational scenarios, professionally oriented tasks, and methodologies that combine technological innovation with human agency are becoming especially important.

Thus, the new educational paradigm is defined not by the question "can artificial intelligence complete a learning task," but by the question "what intellectual work should a person do and how can technology help them do it more effectively." It is precisely this understanding that allows us to view artificial intelligence not as a replacement for a teacher or a student, but as a new tool for the development of education, science, and professional communication.

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Psychological Sciences

MÜASİR CƏMİYYƏTDƏ VİRTUAL ÜNSİYYƏT VƏ EMPATİYA

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Xülasə. *Məqalədə müasir kommunikasiya vasitələrinin başqalarının emosional vəziyyətini anlamaq və hiss etmək qabiliyyətinin (empatiyanın) formalaşmasına necə təsir etdiyi araşdırılır. Məqalədə onlayn ünsiyyət mühitinin insanların, xüsusilə gənclərin empatik bacarıqlarına təsiri haqqında mövcud elmi mənbələrdə yer alan ziddiyyətli yanaşmalar tədqiq edilərək ümumiləşdirilmişdir. Tədqiqatlarda iddia edilir ki, sosial dərketmənin sağlam inkişafı üçün onlayn ünsiyyət formaları ilə canlı münasibətlər arasında düzgün tarazlıq qorunmalıdır. Tədqiqat çərçivəsində gənclərin və humanitar sahədə təhsil alan tələbələrin üstünlük verdikləri ünsiyyət vasitələrindən (üzbəüz görüşlər, sosial platformalar, telefon zəngləri, videozanglar və internet resursları) asılı olaraq empatik göstəricilərinin necə dəyişdiyi təhlil olunmuşdur.*

Açar sözlər: *rəqəmsal mühit, internet, virtual ünsiyyət, empatiya, sosial şəbəkə, virtual bacarıq*

VIRTUAL COMMUNICATIONIN MODERN SOCIETY AND EMPATHY

Salatin Hajiyeva

Abstract. *This article examines how modern communication tools influence the development of the ability to understand and sense the emotional states of others (empathy). It explores and synthesizes conflicting perspectives found in existing scientific literature regarding the impact of online communication environments on people's—particularly young people's—empathic skills. Research suggests that a proper balance between online communication and face-to-face interaction must be maintained for the healthy development of social cognition. The study analyzes how empathy levels vary among young people and students in the humanities based on their preferred communication methods (face-to-face meetings, social platforms, phone calls, video calls, and internet resources). The primary objective of the research is to investigate the manifestations of empathy within the digital environment.*

Keywords: *digital environment, internet, virtual communication, empathy, social network, virtual skill*

Giriş

İnsan fəaliyyətinin bütün sahələrinə dərindən nüfuz edən rəqəmsal texnologiyalar- asudə vaxtın təşkili, təhsil prosesi, əmək fəaliyyəti və sosial ünsiyyət kimi sahələrini sürətli kompyuterləşdirilir və rəqəmsal məkana inteqrasiya edir. Rəqəmsal mühit fərdlərin vaxtının böyük hissəsini sərf etdiyi təbii sosiallaşma və ünsiyyət meydanına çevrilmişdir. Bu baxımdan virtual ünsiyyətin spesifikasiyasının və onun doğurduğu psixoloji fəsadların elmi təhlilinə kəskin zərurət yaranır.

Şəbəkə texnologiyalarının və yeni ünsiyyət platformalarının sürətli inkişafı müasir gənclərin sosiallaşma şəraitini də köklü şəkildə dəyişmişdir. Bu dəyişikliklər iri miqyaslı sosio-mədəni

amillərin fərdin psixi inkişafına, xüsusən də başqalarının emosional halını qavramaq və nəzərə almaq bacarığı olan sosial dərketmə proseslərinə təsirini öyrənməyi aktual edir. Texnoloji vasitələrin sosial dərketmənin inkişafına təsiri yalnız son dövrdə fəal araşdırılmağa başlanmışdır. Halbuki hələ rəqəmsal dövrün əvvəllərində irəli sürülən ilk nəzəriyyələr canlı görüşlərin azalmasının ünsiyyət kanallarını zəiflədəcəyini və insanların bir-birini anlaması ilə həmdərd olması imkanlarını məhdudlaşdıracağını ehtimal edirdi. Bu yanaşmalar elmi ədəbiyyatda sosial ipuclarının süzgəcdən keçirilməsi nəzəriyyələri (*cues-filtered out theories*) kimi tanınır. Əksinə, rəqəmsal ünsiyyətin müsbət tərəflərini vurğulayan konsepsiyalar isə hiperşəxsləşdirilmiş ünsiyyət nəzəriyyələri (*hyperpersonal communication theories*) adlandırılmışdır. Bu ikinci qrup yanaşmalara görə, onlayn mühit insanın özünü daha səmimi ifadə etməsinə və qarşılıqlı münasibətlərdə məhrəmlik səviyyəsinin artmasına imkan yaradır. \

Rəqəmsal texnologiyaların sürətlə inkişaf edərək insana öz məqsədlərini reallaşdırmaq və ehtiyaclarını ödəmək üçün getdikcə daha yeni imkanlar təklif edir. Bu ehtiyaclardan biri də ünsiyyət tələbatıdır. Ünsiyyət prosesində mühüm yerlərdən birini başqasının hiss və həyəcanlarına şərik olmaq, onun halına acımaq — empatiya tutur. Empatiya (Empatiya), geniş mənada ünsiyyətin bir komponenti və fəlsəfə və estetika kontekstində sənət əsərlərinin qavranılmasının bir xüsusiyyəti olaraq, insan qavrayışının bütün kanallarını eyni vaxtda birbaşa əhatə edən dinamik bir prosesdir. Kiberontologiya şəraitində bir sıra dəyişikliklərə məruz qalır. Bu, kiberməkanda və xüsusən də İnternet mühitində reallıq obyektlərinin rəqəmsal analoqlarla - fotolar, videolar və mətnlərlə əvəz olunması ilə izah olunur [Воинова О.И., Плешаков В .А 2012].

Toplanmış azsaylı empirik məlumatlar da birmənalı deyildir. Məsələn, amerikalı tələbələr arasında aparılan 10 illik davamlı müşahidələr zamanı empatik bacarıqların aşağı düşdüyü müəyyən edilmişdir. Bu uzunmüddətli tədqiqatların meta-analizini aparan mütəxəssislər həmin mənfi dinamikanı canlı ünsiyyəti getdikcə sıxışdıran İnternet istifadəsinin artması ilə əlaqələndirirlər. Analizin aparıcı müəllifi sonrakı məqalələrində bildirir ki, bu geriləməyə əsas səbəb həmsöhbətlər arasındakı psixoloji-fiziki məsafənin artması və virtual aləmdə anonimlik və ya şəxsiyyətin yalnız qismən üzə çıxması kimi şəxssizləşmə amilləridir.

Bununla belə, onlayn ünsiyyətlə empatik keyfiyyətlər arasındakı asılılığı araşdıran hərtərəfli empirik işlərin sayı kifayət qədər azdır. Məsələn, aparılan tədqiqatların birində İnternet fəallığı ilə empatiya arasında hər hansı ciddi asılılıq tapılmamışdır. Lakin burada tədqiqatçılar təkcə ünsiyyəti deyil, ümumilikdə internet fəaliyyətlərini nəzərə almışdılar. Digər bir araşdırmada isə Facebook platformasından istifadə ilə empatik bacarıqlar arasında əsasən müsbət əlaqənin olduğu qeyd edilir. N.A. Nosov bunun təsadüfi olmadığını "virtuallıq ideyasının insan varlığının ən dərin qatlarına toxunmasında" görür [Nosov A, 2000].

Amsterdam Kommunikasiya Tədqiqatları Mərkəzinin mütəxəssisləri müəyyən etmişlər ki, virtual ünsiyyət vərdişləri sonradan real həyata keçirilə bilən sosial bacarıqların təcrübədən keçirilməsinə xidmət edir. Tədqiqatçılar bunu onunla izah edirlər ki, müasir onlayn mühitdə anonimlik dərəcəsi getdikcə azalır və yeniyetmələr internetdə əsasən real həyatda tanıdıqları dostları ilə əlaqə saxlayırlar

Niderland alimləri tərəfindən 10–14 yaş aralığında iki uşağı olan 516 ailənin iştirakı ilə aparılmış genişmiqyaslı uzunmüddətli tədqiqatda İnternet ünsiyyətinin yeniyetmələrin empatik inkişafına təsiri öyrənilmişdir. Tədqiqatda həm idrakı, həm də emosional empatiyanın dinamikası nəzərdən keçirilmişdir. Müəlliflər vurğulayırlar ki, empatiyanın bu iki tərəfi davranışa fərqli yollarla təsir edir. Mövzunun aktuallığı ondan ibarətdir ki, empatik göstəricilər gənclərdə cəmiyyətə faydalı davranışların əsas göstəricisi və sağlam şəxslərarası münasibətlərin təməlidir. Beləliklə, araşdırma rəqəmsal əsrdə psixi inkişafın proqnozlaşdırılmasına və valideynlərlə pedaqoqlara praktik tövsiyələrin hazırlanmasına xidmət edir.

Məhz bu tədqiqatda onlayn ünsiyyətin "hiperşəxsi" xarakter daşıdığını və sosial şəbəkə istifadəçilərində həm emosional, həm də idrakı empatiyanı gücləndirdiyini irəli sürən "nikbin

konsepsiyalara" əsaslanılmışdır. Alimlər ehtimal edirdilər ki, onlayn mühitdə bədən dili və üz ifadələrini görmək mümkün olmadığı üçün emosional empatiya çətinləşir və bu səbəbdən ön plana idrakı empatiya keçəcəkdir. Tədqiqat aləti kimi mütəxəssislərin işləyib hazırladığı özünüqiymətləndirmə sorğusu seçilmişdir. Bu şkala üç parametri qiymətləndirir:

1.Emosional empatiya (başqasının hissini bölüşmək);

2. İdraki empatiya (hadisələrə başqasının mövqeyindən baxa bilmək);

3.Simpatiya (empatik qayğı və kömək etməyə hazır olmaq).

Bir il fasilə ilə aparılan iki mərhələli müayinə göstərmişdir ki, yaş artdıqca həm hər üç parametr üzrə nəticələr, həm də onlayn ünsiyyətə ayrılan vaxt (həftədə orta hesabla 6 saat) yüksəlir. Bununla yanaşı, emosional və idrakı empatiyanın internetdə keçirilən vaxtla düz mütənasib olduğu, simpatiya göstəricisinin isə bundan asılı olmadığı müəyyən edilmişdir. Yekunda müəlliflər virtual ünsiyyətin sosial dərketmənin bəzi tərəflərinə müsbət təsir etdiyi qənaətinə gəlmişlər.

Reallıq obyektlərinin rəqəmsal analoqlarla əvəzlənməsi empatiya prosesini də transformasiyaya uğradır. Yuxarıda qeyd edildiyi kimi, müasir dünyanın fərqli informasiya və kommunikasiya xüsusiyyəti vardır. Şəxsi həyatın kiberontoloji konsepsiyasının və insanın kibersosiallaşması nəzəriyyəsinin müəllifi V.A. Pleşakova görə, "insan fəaliyyətinin modeli müasir dünyaya paralel bir reallığın - kiberməkanın mövcudluğu nəzərə alınmaqla qurulur". Kiberməkan müasir insan varlığının reallığını tamamlayır, onun fəaliyyət və ünsiyyət sahələrini genişləndirmək üçün köməkçi mühit kimi xidmət edir. [Воинова О.И., Плешаков В., 2012]. Kiberməkanda ünsiyyət xüsusi əhəmiyyət kəsb edir. Kiberməkan şəraitinə daxilolma kontekstində o, "kiberməkanda insanlar arasında əlaqələrin qurulması və inkişaf etdirilməsi prosesi, o cümlədən informasiya mübadiləsi, onun qarşılıqlı semantik və ifadəli qavranılması, eləcə də bir-birinə təsir etmək cəhdi" kimi müəyyən edilir.

Geniş mənada ünsiyyətin bir komponenti və fəlsəfə və estetika kontekstində sənət əsərlərinin qavranılmasının bir xüsusiyyəti kimi müəyyən edilən empatiya (Empatiya) insan qavrayışının bütün kanallarını eyni vaxtda birbaşa əhatə edən dinamik bir prosesdirvvə o kiberontologiya şəraitində bir sıra dəyişikliklərə məruz qalır. Bu, kiberməkanda və xüsusən də İnternet mühitində reallıq obyektlərinin rəqəmsal analoqlarla - fotoşəkillər, videolar və mətnlərlə əvəz olunması ilə izah olunur. Ən yüksək empatiya dərəcəsi insanda qavranılan obyekt minimal statik olduqda və bir sıra məkan xüsusiyyətlərinə malik olduqda yaranır.Maksimal empatiya üçün obyektin dinamikliyi və məkan dolğunluğu vacibdir. V.Vundtun qeyd etdiyi kimi, fərd müstəvi təsvirlərdəki dərinlik çatışmazlığını öz daxili assosiasiyaları vasitəsilə bərpa edir [Холмогорова, А.Б., Клименкова, Е.Н., 2016]. Təsvirin "canlılığı" empatik rezonansın gücünü müəyyən edir.

İnternetdə isə incəsənət nümunələri və ya insan obrazları ekranın texniki göstəriciləri (ekran keyfiyyəti, fayl parametrləri) vasitəsilə reduksiyaya (məhdudlaşmaya) uğrayır. Obyektivləşdirmə prosesi təmiz, vasitəsiz təmasdan deyil, texniki filterlərdən keçmiş rəqəmsal təsvirdən başlandığı üçün tam daxili rezonans doğura bilmir. Eynilə, şəbəkədə qarşı tərəfin profili, mesajları və fotoları vasitəsilə qurulan intersubyektivlik də natamamdır. E. Husserlin nəzərdə tutduğu kinestetik təcrübə və bədən fəallığının müşahidəsi şəbəkədə məhdudlaşdığı üçün, qarşı tərəfə transsendental *Ego* şamil edilməsi yalnız fərdin öz daxili təsəvvürləri və keçmiş təcrübəsi hesabına tamamlana bilir.

Qeyri-verbal siqnalların (mimika, gest, intonasiya) olmaması internetdə emosional rezonansı əhəmiyyətli dərəcədə zəiflədir. Yazılı nitq məntiqi təfəkkürü inkişaf etdirsə də, emosional vəziyyətlərin dəqiq ötürülməsinə və obyektivləşməsinə mane olur. Bu durum empatiyanın etik tərkib hissəsinə də təsir edir. A. Smit, Q. Spenser və A. Şopenhauerin vurğuladığı mənəvi duyğuların təməli olan "daxili nüfuzetmə" və "həmdərdlik", rəqəmsal mühitdə koqnitiv (idraki) aspektin emosional aspekti üstələməsi səbəbindən zəifləyir. Diqqət informasiyanın məzmununa yönəlir, onun arxasındakı emosional dinamika isə kölgədə qalır. Şəbəkədəki bu rasional-soyuqqanlı

yanaşmanın real həyata transformasiya olunması fərdlərin mənəvi-emosional inkişafı üçün risk yarada bilər.

M. Şeler nəzəriyyəsinə söykənərək demək olar ki, internet mühitinin gətirdiyi distantlıq fərdləri aşırı eyniləşmədən qoruyaraq onları daha rasional empatiya müstəvisində saxlayır. Bu xüsusiyyət patoloji empatiyadan əziyyət çəkən şəxslər üçün qoruyucu bufer rolunu oynaya bilər.
K. Rocers, H. Kohut, T. P. Qavrlova və başqalarının yanaşmasında empatiya başqa bir insanın yaşantılarını hiss etməyə imkan verən proses kimi başa düşülür. Klassik nəzəriyyələrdə empatiyanın formalaşması və təzahüründə iki subyektin vasitəsiz (birbaşa) kontaktına xüsusi yer ayrılırdı. Bu səbəbdən, insanların İnternetdə ünsiyyətə getdikcə daha çox vaxt ayırdığı müasir cəmiyyətdə empatiya qabiliyyətinin formalaşması və inkişafında rəqəmsal mühitin imkanları məsələsi kəskin şəkildə qarşıda durur. Belə ki, rəqəmsallaşma ünsiyyət üçün əlavə imkanlar yaradır. Məsələn, sosial şəbəkələr və tematik internet-forumlar insana, bəlkə də, yaxın ətrafında heç vaxt əldə edə bilməyəcəyi emosional təcrübəni qazanmaq imkanı verir. Tək bir kliklə yer kürəsinin digər başında olan insanlarla əlaqə saxlamaq, öz yaşantılarını onlarla bölüşmək və ya yalnız yazılı nitqdən deyil, həm də fotolardan, səsli mesajlardan, smayliklərdən və s. istifadə edərək onların hissələrinə reaksiya vermək, eləcə də onlara real köməklik göstərmək mümkündür. Bundan əlavə, internet mühiti çətin həyat şəraitində olan və ya sağlamlıq problemləri yaşayan insanlara öz əhvalatlarını danışmaq və buna cavab reaksiya (əks-əlaqə) almaq imkanı yaradır. İştirakçılar arasında əməkdaşlığa, eləcə də virtual personaja kömək və qayğıya yönəlmiş kompyuter oyunları uşaqlara başqasını anlamağın və ona qarşı humanist münasibətin vacibliyini nümayiş etdirə bilər. Beləliklə, böyüməkdə olan nəslin çox vaxt keçirdiyi virtual mühitdən şəxsiyyətin inkişafı üçün istifadə etmək mümkündür.Virtual reallıq texnologiyası əlavə imkanlar təmin edir. VR dəbilqəsini taxaraq və virtual mühitə tam qərq olaraq, müəyyən insanların əhatə olunduğu şəraitə düşmək və onların qarşılaşmalı olduqları problemləri öz üzərində hiss etmək olar ki, bu da onları anlamağa və onlara rəğbət (şəfqət) göstərməyə kömək edə bilər. Məsələn, K. Milk Suriyadan olan qaçqınlar haqqında bir sıra filmlər çəkərək bu imkanları nümayiş etdirmişdir. Digər tərəfdən, emosiya və hissələrin rəqəmsallaşması bir çox suallar doğurur: rəqəmsal mühitdə öz hissələrini necə nümayiş etdirmək olar? Onları nə dərəcədə dəqiq ötürmək mümkündür? Nə dərəcədə dəqiq anlamaq olar? Rəqəmsal məfhumda (məfhumlar aləmində / məkanda) empatiya göstərmək mümkündürmü? Onun səmimiyyətini necə fərqləndirmək olar? Şəbəkədəki və real həyatdakı empatiya bir-birindən nə ilə fərqlənir? İnternet mühitində mənəvi istilik hissiyyatı yaranırmı və bu hiss nəyə əsaslanır? Ümumiyyətlə, üz-üzə kontakt olmadan şəxsiyyətin emosional sferasını inkişaf etdirmək mümkündürmü?.

"Ünsiyyət" fenomeni psixologiya və sosiologiyada müxtəlif nəzəri yanaşmalarla izah olunur. Ənənəvi mənada ünsiyyət "iki və ya daha çox insanın koqnitiv və ya affektiv-qiymətləndirmə məlumatlarının mübadiləsindən ibarət qarşılıqlı əlaqəsi" kimi başa düşülür. Ünsiyyət adətən insanlar arasında praktik qarşılıqlı əlaqələrdə (əməkdaşlıq işi, öyrənmə, komanda oyunu və s.) yer alır və onların fəaliyyətlərinin planlaşdırılmasını, həyata keçirilməsini və nəzarətini asanlaşdırır. Eyni zamanda, ünsiyyət başqaları ilə təmasda olmaq üçün xüsusi bir insanın ehtiyacını ödəyir" [5]. A.A. Bodalyov ünsiyyəti sosial subyektlərin özünüifadəsinə, cəmiyyətin davamlılığına yönəlmiş şüurlu və məqsədyönlü qarşılıqlı təsiri kimi xarakterizə edir [Войскунский, А. Е., 2008]. A.N. Leontyevin qənaətinə görə isə şəxsiyyətlərarası davamlı əlaqələr və qarşılıqlı məsuliyyət hissi yalnız fərdi cəhətdən əhəmiyyətli məlumatların mübadiləsi zamanı formalaşır.

"Kiberməkan" anlayışı ilk dəfə U. Qibsonun bədii əsərində işlədilsə də, müasir elmi məzmununu qlobal şəbəkənin təşəkkülü ilə qazanmışdır. Bu gün kiberməkan məsafədən təhsil, onlayn kommersiya, virtual əmək fəaliyyəti kimi sahələri əhatə edərək ənənəvi həyat tərzinə alternativə çevrilmişdir. Lakin rəqəmsal mühitin dəyəri fərdlərin subyektiv qavrayışından və psixoloji vəziyyətindən bilavasitə asılıdır. Bir sıra tədqiqatçılar qeyd edirlər ki, bəzi istifadəçilər üçün virtual münasibətlər artıq mücərrəd xarakter daşımır. Kompüter arxasında oturan fərdin keçirdiyi

hisslər və düşüncələr rəqəmsal mesajların real emosional məzmununu formalaşdırır. Buna baxmayaraq, şəbəkə kommunikasiyasının tənqidçiləri onlayn münasibətlərin səmimiliyini şübhə altına alırlar. Anonimlik faktoru istifadəçilərə real həyatda çatışmayan xüsusiyyətləri özlərinə aid etməyə və uydurma obrazlar ("persona") yaratmağa imkan verir. Qeyd olunduğu kimi, non-verbal siqnalların və fiziki təmasın yoxluğu həmsöhbətin obrazını ideallaşdırmağa və ya təhrif etməyə şərait yaradır. Xarici görünüşdəki qüsurlar, utancaqlıq və ya nitq çətinlikləri virtual mühitdə öz əhəmiyyətini itirir, məlumat çatışmazlığı isə təxəyyül hesabına doldurulur.

Bu faktorlar fərdlərə öz real kimliklərindən fərqli davranış nümayiş etdirməyə şərait yaradır: çəkingən fərdlər aqressiv, emosional baxımdan qapalı fərdlər isə aşırı həssas ola bilirlər. Onlayn ünsiyyətdəki sərbəstlik emosional yaxınlaşmanı sürətləndirsə də, bu münasibətlərin davamlılığı zəif olur. Əlaqənin asanlıqla qurulması kimi, onun kəsilməsi də bir düymə ilə həyata keçirilir. Virtual ünsiyyət fərdin dəstəklənmə, tanınma və qəbul olunma kimi psixoloji tələbatlarını müvəqqəti təmin etsə də, real həyatdan uzaqlaşmaya gətirib çıxara bilir. Bu paradoks xüsusilə sosiallaşma mərhələsində olan yeniyetmələr üçün ciddi psixoloji risklər yaradır.

Metodlar.

Rəqəmsal mühitdə empatiyanın formalaşması və inkişafı imkanları barədə ekspertlərlə müsahibə, respondentlərlə M. Devisin "Çoxfaktorlu empatiya sorğu vərəqəsi"nin keçirilməsi və respondentlərin sosial şəbəkələrdəki açıq səhifələrinin kontent-analizi

Tədqiqat prosesinə Naxçıvandakı müxtəlif təhsil ocaqlarını (məktəb, kollec və ali məktəb) təmsil edən 150 iştirakçı cəlb edilmişdir. İştirakçılara onların üstün tutduqları ünsiyyət vasitələrini müəyyən edən anket və M. Devis tərəfindən hazırlanmış "Şəxslərarası reaktivlik indeksi" metodikası tətbiq olunmuşdur. Əldə edilən nəticələr göstərir ki, yeniyetmə və gənclərin böyük əksəriyyəti digər vasitələrlə müqayisədə birbaşa canlı ünsiyyətə üstünlük verirlər. Eyni zamanda, canlı təmaslara meyilli olan fərdlərin empatik göstəriciləri sosial şəbəkələri seçənlərə nəzərən daha yüksəkdir.

Nəticə.

Nəticə etibarilə, İnternet vasitəsilə ünsiyyət real təmasları tam əvəz etməməli, yalnız onları tamamlayan köməkçi vasitə kimi çıxış etməlidir. İnternetdə insan obrazının statikliyi və empatiyanın zəifləməsi cəmiyyət qarşısında yeni sosial-pedaqoji vəpsixoloji vəzifələr qoyur:

1.Şəbəkə daxilində ümumi kommunikativ və etik mədəniyyətin yüksəldilməsi;

2.Statik vizual kontentdən emosional mənanı oxumaq (perseptiv-empatik) qabiliyyətinin formalaşdırılması;

3.Emosional vəziyyətlərin mətn vasitəsilə adekvat ifadə olunması bacarıqlarının inkişafı.

Lakin yalnız virtual bacarıqların artırılması problemi kökündən həll etmir. Əsas məsələ real sosiallaşma mühitində empatik potensialı inkişaf etdirmək və bu bacarıqları kibersosiallaşma prosesinə düzgün inteqrasiya etməkdir. Real və virtual aləmdəki ünsiyyət təcrübəsinin balanslaşdırılması fərdlərin rəqəmsal çağda daha tam və sağlam empatiya qurmasına şərait yaradacaqdır.

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INVESTIGATION OF ATTACHMENT CHARACTERISTICS AND PARENTAL ATTITUDES IN CHILDREN WITH COGNITIVE PROBLEMS

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Abstract: Self-regulation deficits, including problems with impulse control, self-soothing, assertiveness, persistence, patience, and inhibition, are the most prominent features of ADHD. It has been suggested that the roots of the self-regulation disorder seen in children with ADHD may stem from tense early interactions between caregiver and child and impaired primary attachment. Studies have shown that individuals with insecure attachment are more susceptible to problems with affective and behavioral regulation. The prominence of social deficits in ADHD provides evidence of a compelling similarity between the developmental consequences of insecure attachment and the difficulties seen in children with ADHD. In one study, it was predicted that parental over-involvement in children at 6 months of age had a stronger influence on distractibility in early childhood and hyperactivity in middle childhood than biological and temperament-related factors. Additionally, it points to the fact that early relationship histories of children with ADHD are similar to those of children with insecure attachment.
Keywords: ADHD, cognitive problem, family, parental attitude, attachment

According to literature review, it has been found that mothers of children with ADHD initiate less interaction with their children, respond less to positive and neutral interactions initiated by their children, and use more negative, more reactive, more domineering, more controlling, but less positive parenting strategies (compared to the control group).

Another study found no relationship between infant disorganized attachment and later childhood ADHD cases. The probability of ADHD in these children was the same as in the general population.

When looking at the average scores our subjects received from the Relationship Scales Questionnaire, there was no statistically significant difference between the patient and control groups in terms of all attachment types. In the patient group, the highest average was seen in the avoidant attachment subtype, while in the control group, the highest average was seen in the secure attachment subtype. In one study, children with combined and dominant hyperactivity types scored higher on anxious and avoidant attachment compared to those with dominant attention deficit.

In contrast, another study found more obsessive attachment in children with attention deficit hyperactivity disorder.

Another study supported the hypothesis that ADHD is related to insecure attachment. Yet another study found high insecure attachment scores in the ADHD group. These results are similar to our findings.

In a study conducted in Turkey with a group of healthy adolescents, the highest average score obtained by adolescents from the subscales of the ADHD was found to belong to the secure attachment subscale. In our study, it was also found that the control group obtained the highest

average from the secure attachment subscale. When examining the average scores obtained by the subjects from the Family Life, Child Rearing and Attitude Scale, no statistically significant difference was found between the patient and control groups in all parental attitude subscales. The most frequently encountered parental attitude style in both patient and control groups was found to be democratic attitude and recognition of equality.

A study investigated the effects of temperament and parenting style on attachment patterns in children with ADHD. Children with combined and predominantly hyperactive types scored higher in anxious and avoidant attachment compared to those with predominantly attention deficit. Their families also showed a higher level of control over these children. Allowing children with variable emotionality to move freely led to anxious attachment, while restricting children with variable activity led to avoidant attachment. It has been shown that inadequate parenting of children with ADHD can increase their difficulties in self-regulation and lead to insecure attachment patterns. It has been suggested that overly controlling or permissive parenting styles in parents of children with ADHD can contribute to the development of insecure attachment patterns. In the study by Keskin and Çamin, it was determined that boys scored higher than girls on the secure attachment and obsessive attachment subscales of the Relationship Scales Questionnaire and developed more secure and obsessive attachments.

In a different study, it was stated that Japanese adolescent girls formed more secure attachments to their parents than adolescent boys.

In yet another study, hyperactivity and conduct disorders, which can be observed together with attachment disorders, were observed more frequently in boys, and genetic factors were found to be important in this group. In our study, when the average scores obtained from the Relationship Scales Questionnaire according to gender in the patient group were examined, no statistically significant difference was found between any attachment types. It was determined that both girls and boys received the highest average score from the avoidant attachment subscale. When examining the average scores obtained by the control group from the Relationship Scales Questionnaire according to gender, no statistically significant difference was found between the two genders in any attachment type. In the control group, both girls and boys received the highest average score from the secure attachment subscale. In another study, a difference was found between genders regarding secure attachment, with the average score of boys being higher than the average score of girls, and the difference was found to be statistically significant. No difference was found between genders regarding fearful attachment, preoccupied attachment, and avoidant attachment.

Although mother-infant attachment disorder cannot be fully explained by mental illnesses, attachment disorder is seen at a higher rate in mothers with depression. In a study demonstrating the severity of this condition, it was found that in severe postpartum depression, the mother's aggressive feelings, anger, thoughts of killing, and/or behaviors towards her baby were increased. Similarly, it has been reported that in these disorders, the baby experiences attachment disorder or insecure attachment to the mother. In a similar study, it was shown that psychiatric illnesses negatively affect mother-infant attachment in the long term, and that in postpartum depression, mother-infant attachment examined one year after birth was insecure.

Insecure attachment is a risk factor for expressive disorder in children who are predisposed due to difficult temperaments or their environment. Insecure attachment style is common in the clinical population and may not be a predisposition specific to ADHD. Attachment style may be part of the clinical presentation of ADHD. In cases of significant early emotional deficits, symptoms of ADHD and attachment disorder (although the nature of the relationship is not clearly defined) are prominent.

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QADINLARDA PSİXİ POZUNTULARIN MÜƏYYƏN GÖSTƏRİCİLƏRİ: EPİDEMİOLOJİ, KLİNİK, BİOLOJİ VƏ PSİXOSOSİAL SÜBUTLARIN İNTEQRATİV İCMALI

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Xülasə
Qadınlar geniş yayılmış psixi pozuntuların dünya üzrə yükünün böyük hissəsini daşıyırlar. Bu icmal qadınlarda psixi pozuntuların göstəriciləri barədə elmdə qəbul olunmuş bilikləri bir yerə toplayır. "Göstəricilər" dedikdə üç şey nəzərdə tutulur: statistik göstəricilər — bu xəstəliklər nə qədər yayılıb, hansı yaşda başlayır və nə qədər ziyan vurur; klinik əlamətlər — xəstəlik qadınlarda özünü necə göstərir; və risk əlamətləri ilə yoxlama vasitələri — hansı hadisələr riski artırır və hansı sadə anketlərlə riskli qadınları erkən tapmaq olar. Bütün mədəniyyətlərdə depressiya və narahatlıq (anksiyete) pozuntuları qadınlarda kişilərə nisbətən təxminən iki dəfə çoxdur; fərq yetkinlik dövründə yaranır və qadın həyatının xüsusi dövrləri ilə formalaşır: aybaşıdan əvvəlki ağır əhval pozuntusu (PMDP) reproduktiv yaşda olan qadınların təqribən 1,6-8 faizində olur; hamiləlik və doğuşla bağlı depressiya dünyada qadınların 10 faizindən çoxuna təsir edir; menopauza ərəfəsi isə depressiya riskini iki-dörd dəfə artırır. Eksperimentlər göstərir ki, əsas bioloji səbəb hormon pozğunluğu deyil, bəzi qadınların beyninin normal hormon dəyişikliklərinə xüsusi həssaslığıdır; bu həssaslıq stress sistemi və sosial təsirlərlə — ilk növbədə ailə və cinsi zorakılıqla — birlikdə fəaliyyət göstərir. Praktik nəticələr: hər qadından qısa reproduktiv-psixiatrik tarixçə soruşmaq, əlverişli məqamlarda sadə anketlərlə (PHQ-9, GAD-7, EPDS, PSST) müntəzəm yoxlama aparmaq və yüksək riskli qruplarda intihar riskini mütləq qiymətləndirmək. Kasıb ölkələr üzrə məlumat azlığı, bioloji testlərin yoxluğu və yoxlamadan müalicəyə gedən yolun problemləri də müzakirə olunur.
Açar sözlər: *qadınların psixi sağlamlığı; depressiya; anksiyete; premenstrual disforik pozuntu; perinatal depressiya; perimenopauza; cins fərqləri; skrininq; risk göstəriciləri*

Giriş

İnsanın qadın və ya kişi olması psixi sağlamlıq riskinə ən çox təsir edən amillərdən biridir. Dünyanın müxtəlif ölkələrində aparılan tədqiqatlar eyni nəticəni göstərir: qadınlarda depressiya və narahatlıq (anksiyete) pozuntuları kişilərə nisbətən təxminən iki dəfə çox rast gəlinir və bu xəstəliklərin yaratdığı ümumi yükün böyük hissəsi qadınların üzərinə düşür. Ümumdünya Səhiyyə Təşkilatının (ÜST) məlumatına görə, dünya əhalisinin təqribən 4 faizi depressiya ilə yaşayır; yetkin qadınlar arasında bu göstərici təxminən 6,9 faiz, kişilər arasında isə 4,6 faizdir. Başqa sözlə, dünyadakı bütün depressiya və narahatlıq pozuntusu hallarının təxminən üçdə ikisi qadınların payına düşür.

Bu icmalda “göstəricilər” sözü geniş mənada işlədilir və üç şeyi əhatə edir. Birincisi, statistik göstəricilər: bu xəstəliklər qadınlar arasında nə qədər yayılıb, hansı yaşda başlayır və nə qədər ziyan vurur. İkincisi, klinik əlamətlər: xəstəlik qadınlarda özünü necə büruzə verir, hansı simptomlar daha çox görünür. Üçüncüsü, risk əlamətləri və yoxlama vasitələri: hansı hadisələr və şərait riski artırır və hansı sadə sorğu-anketlərlə riskli qadınları erkən tapmaq olar.

Qadınların psixi sağlamlığını başa düşmək üçün bütöv həyat yoluna baxmaq lazımdır. Uşaqlıqda qızlarla oğlanlar arasında depressiya fərqi yoxdur; fərq yetkinlik dövrünün başlanğıcında (pubertatda) yaranır, reproduktiv illər boyu davam edir və qadın orqanizminin xüsusi dövrlərində — aybaşı siklində, hamiləlikdə, doğuşdan sonra və menopauza ərəfəsində — risk daha da artır. Bu dövrlərin hamısında hormonlar kəskin dəyişir və eyni zamanda qadının həyat şəraiti də dəyişir; buna görə alimlər hesab edirlər ki, əsas səbəb hormon dəyişikliyi, fərdi həssaslıq və sosial mühitin birgə təsiridir.

Bu icmalın məqsədi qadınlarda psixi pozuntuların göstəriciləri barədə elmdə qəbul olunmuş bilikləri bir yerə toplamaqdır. İcmal böyük əhali sorğularına, çoxsaylı tədqiqatları birləşdirən təhlillərə (meta-analizlərə) və Qlobal Xəstəlik Yükü tədqiqatı, Ümumdünya Psixi Sağlamlıq Sorğuları və psixiatriyanın əsas diaqnostik təlimatı olan DSM-5-TR kimi nüfuzlu mənbələrə əsaslanır. Əsas diqqət ya yalnız qadınlarda olan xəstəliklərə — aybaşıdan əvvəl yaranan ağır əhval pozuntusu (premenstrual disforik pozuntu) və hamiləlik-doğuş dövrünün psixi pozuntuları kimi, ya da qadınlarda xeyli çox rast gəlinən xəstəliklərə — depressiya, narahatlıq pozuntuları, ağır sarsıntıdan sonra yaranan stress pozuntusu (PTSP) və yemək davranışı pozuntuları kimi — yönəlib. Sonda erkən aşkarlama üsulları, həkimlər üçün praktik nəticələr və gələcək tədqiqat istiqamətləri müzakirə olunur.

Yayılma göstəriciləri: qadınlarla kişilər arasındakı fərq

Nə qədər yayılıb və nə qədər yük yaradır? Depressiyanın qadınlarda kişilərə nisbətən təxminən iki dəfə çox olması psixiatriya elminin ən çox təsdiqlənmiş faktlarından biridir. Bu fərq ABŞ-ın böyük milli sorğularında, on ölkəni əhatə edən müqayisələrdə və on beş ölkədə aparılmış Ümumdünya Psixi Sağlamlıq Sorğularında dəfələrlə təsdiqlənib; fərq həm varlı, həm kasıb, həm Qərb, həm Şərq ölkələrində mövcuddur. Bugünkü qlobal rəqəmlərə görə, hər hansı bir anda depressiya qadınlarda kişilərdən təxminən 1,5 dəfə çoxdur: bütün depressiya hallarının təxminən 65 faizi, narahatlıq pozuntusu hallarının isə 63 faizi qadınlardadır.

Xəstəliyin yaratdığı ziyanı ölçən göstəricilər də eyni mənzərəni verir. Qlobal Xəstəlik Yükü Tədqiqatına görə, depressiya və narahatlıq pozuntuları dünyada insanları əmək qabiliyyətindən məhrum edən əsas səbəblər sırasındadır və depressiyanın qadınlardan aldığı sağlam ömür illəri kişilərdəkindən 1,5 dəfədən çox artıqdır. COVID-19 pandemiyası bu fərqi daha da böyütdü: təkcə 2020-ci ildə dünyada əlavə 53 milyon depressiya və 76 milyon narahatlıq pozuntusu halının yarandığı hesablanıb və bu artımın böyük hissəsi qadınlara aiddir.

Hansı yaşda başlayır? Qadın-kişi fərqi yaşla bağlı müəyyən qanunauyğunluqla yaranır. Yetkinlik dövründən əvvəl qızlarda və oğlanlarda depressiya təxminən eyni səviyyədədir; təqribən 11-15 yaş arasında qızlarda göstəricilər sürətlə artır və orta yeniyetməlik dövründə fərq artıq tam formalaşır. Narahatlıq pozuntuları isə daha erkən ayrılır: qızlarda müxtəlif qorxular və narahatlıq halları uşaqlıqdan etibarən daha çoxdur. Statistika həmçinin göstərir ki, qadınlarda narahatlıq pozuntuları ən çox gənclik illərində — 20-24 yaşda təqribən 7 faiz səviyyəsində — pik həddə çatır, depressiya isə orta yaşda zirvəyə çatır və 50-69 yaşlı qadınların təxminən 6-7 faizinə təsir edir. Bu qanunauyğunluğun praktik mənası var: gənc qadınlarda ilk növbədə narahatlıq pozuntularına, orta yaşlı qadınlarda isə depressiyaya diqqətli olmaq lazımdır.

Zamanla dəyişikliklər. Daha bir mühüm müşahidə son illərə aiddir. Bir sıra inkişaf etmiş ölkələrin sorğuları göstərir ki, 2010-cu illərin əvvəllərindən yeniyetmə qızlar və gənc qadınlar arasında depressiya, özünə zərər vermə və psixoloji gərginlik halları artır; bu artım pandemiyadan əvvəl başlamışdı, lakin pandemiya onu kəskin sürətləndirdi. Artım məhz qadın-kişi fərqinin ilk yarandığı yaş qrupunda baş verdiyi üçün gənc qadınların vəziyyətini izləmək bütövlükdə cəmiyyətin psixi sağlamlığı üçün erkən xəbərdarlıq siqnalı rolunu oynayır. Sosial şəbəkələrin təsiri, yuxu azlığı, dərs yükü və simptomları daha açıq bildirmək — bunların hansının əsas səbəb olduğu hələ mübahisəlidir.

Fərqin əks olduğu və daha da böyük olduğu xəstəliklər. Qadın üstünlüyü bütün psixi xəstəliklərə aid deyil. Alkoqol və narkotik asılılığı, antisosial şəxsiyyət pozuntusu və diqqət çatışmazlığı sindromu kişilərdə daha çoxdur; şizofreniya isə hər iki cinsdə təxminən bərabər rast gəlinir, sadəcə qadınlarda daha gec başlayır. Digər tərəfdən, bəzi xəstəliklərdə qadın üstünlüyü daha da böyükdür: anoreksiya və bulimiya (yemək davranışı pozuntuları) qadınlarda kişilərdən 3-10 dəfə çoxdur. Ağır sarsıntıdan sonrakı stress pozuntusu (PTSP) da qadınlarda təxminən iki dəfə çoxdur — halbuki kişilər ümumilikdə daha çox travmatik hadisə yaşayırlar. Aybaşıdan əvvəlki ağır əhval pozuntusu, doğuşdan sonrakı depressiya və menopauza ərəfəsi depressiyası isə təbiəti etibarilə yalnız qadınlarda olur. Bu müxtəliflik göstərir ki, fərqin tək bir səbəbi yoxdur: bioloji cins, qadınların həyatda üzləşdiyi fərqli təsirlər və yardım axtarma vərdişləri hər xəstəlikdə fərqli nisbətdə rol oynayır.

Klinik əlamətlər: xəstəlik qadınlarda özünü necə göstərir

Depressiya. Qadınlarda depressiya təkcə daha tez-tez deyil, həm də bir qədər fərqli formada olur. Depressiyalı qadınlar kişilərlə müqayisədə orta hesabla daha ağır ümumi vəziyyət, daha çox “atipik” əlamətlər (həddindən artıq yuxu, iştahanın artması, çəki artımı, bədəndə ağırlıq hissi), daha çox yanaşı narahatlıq və daha çox bədən şikayətləri — yorğunluq, iştaha pozğunluğu, ağrılar — bildirirlər. Qadınlarda daha bir xarakterik cəhət — eyni mənfi fikirlərin daim beyində fırlanmasıdır (elmdə buna “ruminasiya” deyilir): bu vərdiş depressiyanın başlamasını və uzanmasını qabaqcadan xəbər verən ən etibarlı psixoloji əlamətlərdən biridir. Qadınlarda mövsümi pisləşmə və təkrarlanma da bir qədər çoxdur, lakin xəstəliyin davamiyyəti və müalicəyə cavab hər iki cinsdə oxşardır.

Bir mühüm məqam: qadın üstünlüyü əsasən hisslərin “daxilə yönəlmiş” ifadəsinə aiddir. Kişilərdə isə depressiya çox vaxt başqa cür — qəzəb, əsəbilik, içki, riskli davranış şəklində üzə çıxır; bu formalar da nəzərə alınanda cinslər arası fərq xeyli azalır. Həkim üçün nəticə budur: klassik depressiya əlamətləri qadınlarda xəstəliyi daha yaxşı göstərir, kişilərdə isə gözdən qaçıra bilər; qadınlarda isə qabarıq əsəbilik altda yatan depressiyadan diqqəti yayındırmamalıdır.

Narahatlıq pozuntuları. Narahatlıq pozuntuları dünyada ən geniş yayılmış psixi xəstəlik qrupudur: hər an dünya əhalisinin təqribən 4,4 faizində mövcuddur və qadınlar hər yaşda kişilərdən daha çox təsirlənir. Bu, daimi narahatlıq (generalizə olunmuş anksiyete), panik tutmaları, açıq yerlərdən qorxu, müxtəlif fobiyalar və qismən sosial qorxu üçün keçərlidir. Qadınlarda bu pozuntular daha erkən başlayır, daha uzun çəkir, daha tez-tez bir-biri ilə və depressiya ilə birgə gedir və daha çox bədən əlamətləri ilə müşayiət olunur: panik tutmalarında nəfəs darlığı və evdən çıxmaqdan qaçınma, daimi narahatlıqda isə əzələ gərginliyi, yorğunluq və yuxu pozğunluğu qadınlarda daha çox görünür.

Travma ilə bağlı pozuntular. Burada maraqlı ziddiyyət var: kişilər ümumilikdə daha çox travmatik hadisə (qəza, döyüş, hücum) yaşayırlar, amma PTSP qadınlarda iki dəfə çox yaranır. Tədqiqatların ümumi təhlili göstərir ki, bunun bir səbəbi qadınların ən ağır nəticələr verən travmalara — cinsi zorakılığa və uşaqlıqda cinsi istismara — daha çox məruz qalmasıdır; lakin hətta eyni növ travmadan sonra da qadınlarda PTSP ehtimalı yüksəkdir. Qadınlarda bu pozuntunun əlamətləri arasında hadisəni təkrar-təkrar yaşamaq, daimi gərginlik, güclü utanc və özünüqınama hissi, reallıqdan qopma epizodları, sonradan isə depressiya, xroniki ağrılar və alkoqol probleminə meyillik var. Zorakılıq qadınların travma yükündə o qədər böyük yer tutur ki, keçmişdə və ya hazırda zorakılığa məruz qalma barədə hər hansı məlumat qadın pasiyentdə psixi sağlamlıq riskinin ən güclü tək əlamətlərindən biri sayılmalıdır.

Yemək davranışı pozuntuları. Anoreksiya (yeməkdən imtina), bulimiya (yemə-qusma tsiklləri) və kompulsiv yemə qadınlarda xeyli çoxdur. Əhali arasında qadınlarda anoreksiyaya həyat boyu təqribən 0,9-2 faiz, bulimiyaya 1-2 faiz, kompulsiv yeməyə isə təxminən 3,5 faiz hallarda rast gəlinir. Diqqət edilməli əlamətlər: kəskin pəhriz məhdudiyyəti, yedikdən sonra qusdurma və ya həddindən artıq idman, aybaşının kəsilməsi və ya pozulması, analizlərdə izahsız duz-mineral

pozğunluğu, diş minasının yeyilməsi. Bu əlamətlər xəstəliyin ən çox başladığı qrupda — yeniyetmə qızlarda və gənc qadınlarda — mütləq soruşulmalıdır. Yemək davranışı pozuntuları həm bədən ağırlaşmaları, həm də intihar səbəbindən bütün psixi xəstəliklər arasında ən yüksək ölüm göstəricilərindən birinə malikdir; buna görə erkən tanınma xüsusilə vacibdir.

Bədən şikayətləri arxasında gizlənən pozuntular. Depressiya və ya narahatlıq pozuntusu olan qadınlar həkimə çox vaxt "əhvalım pisdir" deyə yox, bədən şikayətləri ilə gəlirlər: yorğunluq, yuxusuzluq, baş ağrısı, mədə-bağırsaq narahatlığı, çanaq və ya əzələ ağrıları. Müayinələrdə səbəbi tapılmayan şikayətlər, həkimə çox tez-tez müraciət və fibromialgiya, qıcıqlanmış bağırsaq sindromu kimi xroniki ağrı halları (bunlar da qadınlarda üstünlük təşkil edir və çox vaxt psixi pozuntularla yanaşı gedir) — bütün bunlar praktikada dolayı siqnaldır: belə hallarda əhval və narahatlıq üzrə qısa sorğu-anket mütləq aparılmalıdır.

Bipolyar pozuntu və psixozlar. Bipolyar pozuntu (əhvalın kəskin yüksəliş və eniş dövrləri ilə gedən xəstəlik) hər iki cinsdə təxminən eyni tezlikdə olsa da, qadınlarda fərqli gedir: depressiya dövrləri üstünlük təşkil edir, xəstəliyin daha yüngül görünən, amma çox depressiyalı forması (bipolyar II), tez-tez dövr dəyişməsi və qarışıq vəziyyətlər daha çoxdur; qalxanabənzər vəzi xəstəlikləri, miqren və yemək davranışı pozuntuları daha çox yanaşı gedir. Ən vacibi: doğuşdan sonra residiv (xəstəliyin qayıtması) riski müstəsna dərəcədə yüksəkdir — təhlillər göstərir ki, bipolyar pozuntusu olan qadınların təxminən üçdə biri doğuşdan sonra residiv yaşayır, hamiləlikdə dərmanlar dayandırılıbsa, risk daha da artır. Şizofreniyada qadınlarda xəstəlik daha gec başlayır və menopauza ərəfəsində ikinci başlanğıc dalğası müşahidə olunur ki, bu da estrogen hormonunun qoruyucu rolu fərziyyəsi ilə uzlaşır. Praktik nəticə: bipolyar pozuntusu və ya əvvəllər doğuşdan sonrakı psixozu olmuş hər qadında hamiləlik və doğuş dövrü üçün qabaqcadan plan qurulmalı, menopauza yaşındakı qadınlarda ilk dəfə yaranan psixoz və ya manik hallara isə xüsusi diqqət yetirilməlidir

Qadın həyatının xüsusi dövrləri ilə bağlı göstəricilər

Qadınlarda psixi pozuntuların ən səciyyəvi cəhəti odur ki, xəstəliyin başlanğıcı və qayıtması çox vaxt reproduktiv keçid dövrlərinə düşür. Bu dövrlərin hər birində hormonlar kəskin dəyişir, eyni zamanda qadının həyatı da köklü dəyişir — və hər dövrün özünəməxsus xəbərdarlıq əlamətləri var.

Yetkinlik dövrü. Qızlarda depressiyanın artması təqvim yaşından çox bədənin yetkinləşmə mərhələsi ilə bağlıdır: fiziki yetkinləşmənin müəyyən mərhələsinə çatmış qızlarda depressiya artır, erkən yetkinləşən qızlarda isə risk daha da yüksəkdir. Yeniyetmə qızlarda risk əlamətləri: erkən aybaşı başlanğıcı, öz bədənindən narazılıq, həmyaşıdlar tərəfindən cinsi məzmunlu təzyiq, mənfi fikirlər üzərində ilişib qalma vərdişi və əvvəlcədən mövcud narahatlıq pozuntusu — sonuncu çox vaxt ilk depressiyadan əvvəl gəlir və onu xəbər verir.

Aybaşıdan əvvəlki pozuntular. Qadınların 90 faizə qədəri aybaşıdan əvvəl ən azı bir narahatedici əlamət hiss edir; beynəlxalq hesablamalara görə, aybaşıönü sindrom (PMS) qadınların təqribən 30-48 faizində olur. Bunun ağır forması — premenstrual disforik pozuntu (PMDP) — artıq xəstəlik sayılır və DSM-5 təlimatına depressiv pozuntu kimi daxil edilib: aybaşıdan əvvəlki günlərdə kəskin əhval dəyişkənliyi, əsəbilik, kədər və narahatlıq yaranır, aybaşı başlayandan bir neçə gün sonra isə keçib gedir və bu, hər ay təkrarlanaraq qadının həyatını ciddi pozur. Ciddi meyarlarla təsdiqlənmiş PMDP qadınların təqribən 1,6 faizində, daha geniş meyarlarla 3-8 faizində olur.

PMDP-nin əhəmiyyəti təkcə öz əziyyəti ilə bitmir. Bu pozuntu çox vaxt digər əhval xəstəlikləri ilə birgə gedir — təhlillərə görə, PMDP/PMS olan qadınların 42-49 faizində eyni zamanda əhval pozuntusu da var. Üstəlik, PMDP olan qadınlarda intihar riski nəzərəçarpacaq dərəcədə yüksəkdir: intihar fikirləri təqribən 4 dəfə, intihar cəhdləri isə 7-yə yaxın dəfə çoxdur. Buna görə diqqətlə soruşulmuş aybaşı tarixçəsi — ideal halda iki ay ərzində gündəlik simptom qeydləri ilə təsdiqlənməklə — həm diaqnoz üsulu, həm də ümumi risk qiymətləndirməsidir. İlkin yoxlama üçün sadə PSST sorğu-anketi mövcuddur.

Hamiləlik və doğuşdan sonrakı dövr. Psixi pozuntular hamiləliyin ən çox rast gəlinən ağırlaşmalarındandır. Ümumi hesablamalara görə, qadınların təqribən 10-13 faizi hamiləlik

dövründə və ya doğuşdan sonrakı ilk il ərzində depressiya yaşayır; hamiləliyin son üç ayında və doğuşdan sonrakı ilk aylarda göstəricilər ən yüksək olur. ÜST-nin qiymətləndirməsinə görə, dünyada hamilə və yeni doğmuş qadınların 10 faizindən çoxu depressiya yaşayır; kasıb və orta gəlirli ölkələrdə göstəricilər daha yüksəkdir — hamiləlikdə 16 faizə, doğuşdan sonra 20 faizə yaxın. Son təhlillər həmçinin göstərir ki, bu dövrdə qadınların təqribən 8-10 faizində depressiya ilə narahatlıq eyni vaxtda olur, uşaq salma hallarından sonrakı altı həftə ərzində isə qadınların təxminən üçdə biri ciddi narahatlıq və ya depressiya əlamətləri yaşayır.

Doğuşla bağlı depressiyanın əsas risk əlamətləri bunlardır: keçmişdə depressiya və ya narahatlıq pozuntusu (ən güclü tək amil), əvvəlki doğuşdan sonra depressiya, hamiləlik dövründə əhval pisliyi və narahatlıq, ərin/partnyorun dəstəyinin azlığı, ailədə zorakılıq, ağır həyat hadisələri, arzuolunmaz hamiləlik, doğuş ağırlaşmaları və hamiləlik itkisi, maddi çətinliklər. Doğuşdan sonrakı ilk həftədə qadınların yarısında və daha çoxunda görünən keçici kövrəklik ("doğuş kədəri") adətən öz-özünə keçir, lakin ağır formada olduqda depressiyanın xəbərçisi ola bilər. Ən ağır hal — doğuşdan sonrakı psixoz — təqribən hər 1000 doğuşdan 1-2-də baş verir və təcili psixiatrik yardım tələb edir; əsas xəbərdarlıq əlamətləri: qadında və ya ailəsində bipolyar pozuntu, əvvəlki doğuşdan sonra psixoz, doğuşdan sonrakı ilk iki həftədə qəflətən yaranan çaşqınlıq, kəskin əhval dalğalanması və qəribə inanclar. Bu dövrdə yoxlama üçün xüsusi hazırlanmış Edinburq şkalası (EPDS) bir çox ölkələrdə doğuş xidmətinin standart hissəsidir.

Hamiləlik dövrünün psixi problemləri depressiya ilə bitmir. Narahatlıq pozuntuları hamiləlikdə ən azı depressiya qədər yayılıb, doğuşun özü isə bəzi qadınlar üçün ağır sarsıntıya çevrilə bilər: təhlillərə görə, qadınların təqribən 3-4 faizində doğuşdan sonra PTSP yaranır, təcili (qeysəriyyə) doğuş, ağır fəsadlar, ölü doğuş və ya keçmiş travma olan qadınlarda isə bu göstərici 15 faizi keçir. Əlamətlər: doğuş səhnələrinin gözlər önündə təkrar canlanması, xəstəxana və həkimlərdən, hətta növbəti hamiləlikdən qaçınma, aldığı qulluq barədə ağır xatirələr, körpə ilə bağlılıq çətinlikləri. Belə qadınlar özləri kömək üçün az müraciət etdiklərindən, xüsusilə çətin doğuşdan sonra qadının doğuş təcrübəsini özündən soruşmaq faydalıdır.

Menopauza ərəfəsi. Uzunmüddətli müşahidələr göstərir ki, menopauzadan əvvəlki keçid illəri (perimenopauza) depressiya üçün yüksək risk dövrüdür. Bir tədqiqatda bu dövrə daxil olan qadınlarda ağır depressiv əlamətlər dörd dəfədən çox, diaqnoz qoyulan depressiya isə təqribən 2,5 dəfə çox rast gəlinmişdir. Başqa bir tədqiqatda heç vaxt depressiya keçirməmiş qadınlar arasında bu keçid dövrünə daxil olanların ilk dəfə depressiyaya düşmə ehtimalı iki dəfə yüksək olmuş, istilik basmaları olan qadınlarda isə risk daha da artmışdır. Bu dövrdə riskin əlamətləri: keçmişdə depressiya (doğuşdan sonrakı depressiya və PMDP daxil olmaqla), güclü və uzunmüddətli istilik basmaları və gecə tərləmələri, yuxu pozulması, cərrahi yolla menopauza, ağır həyat hadisələri və hormon səviyyəsinin özünün deyil, kəskin dalğalanmasının olması. Menopauza şikayətləri ilə depressiya əlamətləri çox oxşadığından, bu ikisini fərqləndirmək üçün xüsusi diqqət lazımdır.

Bioloji göstəricilər və mexanizmlər

Cinsi hormonlar və fərdi həssaslıq. Risk dövrlərinin hormon dəyişikliyi dövrləri ilə üst-üstə düşməsi alimlərin diqqətini estrogen, progesteron və progesterondan yaranan, beyni sakitləşdirən təsirə malik allopreqnanolon maddəsinə yönəldib. Ən vacib tapıntı budur: xəstə və sağlam qadınlarda hormonların səviyyəsi eynidir — fərq beynin normal hormon dəyişikliyinə necə reaksiya verməsindədir. Məşhur bir eksperimentdə qadınlarda hormonlar əvvəl dərmanla dayandırılıb, sonra süni şəkildə geri qaytarılıb: eyni prosedura baxmayaraq, simptomlar yalnız əvvəllər aybaşıönü şikayətləri olmuş qadınlarda yaranıb, sağlam qadınlarda yox. Doğuşdan sonrakı hormon enişini süni yaradan oxşar eksperimentdə də depressiya əlamətləri yalnız keçmişdə doğuşdan sonrakı depressiya keçirmiş qadınlarda meydana çıxıb. Deməli, əsas bioloji amil hormon pozğunluğu deyil, bəzi qadınların hormon dəyişikliklərinə xüsusi həssaslığıdır. Bu həm də izah edir ki, nə üçün hormonla bağlı bir problem yaşamış qadında (PMDP, doğuşdan sonrakı depressiya,

hormonal kontrasepsiya fonunda əhval pisləşməsi) həyatın sonrakı dövrlərində digər problemlərin ehtimalı da artır.

Stress sistemi. İkinci mexanizm orqanizmin stress sistemidir (elmdə "hipotalamus-hipofiz-böyrəküstü vəzi oxu" adlanır). Depressiyalı qadınlarda bu sistemin işində kişilərdəkindən fərqli pozulmalar müşahidə olunur və qadın cinsi hormonları stress hormonu olan kortizolun tənzimlənməsinə birbaşa təsir edir. Stress zamanı kortizolun həddindən az və ya çox ifrazı, gün ərzində kortizol ritminin pozulması və orqanizmdə iltihabi reaksiyaların artması — bunların hamısı qadınlarda depressiya riski ilə əlaqələndirilib, lakin heç biri hələ ayrıca diaqnostik test kimi istifadə edilə biləcək dəqiqliyə çatmayıb; hələlik bunlar tədqiqat mərhələsindədir.

İrsiyyət. Əkizlər üzərində aparılan tədqiqatlara görə, depressiya riskinin təqribən 35-40 faizi irsiyyətlə bağlıdır və qadınlarda irsi payın bir qədər yüksək olması barədə məlumatlar var. Buna görə ailədə depressiya və ya bipolyar pozuntunun olması ən praktik risk əlamətlərindən biridir. Beyin görüntüləmə tədqiqatları hormonların beynin emosiya mərkəzlərinə təsirini təsdiq edir, lakin bu üsullar da hələ fərdi proqnoz üçün yararlı deyil.

Qalxanabənzər vəzi. Qadınlarda bir neçə dəfə çox rast gəlinən və xüsusilə doğuşdan sonra tez-tez pozulan qalxanabənzər vəzi funksiyası depressiya və narahatlıq əlamətlərini təqlid edə və ya gücləndirə bilər. Buna görə qadında yeni yaranan əhval pozğunluğunda tiroid hormonunun (TSH) yoxlanması standart addımdır, doğuşdan sonrakı əhval pozğunluğunda isə doğuşdan sonrakı tiroidit də nəzərə alınmalıdır.

Mexanizmdən müalicəyə. Hormon həssaslığı nəzəriyyəsi artıq real müalicə verib. Allopreqnanolonun dərman forması olan breksanolon doğuşdan sonrakı depressiyada aparılan ciddi klinik sınaqlarda simptomları sürətlə azaltmış və bu xəstəlik üçün xüsusi təsdiqlənən ilk dərman olmuşdur; ardınca həb şəklində qəbul edilən oxşar dərman — zuranolon gəlib. Bunun iki mühüm mənası var. Birincisi, hormonla bağlı psixi problemlərin real bioloji əsası olduğu bilavasitə sübut olunub — deməli, qadının hormonla bağlı psixiatrik keçmişini soruşmaq sadəcə formallıq deyil, mexanizmi əks etdirən məlumatdır. İkincisi, qadın orqanizminin dövrləri ilə bağlı xəstəliklər hədəfli müalicə üçün əlverişli sahədir — bu da onların düzgün tanınmasının dəyərini artırır.

Sosial amillər risk əlamətləri kimi

6.1 Qadınlara qarşı zorakılıq. Ər/partnyor zorakılığı və cinsi zorakılıq qadınların psixi sağlamlığını pozan ən güclü və ən yaxşı öyrənilmiş amillərdəndir. Qlobal hesablamalara görə, nə vaxtsa partnyoru olmuş qadınların təqribən 27-30 faizi həyatı boyu fiziki və ya cinsi partnyor zorakılığı yaşayır. Uzunmüddətli tədqiqatların təhlili ikitərəfli əlaqə göstərir: zorakılıq depressiya riskini təxminən iki dəfə artırır və intihar cəhdləri ilə bağlıdır; digər tərəfdən, depressiyada olan qadın zorakılığa qarşı daha müdafiəsiz olur. Eyni əlaqə narahatlıq pozuntuları və PTSP üçün də mövcuddur. Uşaqlıqda cinsi istismar — buna daha çox qızlar məruz qalır — böyüklükdə depressiya, PTSP, yemək davranışı pozuntuları və özünə zərər vermə riskini artırır. Praktik nəticə: zorakılıq barədə istənilən məlumat tam psixi sağlamlıq qiymətləndirməsi, təhlükəsizlik planı və həssas yanaşma tələb edən çox ciddi siqnaldır; əksinə, müalicəyə tabe olmayan depressiya, xroniki çanaq ağrısı və ya təkrarlanan izahsız zədələr görəndə zorakılıq barədə ehtiyatla soruşmaq lazımdır.

6.2 Maddi vəziyyət, rollar və qulluq yükü. Yoxsulluq, qeyri-sabit gəlir, aşağı təhsil və uşağı təkbaşına böyütmək — bunların hamısı qadınlarda psixi pozuntuların yüksək göstəriciləri ilə bağlıdır və maddi vəziyyətin təsiri qadınlarda çox vaxt kişilərdəkindən kəskindir. Dünyada ödənişsiz qulluq işinin — uşaq, xəstə, yaşlı qulluğunun — böyük hissəsini qadınlar görür; həddindən artıq yüklənmə və xəstə qohuma uzunmüddətli qulluq depressiya və narahatlığın təsdiqlənmiş səbəblərindəndir. İşdə ayrı-seçkilik, maaş fərqi və cinsi təzyiq əlavə yük yaradır. COVID-19 dövründə qadınlarda xəstələnmənin daha çox artması qismən onunla izah olunur ki, qadınlar həm iş itkisinə daha çox məruz qaldılar, həm də ev və qulluq yükləri artdı.

6.3 Fərq süni ola bilərmi? Uzun müddət belə fikir olub ki, qadın-kişi fərqi qadınların hisslərini daha açıq deməsi və həkimə daha çox getməsi ilə bağlıdır. Araşdırmalar göstərir ki, belə fərqlər var,

amma onlar əsas fərqi izah etmir: qadın üstünlüyü müxtəlif ölçmə üsullarında — anketlərdə, üz-üzə müsahibələrdə, yaxınların məlumatlarında — eyni dərəcədə qorunur. Bununla belə, müraciət vərdişlərinin özü də faydalı məlumatdır: qadınlar həkimə daha tez-tez getdiyindən onları yoxlamaq üçün imkan çoxdur, kişilərdə isə depressiya çox vaxt içki və ya iş problemləri şəklində üzə çıxır.

Miqrasiya və mədəniyyət. Risk əlamətləri bütün qadınlarda eyni işləmir. Miqrant və qaçqın qadınlarda doğuşdan sonrakı depressiya xüsusilə çoxdur: təhlillərə görə, təqribən 20 faiz — yerli qadınlardakından təxminən iki dəfə çox; səbəblər arasında təklik, dil maneəsi, sənəd problemləri, ailə dəstəyindən uzaqlıq və köçdən əvvəl yaşanmış travmalar var. Ümumiyyətlə, hamiləlik-doğuş dövrünün psixi pozuntuları kasıb ölkələrdə varlı ölkələrə nisbətən xeyli çoxdur, hər ölkənin daxilində isə azlıq statusu, ayrı-seçkilik və maddi çətinliklər riski daha da artırır. Nəzərə almaq lazımdır ki, müxtəlif mədəniyyətlərdə insanlar sıxıntını fərqli ifadə edirlər — bir çox yerlərdə şikayətlər əsasən bədən dili ilə (“ürəyim sıxılır”, “başım ağrıyır”) deyilir; buna görə yerli dilə uyğunlaşdırılmış anketlər və lazım olduqda tərcüməçi dəstəyi vacibdir

Erkən aşkarlama üçün sorğu-anketlər

Risk barədə bilikləri praktikaya çevirmək üçün qısa, yoxlanılmış sorğu-anketlər lazımdır. Aşağıdakı alətlər qadınlarda ən çox istifadə olunanlardır və poliklinika, qadın məsləhətxanası və doğum evi şəraitinə uyğundur.

Cədvəl 1. *Qadınlarda geniş yayılmış psixi pozuntular üçün ən çox istifadə olunan skrininq alətləri.*

Alət	Nəyi ölçür	Maddə sayı	Geniş istifadə olunan kəsim nöqtəsi
PHQ-9	Depressiya (ağırlıq 0–27 bal)	9	≥ 10
GAD-7	Narahatlıq (anksiyete)	7	≥ 10
EPDS	Hamiləlik və doğuşdan sonrakı depressiya	10	≥ 10–13 (şəraitdən asılı)
PSST	Aybaşıönü şikayətlər (PMS/PMDP)	19	Simptom meyarlarına əsasən
PCL-5	Travmadan sonrakı stress (PTSP)	20	≥ 31–33
SCOFF	Yemək davranışı pozuntuları	5	≥ 2

PHQ-9 — depressiya üçün doqquz sualdan ibarət anketdir, nəticə 0-27 bal arasında qiymətləndirilir; 10 və yuxarı bal depressiyanı təqribən 88 faiz dəqiqliklə göstərir. GAD-7 narahatlıq üçün oxşar anketdir, kəsim nöqtəsi yenə 10 baldır. Edinburq şkalası (EPDS) hamiləlik və doğuş dövrü üçün xüsusi hazırlanıb: hamiləliyin öz təbii əlamətləri (yorğunluq, iştaha dəyişikliyi) nəticəni pozmasın deyə bədənlə bağlı suallar çıxarılıb; şəraitdən asılı olaraq 10-13 bal həddi istifadə olunur, 10-cu sual isə birbaşa özünə zərər vermə fikirlərini soruşur. PSST anketi aybaşıönü şikayətlərin ilkin yoxlanması üçündür; rəsmi diaqnoz üçün əlavə olaraq iki ay gündəlik simptom qeydləri aparılmalıdır. Travma üçün PC-PTSD-5 və PCL-5 anketləri, yemək davranışı pozuntuları üçün isə cəmi beş sualdan ibarət SCOFF anketi istifadə olunur — sonuncu gənc qadınlarda ilkin yoxlama üçün yaxşı nəticə verir.

Dünyada ümumi meyl bu yoxlamaları qadınların onsuz da olduğu yerlərdə hamıya tətbiq etməkdir. ABŞ-ın profilaktika üzrə rəsmi qurumu bütün yetkinlərdə — hamilə və yeni doğmuş qadınlar da daxil olmaqla — depressiya yoxlamasını, 64 yaşa qədər isə narahatlıq yoxlamasını tövsiyə edir; mamalıq qurumları hamiləlikdə ən azı bir dəfə və doğuşdan sonra yenidən yoxlama tövsiyə edir. İki vacib qeyd: birincisi, anketdə yüksək bal hələ diaqnoz deyil — yalnız həkim qiymətləndirməsinə göndəriş üçün əsasdır; ikincisi, yoxlama yalnız o halda mənalıdır ki, müsbət nəticə çıxanda qadını

qəbul edib müalicə edə biləcək xidmət mövcud olsun — bu, xüsusilə xidmətlərin az olduğu kasıb ölkələr üçün ciddi ədalət məsələsidir.

Xəstəliklərin birgə getməsi və intihar riski

Qadınlarda psixi pozuntular çox vaxt tək gəlmir. Narahatlıq pozuntusu adətən depressiyadan əvvəl başlayır və sonradan depressiya, içki-narkotik problemi və intihar fikirlərinin riskini müstəqil şəkildə artırır. Depressiya ilə narahatlıq birgə olanda xəstəlik daha ağır, daha uzun və müalicəyə daha çətin tabe olur. Qadın həyatının dövrləri ilə bağlı pozuntular da bir-biri ilə zəncirvarı bağlıdır: PMDP olan qadında ümumi depressiya və doğuşdan sonrakı depressiya ehtimalı yüksəkdir, doğuşdan sonrakı depressiya isə öz növbəsində həm sonrakı PMDP-ni, həm də menopauza ərəfəsi depressiyasını xəbər verir — bunların hamısının kökündə eyni hormon həssaslığı durur.

İntiharla bağlı vəziyyət "gender paradoksu" adlanan xarakterik mənzərə göstərir: intihar fikirləri və intihar cəhdləri qadınlarda xeyli çoxdur, lakin intihar nəticəsində ölüm kişilərdə iki-dörd dəfə çoxdur — bunun əsas səbəbi seçilən üsulların fərqidir. Özünə zərər vermə halları ən çox yeniyetmə qızlarda və gənc qadınlarda cəmlənib. Qadınlarda intihar riskini xüsusilə artıran hallar: PMDP (yuxarıda göstərilən risk artımları ilə), doğuşla bağlı depressiya — bir sıra inkişaf etmiş ölkələrdə intihar doğuşdan sonrakı ilk ildə ana ölümünün əsas səbəblərindəndir — yemək davranışı pozuntuları, cinsi zorakılıqdan sonrakı PTSP və şəxsiyyət pozuntuları. Bu hallar aşkar ediləndə intihar riski mütləq və müntəzəm qiymətləndirilməli, intihar fikirlərinin aybaşıdan əvvəl güclənməsi isə qeyd edilməlidir.

Gedişlə bağlı daha bir əlamət içki və narkotik məsələsidir. Bu problemlər kişilərdə hələ də çox olsa da, fərq son nəsillərdə azalıb və qadınlarda xəstəlik "teleskop" kimi gedir: daha gec başlayır, amma ilk istifadədən asılılığa qədər yol daha qısa olur və qadın həkimə çatanda vəziyyət adətən daha ağırdır. Qadınlarda içki problemi çox vaxt depressiya, narahatlıq və ya travmanın üstündə yaranır və hamiləlikdə əlavə təhlükə daşıyır. Buna görə narahatlıq və ya travma keçmişi olan qadında yaranan alkoqol problemi sadəcə asılılıq kimi deyil, müalicə olunmamış psixi pozuntunun əlaməti kimi qiymətləndirilməli və hər ikisi birlikdə müalicə edilməlidir..

Mövcud biliklərin məhdudiyyətləri və gələcək istiqamətlər

Bu icmalda təqdim olunan bilikləri bir neçə məhdudiyyət şərtləndirir. Yayılma rəqəmləri istifadə olunan anketdən, bal həddindən və seçmə üsulundan asılı olaraq dəyişir — buna görə müxtəlif tədqiqatlarda fərqli rəqəmlər görmək mümkündür. Elmi məlumatların böyük hissəsi varlı ölkələrdən gəlir; qadınların yükünün ən böyük olduğu kasıb və orta gəlirli ölkələr isə hələ də az öyrənilib. Bioloji cinslə sosial gender amillərini bir-birindən ayırmaq çətindir və transgender insanlar üzrə tədqiqatlar yenicə başlayır. Bioloji göstəricilər mexanizmi yaxşı izah etsə də, hələ konkret insanın riskini qabaqcadan deməyə imkan vermir; hansı qadının PMDP və ya doğuşdan sonrakı depressiya yaşayacağını göstərəcək bioloji testlərin tapılması aktual məqsəddir. Nəhayət, aşkarlama tədqiqatları müalicə tədqiqatlarını qabaqlayıb: yoxlama artıq geniş tövsiyə olunur, amma onun faydası yalnız müalicənin real əlçatan olduğu yerlərdə özünü göstərir.

Gələcək tədqiqatların prioritetləri: qadınları ilk aybaşıdan menopauzadan sonrakı dövrə qədər izləyən, hormonları, həyat şəraitini və simptomları müntəzəm ölçən uzunmüddətli tədqiqatlar; reproduktiv tarixçə ilə sosial amilləri birləşdirən qısa risk qiymətləndirmə alətlərinin yoxlanması; ginekoloji və doğuş xidmətlərində "yoxlamadan müalicəyə" yolunun real şəraitdə qurulması; və doğuşdan sonrakı depressiya üçün ilk xüsusi dərmanları artıq vermiş hormon-beyin mexanizmlərinin daha dərindən öyrənilməsi.

Nəticə

Qadınlarda psixi pozuntuların aydın və praktikada istifadə edilə bilən əlamətlər sistemi var. Rəqəmlər baxımından qadınlar depressiya, narahatlıq, travma və yemək davranışı pozuntularının təxminən iki qat yükünü daşıyır; bu fərq yetkinlik dövründə yaranır və qadın həyatının dövrləri boyunca formalaşır. Klinik baxımdan qadınlarda xəstəlik daha çox daxili sıxıntı və bədən şikayətləri şəklində görünür, xəstəliklər tez-tez birgə gedir və intiharla bağlı özünəməxsus mənzərə

mövcuddur. Mexanizm baxımından ən yaxşı sübut olunmuş izah budur: bəzi qadınların beyni normal hormon dəyişikliklərinə xüsusi həssasdır və bu həssaslıq stress sistemi və ağır sosial təsirlərlə — ilk növbədə zorakılıq və maddi çətinliklərlə — birləşəndə xəstəlik yaranır. Praktik baxımdan bir neçə sadə anket, qadınların onsuz da həkimə gəldiyi məqamlarda tətbiq edilməklə, riskli qadınları erkən tapmağa imkan verir. Qadının reproduktiv-psixiatrik tarixçəsini soruşmaq qadın sağlamlığı xidmətində hamiləlik tarixçəsi qədər adi hala çevrilməlidir: bu, qısa, xərcsiz və psixiatriyada mövcud olan ən məlumatverici risk qiymətləndirmələrindən biridir. Elm sayəsində artıq bilinənlərlə səhiyyə sistemlərinin real aşkarlayıb müalicə etdikləri arasındakı boşluğun aradan qaldırılması qadınların psixi sağlamlığı sahəsində əsas vəzifə olaraq qalır.

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Art History

ЛИЧНОСТЬ АХМЕТА ЖУБАНОВА В ВОСПОМИНАНИЯХ БАГЫБЕКА КУНДАКБАЕВА: ЭТИЧЕСКИЕ АСПЕКТЫ[1]

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Аннотация. Статья посвящена личности академика Ахмета Жубанова в воспоминаниях театроведа, доктора искусствоведения Багыбека Кундакбаева «Дни, проведенные вместе с Ахметом Жубановым». На основе мемуарных свидетельств показаны три взаимосвязанных аспекта личности ученого: человечность, мера интеллигентности и научная этика. Особое внимание уделяется поддержке А.Жубановым молодых исследователей, его наставнической деятельности, культуре научной дискуссии, принципиальности в вопросах изучения национального искусства и профессиональным взаимоотношениям с коллегами. Выявляется значение воспоминаний Б.Кундакбаева как источника, дополняющего биографию А.Жубанова и позволяющего раскрыть его человеческие и аналитические качества. Определяется преемственность научно-наставнической традиции, связующей деятельность А.Жубанова и Б.Кундакбаева в развитии отечественного искусствоведения.

Ключевые слова: мемуары, человечность, культура, интеллигентность, научная этика, искусствоведение.

Аңдатпа. Мақала өнертану ғылымдарының докторы, театртанушы Бағыбек Құндақбаевтың «Ахмет Жұбановпен бірге өткен күндер» атты естелігіндегі академик Ахмет Жұбановтың тұлғалық болмысына арналған. Естелік деректері негізінде ғалым тұлғасының өзара байланысты үш қыры көрсетіледі: оның адамгершілігі, зиялылық мәдениеті және ғылыми этикасы. Ахмет Жұбановтың жас зерттеушілерге көрсеткен қолдауына, тәлімгерлік қызметіне, ғылыми пікір алмасу мәдениетіне, ұлттық өнерді зерттеу мәселелеріндегі ұстанымдылығына және әріптестерімен кәсіби қарым-қатынасына ерекше назар аударылады. Бағыбек Құндақбаев естеліктерінің Ахмет Жұбанов өмірбаянын толықтыратын әрі оның талдау шеберлігі мен адами қасиеттерін ашатын маңызды дереккөз ретіндегі мәні айқындалады. Отандық өнертануды дамытудағы А.Жұбанов пен Б.Құндақбаев қызметін жалғастырып жатқан ғылыми-тәлімгерлік дәстүрдің сабақтастығы белгіленеді.

[1] Работа выполнена в рамках реализации проекта Комитета науки Министерства науки и высшего образования Республики Казахстан BR27101897 «Цифровая трансформация экосистемы литературоведения, фольклористики и искусствоведения Казахстана: междисциплинарные исследования».

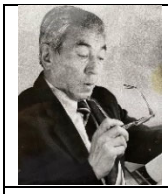
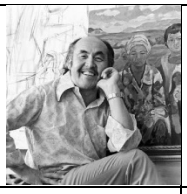
Түйін сөздер: естеліктер, адамгершілік, мәдениет, зиялылық, ғылыми этика, өнертану.

Abstract. The article is devoted to the personality of Academician Akhmet Zhubanov in the memoirs of theater critic, Doctor of Art History Bagybek Kundakbayev “Days Spent Together with Akhmet Zhubanov”. On the basis of memoir evidence, three interconnected aspects of the scientist’s personality are shown: humanity, the measure of intellectuality, and scientific ethics. Particular attention is paid to A.Zhubanov’s support for young researchers, his mentoring activities, the culture of scientific discussion, integrity in matters of studying national art, and professional relationships with colleagues. The significance of B.Kundakbayev’s memoirs as a source complementing the biography of A.Zhubanov and revealing his human and analytical qualities is identified. The continuity of the scientific and mentoring tradition connecting the activities of A.Zhubanov and B.Kundakbayev in the development of domestic art history is determined.

Keywords: memoirs, humanity, culture, intellectuality, scientific ethics, art history.

В этом году казахстанское общество отмечает юбилейные даты ряда выдающихся деятелей, внесших неоценимый вклад в становление и развитие образования, науки и искусства, а также в сохранение и дальнейшее развитие национального культурного наследия. Среди них немало представителей культуры, чьи столетние юбилеи отмечаются в текущем году.

В числе юбиляров – актер кино и театра, Заслуженный артист Казахской ССР Макилькожа Куланбаев; выдающаяся кобызистка, Народная артистка СССР Фатима Балгаева, поднявшая искусство исполнения на кобызе на профессиональный уровень и сформировавшая исполнительскую школу; домбрист, педагог, Заслуженный деятель искусств Казахской ССР Хабидолла Тастанов; выдающийся представитель изобразительного искусства Казахстана, Народный художник, художник кино и график Сахи Романов; известный режиссер Абдулла Карсакбаев, внесший значительный вклад в формирование золотого фонда казахского кино; Народный артист СССР и Казахстана Ермек Серкебаев, прославивший казахское оперное искусство на мировом уровне.

					
Макилькожа Куланбаев	Фатима Балгаева	Хабидолла Тастанов	Сахи Романов	Абдолла Карсакбаев	Ермек Серкебаев

Каждый из них внес свой особый вклад в профессиональное становление и развитие определенного направления национального искусства. В числе юбиляров – и театровед, доктор искусствоведения Багыбек Кундакбаев.

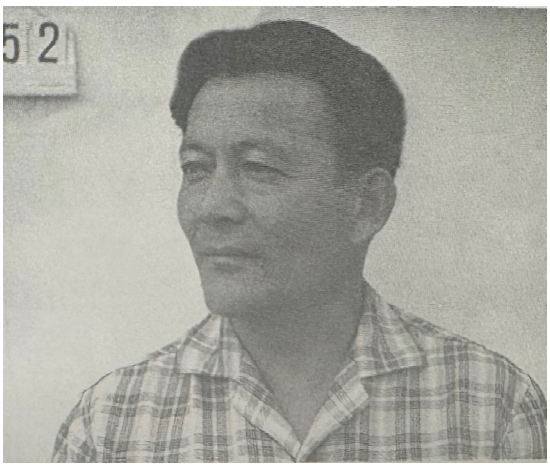
Столетний юбилей Багыбека Кундакбаева – ученого, внесшего особый вклад в становление и развитие казахстанского искусствоведения (прежде всего, театроведения) – предоставляет возможность вновь обратиться к его научному наследию, исследовательским принципам и трудам, посвященным изучению истории национального театрального искусства.

При изучении творческого и научного наследия Багыбека Кундакбаева особое значение имеют и воспоминания о современниках и учителях. Среди них особое место

занимает его очерк об академике Ахмете Жубанове[2]. Воспоминания «Дни, проведенные вместе с Ахметом Жубановым» Кундакбаев посвятил 100-летнему юбилею академика. В этой работе автор пишет не только о вкладе выдающегося ученого в развитие музыковедения, но и подробно раскрывает его организаторскую роль в становлении казахстанского искусствознания, заботу о молодых ученых, гражданскую позицию в вопросах национального искусства и высокую интеллигентность.

С этой точки зрения воспоминания Багыбека Кундакбаева представляют интерес не только как мемуарный источник, дополняющий биографию Ахмета Жубанова, но и как ценное свидетельство, позволяющее глубже понять человеческие и интеллектуальные качества ученого. Вместе с тем конкретные события и авторские оценки, представленные в тексте, позволяют увидеть особенности взаимоотношений академика Ахмета Жубанова в научной среде, его позицию в вопросах защиты национального искусства, а также культуру научной дискуссии. Эти особенности имеют существенное значение для более глубокого осмысления этических аспектов, с одной стороны, и, с другой – позволяют раскрыть отношение автора к представителю старшего поколения ученых, основанное на искреннем уважении и признательности, а также показать качество их профессиональных и личных взаимоотношений.

Ахмет Жубанов



Багыбек Кундакбаев

Анализ сведений, содержащихся в воспоминаниях, с точки зрения этических аспектов позволяет раскрыть несколько граней личности академика А.Жубанова в интерпретации Б.Кундакбаева. В данной статье его образ воссоздан сквозь призму личностных качеств, подлинной интеллигентности и морали.

1. Человечность. К данной грани относятся личная поддержка и внимание А.Жубанова к Б.Кундакбаеву, его простота в общении, чувство юмора, а также способность осознавать вес собственных слов и впоследствии смягчать их воздействие.

В воспоминаниях Багыбека Кундакбаева человеческий облик Ахмета Жубановаю, прежде всего, раскрывается через его заботу о молодых специалистах и поддержку их профессионального становления. Именно совет академика побудил автора отправиться в Москву для обучения в аспирантуре. Жубанов, оценив творческие возможности Кундакбаева, дал ему конкретное направление для дальнейшего научного поиска: «Багыбек, ты много пишешь статей в газеты и журналы, и это правильно – для театрального

[2] Напомним, что в этом году отмечается 120-летие академика Ахмета Жубанова. В данном контексте следует отметить, что рассматриваемые воспоминания были написаны к 100-летнему юбилею Ахмета Жубанова.

критика очень полезно постоянно публиковаться. Я читаю твои материалы, у тебя уже отлично набита рука. Если послушаешь моего совета: бросай сейчас всё и поезжай в Москву, поступай в аспирантуру. Ты человек пишущий, поэтому кандидатскую диссертацию завершишь буквально за год-два. Супруге, конечно, придется немного нелегко, зато в итоге ты станешь настоящим учёным» [1, 16].

Из этих слов видно, что А.Жубанов не только распознал способности молодого исследователя, но и ответственно отнесся к его профессиональному будущему. Он не ограничивался советами, а следил за учебой Б.Кундакбаева в Москве, ориентировал его на завершение диссертационной работы в более короткие сроки, а также посещение театральных постановок и знакомство с профессиональной литературой.

Забота академика не ограничивалась научными советами. В воспоминаниях Б.Кундакбаева упоминается также его помощь в решении жилищного вопроса. Этот эпизод показывает, что А.Жубанов не оставался безучастным и к бытовым обстоятельствам молодого специалиста. Характер этих отношений ясно передают следующие слова автора: «Я получил двухкомнатную квартиру и благословение…» [1, 18].

Еще одна особенность, раскрывающая человеческий облик Жубанова, – его простота в общении, склонность к шутке и непринужденность в отношениях с людьми. Вспоминая новогодний вечер 1965 года, Кундакбаев пишет: «Ахмет Куанович любил общаться с молодёжью и коллегами, а при случае был не прочь и повеселиться» [1, 17].

Эта характеристика позволяет увидеть одновременно высокий авторитет академика в официальной научной среде и его простоту в повседневном общении. Игра на пианино, аккомпанирование пению, шутки с коллегами и совместное времяпрепровождение свидетельствуют о его способности устанавливать близкие и располагающие отношения с окружающими.

Ценность воспоминаний заключается также в том, что автор не ограничивается исключительно положительными характеристиками А.Жубанова, а показывает и сложные стороны его характера. Б.Кундакбаев открыто пишет о том, что в 1967 году после критического отзыва о спектакле А.Мамбетова «Қарақыпшақ Қобыланды» Жубанов оказался задет сложившейся ситуацией. Однако впоследствии академик сам поинтересовался, не ранили ли автора ранее сказанные им слова, и попытался смягчить ситуацию: «Дорогой мой Багыбек, ты не обиделся на те недавние слова твоего старшего брата?» [1, 19].

В воспоминаниях современников А.Жубанова можно встретить свидетельства того, что эти человеческие качества проявлялись не только в повседневной жизни, но и в его научной деятельности. Так, Бауыржан Момышулы в воспоминаниях «Академик Ахмет Жубанов» отмечает: «Таким образом, достойно выполнил гражданский долг перед Курмангазы. Я считаю этот труд великой гуманитарной и гражданской заслугой Ахана» [2, 106]. Подобные примеры можно привести и из трудов других исследователей, посвященных творчеству и деятельности Ахмета Жубанова. В сравнительно-исследовательском аспекте данный вопрос требует дальнейшего изучения.

Этот эпизод напоминает о необходимости воспринимать личность Жубанова не как безупречный образ, а как сложную человеческую индивидуальность, обладающую собственными чувствами и особенностями характера. Его стремление впоследствии переосмыслить вес сказанных им слов и восстановить гармонию в отношениях предстает как важная составляющая его человеческой культуры.

2. Интеллигентность. Образ Ахмета Жубанова как интеллигента раскрывается через его тактичность, манеру речи, умение выражать свою позицию посредством юмора и иронии, глубокое знание различных видов искусства, а также стиль общения с людьми старшего и младшего поколения.

В воспоминаниях Багыбека Кундакбаева интеллигентность Ахмета Жубанова раскрывается через широту его культурного кругозора, интерес к различным видам искусства и тактичность в отношениях с людьми. Автор особо подчеркивает, что Жубанов глубоко знал и театральное искусство: «Мысль, которая тогда у меня возникла, заключалась в том, что Ахмет Куанович также всесторонне разбирался в театре» [1, 17].

Это мнение представляет собой не просто оценочное суждение мемуарного характера. Б.Кундакбаев, увидев А.Жубанова в качестве своего первого оппонента на защите диссертации, убедился в том, что он был готов профессионально анализировать вопросы театроведения: «Выступив в качестве первого оппонента диссертации, Ахан – с одобрением, глубоким научным анализом и одинаковым мастерством владея как казахским, так и русским языком, – говорил с настоящим вдохновением» [1, 17].

В данном контексте понятие интеллигентности не ограничивается широтой знаний или эрудицией. Оно проявляется также в способности уместно применять полученные знания, понимать проблематику другой области искусства и корректно, убедительно выражать собственную позицию.

Культура общения Жубанова проявлялась и в особенностях речи. Кундакбаев характеризует его следующим образом: «Ахмет Куанович был человеком принципиальным и самолюбивым – он никогда и никому не позволял брать над собой верх в споре. Будучи мастером тонкой иронии и сарказма, он, не повышая голоса, мягко и спокойно умел поставить любого оппонента на место» [1, 17].

Здесь автор показывает не только чувство собственного достоинства А. Жубанова, но и его способность разрешать спорные ситуации не посредством повышенного тона или конфронтации, а с помощью слова, иронии и интеллектуальной аргументации. В этом смысле мера интеллигентности Жубанова непосредственно связана с уровнем научной и межличностной дискуссии.

Следующая характеристика, приведенная в заключительной части воспоминаний, обобщает естественное единство внешней воспитанности и внутренней культуры Жубанова: «Встречая старших по возрасту или сверстников, он здоровался, приподнимая одной рукой шляпу и слегка улыбаясь» [1, 19].

Автор воспринимает этот жест не просто как элемент подчеркнутой вежливости, а как проявление природы личности. Поэтому итоговая характеристика в воспоминаниях также подтверждает эту мысль: «Интеллигентность, высокая культура и мудрость были присущи Ахану от природы, составляя основу его глубокой человечности» [1, 19].

В интерпретации Багыбека Кундакбаева интеллигентность А.Жубанова проявляется не только в его образованности и широте знаний, но и в манере речи, уровне ведения дискуссии, уважительном отношении к старшим и тактичности в общении с окружающими.

3. Научная этика. Особое значение имеют такие аспекты, как выступление А.Жубанова в качестве первого оппонента, его участие в защите диссертаций молодых ученых, а также принципиальная позиция в вопросах историко-теоретического изучения национального искусства. Именно они составляют основные аргументы статьи, связанные с проблематикой научной этики.

В воспоминаниях Багыбека Кундакбаева научная этика Ахмета Жубанова, прежде всего, проявляется в поддержке молодых исследователей, создании условий для их становления и принципиальном отношении к научным проблемам. Обстоятельства защиты диссертации самого Б.Кундакбаева являются конкретным тому примером. А.Жубанов заранее сообщил ему, что будет первым оппонентом, и дал рекомендации относительно подготовки к защите: «Институт языкознания и Институт литературы и искусства организуют объединенный ученый совет, так что готовься к нему. Мы пригласили ученых-театроведов из Москвы и Ташкента, а я – твой первый оппонент, ты ведь не против? Только вот

защищаться на этом совете будет посложнее, чем в Москве: задать могут очень много вопросов» [1, 17].

В данном случае можно увидеть сочетание научного наставничества и профессиональной ответственности старшего коллеги. Жубанов стремился не просто обеспечить успешную защиту Кундакбаева, но и требовал от него готовности к серьезной дискуссии. Таким образом, поддержку молодого ученого он не противопоставлял предъявлению к нему строгих требований.

Б.Кундакбаев особо отмечает уровень научной экспертизы А.Жубанова в области театроведения. Повторим важный тезис: «Выступив в качестве первого оппонента диссертации, Ахан – с одобрением, глубоким научным анализом и одинаковым мастерством владея как казахским, так и русским языком, – говорил с настоящим вдохновением» [1, 17].

Судя по приведенным автором сведениям, влияние А.Жубанова в научной среде не ограничивалось поддержкой отдельных исследователей. Б.Кундакбаев характеризует его как ученого, оказавшего существенное влияние на становление первых казахстанских театроведов и музыковедов: «Таким образом, присвоение ученых степеней первым отечественным театроведам, защитившимся у нас в республике, было инициативой Ахмета Жубанова» [1, 17].

В этой связи можно отметить созвучие данной мысли с высказыванием С.Кузембай: «А.К.Жубанов оказал большое воздействие также на развитие смежных гуманитарных наук – на литературоведение, фольклористику, этнографию» [3, 490].

Кроме того, автор называет Гафуру Бисенову, Бисенгали Гизатова, Зейнура Коспакова, Алтын Кетегенову, защитивших кандидатские диссертации под руководством Жубанова, а также Мариям Ахметову и Алму Темирбекову, испытавших его влияние, «первыми национальными музыковедами». Эти сведения свидетельствуют о значительной роли академика в формировании научной школы [4].

Еще один важный этический аспект проявляется в позиции Жубанова относительно объективной оценки национального искусства. Во время обсуждения в Москве многотомного издания по истории советской музыки он принципиально выступил против вступительной части, в которой музыкальному искусству национальных республик уделялось недостаточное внимание: «Недостаточное внимание к музыке других народов – явление нелепое и необоснованное как с научной, так и с культурной точки зрения» [1, 18].

Это высказывание позволяет понять представление А.Жубанова о научной объективности. Изучение казахской (и другой) музыки он рассматривал и с точки зрения национальных интересов, и в контексте общенаучных требований и культурной ответственности. По его мнению, ограничиваться лишь перечислением названий произведений при рассмотрении музыкального наследия республик означало отступать от принципа требуемой полноты.

В данном эпизоде отчетливо проявляется и позиция А.Жубанова в возникшей дискуссии. Он не только открыто высказывает свое мнение, но и обосновывает его с научной и культурной точек зрения. Оценка Кундакбаева – «Принципиальность и гордость Ахана, с которыми он защищал как национальное искусство, так и честь народа, а также его глубокомыслие, высокая культура и мудрость в высказывании критики проявились на высочайшем этическом уровне, служащем истинным примером» [1, 18] – представляет собой авторское осмысление данного эпизода.

Таким образом, понятие научной этики в данном контексте не ограничивается исключительно профессиональными обязанностями исследователя. Оно предстает как более широкая система принципов, включающая приверженность истине, объективную оценку искусства различных культур, поддержку молодых ученых при одновременном

предъявлении к ним высоких профессиональных требований и чувство ответственности перед научным сообществом.

В своей научной деятельности Багыбек Кундакбаев глубоко осознавал значение поддержки и наставнического примера Ахмета Жубанова, который тот оказывал молодым ученым, и сделал эти принципы одними из важных ориентиров собственной профессиональной деятельности. Полученный от А.Жубанова научно-нравственный опыт Б.Кундакбаев впоследствии продолжил сам, оказывая поддержку поискам многих молодых исследователей, работавших в области музыки, театра, кино и изобразительного искусства, и способствуя защите их диссертационных работ.

За трибуной Багыбек Кундакбаев (2007) – Председатель Диссертационного совета Института литературы и искусства им. М.О.Ауэзова

Тунгышбай Жаманкулов, Шахым Гуллыев, Аклима Омарова, Багыбек Кундакбаев, Тухтасин Гафурбеков, Айнур Казтуганова (2007)

Особенно показательна в этом отношении его деятельность в качестве председателя Диссертационного совета ИЛИ, которая позволяет более отчетливо определить масштаб его вклада в развитие искусствоведения и формирование научных кадров. Именно с этой точки зрения научно-организационная деятельность Б.Кундакбаева свидетельствует о преемственности научной традиции, сформированной А.Жубановым.

Сегодня научный путь исследователей, плодотворно работающих в различных областях искусствоведения, позволяет проследить преемственность этой традиции и свидетельствует о жизнеспособности научного и наставнического наследия А.Кундакбаева.

Считаем необходимым в дальнейшем расширить рамки изучения данной проблемы. Во-первых, важно сопоставить оценки, содержащиеся в воспоминаниях других ученых об Ахмете Жубанове, и выявить их общность и отличительные особенности. Во-вторых, необходимо уточнить сведения, представленные в воспоминаниях, на основе дополнительных материалов, более подробно раскрыть ход научных обсуждений в Москве, особенности профессиональных взаимоотношений между учеными и вопросы, поднимавшиеся в ходе дискуссий. В-третьих, актуальным представляется более широкое рассмотрение масштабов научно-организационной деятельности, осуществлявшейся в стенах Института литературы и искусства имени М.О.Ауэзова. В-четвертых, необходимо обозначить на основе конкретных материалов принципиальность А.Жубанова в научных вопросах и его гражданскую позицию в отношении национального искусства. В-пятых, важно оценить влияние ученых старшего поколения на формирование научного мировоззрения и профессиональное становление молодых исследователей. Исследования в этих направлениях позволят глубже осмыслить сведения, содержащиеся в воспоминаниях Багыбека Кундакбаева, и в полной мере воспринять их научно-познавательную ценность.

Воспоминания Багыбека Кундакбаева предстают важным мемуарным источником, позволяющим раскрыть научную деятельность Ахмета Жубанова, его человеческий и интеллектуальный облик. Сочетая личное уважение автора к А.К.Жубанову с профессиональной оценкой его деятельности, воспоминания раскрывают научно-этические принципы ученого через его поддержку молодых исследователей, защиту национального искусства, культуру научной дискуссии и характер профессиональных взаимоотношений с коллегами.

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Sociological Sciences

ARTIFICIAL INTELLIGENCE AS A DIGITAL INTERLOCUTOR: TRANSFORMING INTERPERSONAL INTERACTION IN CONTEMPORARY KAZAKHSTAN

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Abstract

The rapid integration of generative artificial intelligence into everyday life is transforming not only information-seeking and professional practices but also interpersonal communication, advice-seeking, self-disclosure, and emotional support. This study examines how generative AI functions as an adviser, conversational partner, and communicative resource among adults in Almaty, Kazakhstan, focusing on two potentially coexisting processes: interaction substitution, whereby AI partially replaces human interaction in selected communicative and supportive functions, and interaction augmentation, whereby AI facilitates subsequent communication with other people. A quantitative cross-sectional survey was conducted among 427 adults aged 18 years and older. The analysis included descriptive statistics, reliability analysis, Spearman correlations, group comparisons, and multiple regression modelling. The findings showed that interaction augmentation was more prevalent than interaction substitution. Personal AI use was strongly associated with both substitution and augmentation, while substitution was additionally associated with greater AI self-disclosure and loneliness and with lower perceived social support. AI trust emerged as the strongest independent correlate of interaction augmentation. Significant age differences were also identified, with younger respondents and students reporting substantially higher levels of both forms of AI-mediated interaction. Importantly, substitution and augmentation were positively correlated, indicating that they represent coexisting rather than mutually exclusive patterns of human–AI interaction. The findings suggest that generative AI does not simply replace interpersonal communication but contributes to a broader redistribution of communicative functions between human and technological actors. By providing evidence from Almaty, the study extends the emerging literature on human–AI interaction to a Central Asian urban context and highlights the need to conceptualise generative AI as an increasingly embedded component of contemporary social interaction.

Keywords: generative artificial intelligence; human AI interaction; interpersonal communication; interaction substitution; interaction augmentation; AI-mediated communication; self-disclosure; social support; loneliness; Kazakhstan.

Introduction

The rapid development of generative artificial intelligence (AI) is reshaping not only technological and professional practices but also the ways in which individuals communicate, seek advice, disclose personal experiences, and obtain social and emotional support. Earlier stages of digitalisation primarily changed the channels through which interpersonal communication occurred, allowing individuals to maintain social relationships across spatial and temporal

boundaries. Generative AI introduces a qualitatively different form of mediation. Rather than functioning solely as a channel connecting human actors, AI systems can participate in the communicative process by generating messages, interpreting users' requests, offering recommendations, and sustaining extended dialogue. This development challenges conventional distinctions between interpersonal and technologically mediated communication and raises broader sociological questions concerning agency, trust, social presence, and the changing boundaries of social interaction. The concept of artificial intelligence-mediated communication (AI-MC) provides an important starting point for understanding this transformation. Hancock et al. (2020) define AI-mediated communication as interpersonal communication in which an intelligent agent modifies, augments, or generates messages in pursuit of communicative goals. The increasing sophistication of large language models, however, extends the role of AI beyond mediation between human communicators. Contemporary conversational systems can themselves become objects of interaction: users may ask them for advice, discuss personal difficulties, seek assistance in decision-making, prepare for conversations with other people, or use them as sources of informational and emotional support. Consequently, the sociological significance of generative AI lies not only in the automation of communication but also in its gradual incorporation into practices that have traditionally depended on interaction with other human beings.

Recent research provides growing evidence that human AI interaction may acquire relational characteristics that go beyond instrumental technology use. Zhang et al. (2024), for example, demonstrate that users may conceptualise their relationship with AI assistants in different ways, including partnership-oriented forms of interaction, and show that perceived social support mediates the relationship between human–AI relationship type and subjective well-being. More recent studies have similarly examined the emergence of emotional attachment to social companion AI. Hu et al. (2025) found that interpersonal circumstances, perceptions of AI personification, and evaluations of the benefits and costs of interaction contribute to the formation of attachment to AI companions. Experimental research further suggests that interaction with AI can generate perceptions of interpersonal closeness under particular conditions, demonstrating that the social consequences of conversational AI cannot be reduced to its technical functionality alone (Qian & Wan, 2025). One particularly important dimension of this emerging relationship concerns emotional support and loneliness. AI companions have been discussed as accessible conversational partners capable of providing users with a sense of being heard and supported. De Freitas et al. (2024) found evidence that interaction with AI companions can reduce momentary feelings of loneliness and that the perception of being heard plays an important role in this effect. Jacobs (2024), however, approaches AI companionship from a more critical perspective, drawing attention to the ways in which technologically mediated companionship may alter experiences of recognition, meaningful relatedness, and loneliness. Recent large-scale evidence also indicates that the relationship is unlikely to be uniform: associations between AI companionship and subjective well-being can vary according to users' existing social connectedness and levels of loneliness (Takahashi et al., 2026). These findings suggest that interaction with AI should not be conceptualised as inherently socially beneficial or inherently isolating; rather, its consequences may depend on the social circumstances in which AI becomes incorporated into everyday life. This ambiguity points to a central issue for the sociology of contemporary human–AI relations: whether conversational AI substitutes for or augments interpersonal interaction. The substitution perspective suggests that readily available, responsive, and non-judgmental AI systems may reduce users' reliance on friends, relatives, colleagues, or other significant persons for advice, discussion, and emotional support. If individuals increasingly turn to AI before approaching another person, some communicative and supportive functions previously embedded in interpersonal networks may become partially transferred to technological

systems. Concerns about such displacement have become particularly relevant in discussions of companion AI, where prolonged reliance on artificial conversational partners may potentially affect users' engagement with human relationships (Malfacini, 2025).

An augmentation perspective leads to a different expectation. AI may support rather than displace interpersonal relations by helping individuals clarify their thoughts, formulate messages, consider alternative perspectives, or prepare for difficult conversations. In this case, interaction with AI becomes an intermediate stage within a broader human-to-human communicative process. Such a perspective is consistent with the original conception of AI-mediated communication as technology capable of modifying or augmenting communicative behaviour (Hancock et al., 2020). It also reflects the broader possibility that relationships with AI may produce informational or emotional support without necessarily replacing existing human social ties (Zhang et al., 2024). The distinction between substitution and augmentation is therefore analytically important because similar levels of AI use may correspond to substantially different transformations of social interaction. These questions are especially relevant in Kazakhstan, where AI is becoming increasingly embedded in the country's broader process of digital transformation. The Government of Kazakhstan approved the Concept for the Development of Artificial Intelligence for 2024–2029, establishing the development of an AI ecosystem, human capital, research capacity, infrastructure, data governance, and regulation among national priorities (Government of the Republic of Kazakhstan, 2024). This institutional development reflects a wider digital environment in which technology is increasingly incorporated into citizens' interactions with education, employment, services, and information. Kazakhstan has consequently become an important Central Asian context in which to examine not only the economic and institutional adoption of AI but also its emerging social consequences.

Yet the social implications of AI adoption remain considerably less understood than its technological, educational, and economic dimensions. In particular, limited empirical attention has been devoted to how residents of Kazakhstan integrate generative AI into personal communication, advice-seeking, emotional disclosure, and everyday decision-making. This gap is significant because the consequences of AI cannot be inferred solely from technological adoption rates. The same conversational system may function for one user primarily as a productivity tool, for another as a source of information, and for another as a confidential conversational partner. Understanding the transformation of social interaction therefore requires examining not simply whether individuals use AI, but how AI is positioned in relation to existing interpersonal ties. Almaty provides a particularly relevant urban setting for examining these emerging practices. As Kazakhstan's largest metropolitan and major educational, professional, cultural, and technological centre, the city brings together populations differing substantially in age, education, employment status, family circumstances, and patterns of digital engagement. Examining adults across different age groups is particularly important because the social incorporation of generative AI is unlikely to be generationally uniform. Younger adults may encounter AI through education, digital communication, and emerging professional practices, whereas middle-aged and older residents may integrate these technologies into different configurations of work, family life, information seeking, and interpersonal support. A city-level study therefore makes it possible to investigate variation in human AI interaction without assuming that a single pattern characterises Kazakhstan as a whole. Against this background, the present study examines the role of generative AI in the transformation of interpersonal interaction among adult residents of Almaty, Kazakhstan. Rather than treating AI use solely as an indicator of technological adoption, the study conceptualises it as a potentially relational social practice encompassing advice-seeking, emotional support, self-disclosure, perceived understanding, communication preparation, and reliance on AI relative to human contacts. Particular attention is given to two competing but potentially coexisting processes: interaction substitution, whereby AI reduces reliance on other people for certain

communicative or supportive functions, and interaction augmentation, whereby AI facilitates subsequent interpersonal communication. Accordingly, the study addresses the following research question: How is the use of generative artificial intelligence as an adviser, conversational partner, and source of support associated with the transformation of interpersonal interaction among adults in Almaty, Kazakhstan? More specifically, it examines whether greater engagement with AI for personal purposes is associated with the partial substitution of human advice and communication, whether AI is used to facilitate and improve subsequent interpersonal interaction, and how these patterns vary according to respondents' socio-demographic characteristics, loneliness, perceived social support, trust in AI, and willingness to disclose personal information. By shifting the analytical focus from AI adoption to the relational practices surrounding its use, the study seeks to contribute to the emerging sociology of human–AI interaction and to provide empirical evidence from a Central Asian urban context that remains underrepresented in the international literature.

The aim of this study is to examine how the growing use of generative artificial intelligence as an adviser, conversational partner, and source of informational and emotional support is associated with the transformation of interpersonal interaction among adult residents of Almaty, Kazakhstan, with particular attention to whether AI-mediated practices substitute for or augment traditional forms of human-to-human communication.

The object of the study is interpersonal social interaction among adult residents of Almaty in the context of the increasing integration of generative artificial intelligence into everyday life. *The subject of the study* comprises patterns of interaction with generative AI, including its use for personal advice, emotional support, self-disclosure, decision-making and communication assistance, as well as the relationship of these practices with trust in AI, perceived social support, loneliness, and the substitution or augmentation of interpersonal interaction.

Research Hypotheses

H1. Higher levels of personal and emotionally oriented AI use are associated with a greater tendency to substitute AI interaction for traditional interpersonal practices, including seeking advice, discussing personal problems, and turning to other people for support.

H2. Higher levels of AI use for communication-related purposes are associated with greater augmentation of interpersonal interaction, expressed in using AI to prepare for difficult conversations, formulate thoughts and emotions more clearly, and facilitate subsequent communication with other people.

The two hypotheses are not treated as mutually exclusive. Generative AI may simultaneously substitute for some forms of interpersonal interaction while augmenting others. The study therefore conceptualises the social consequences of AI use as a continuum between interaction substitution and interaction augmentation, rather than assuming an exclusively positive or negative effect of AI on human relationships.

Theoretical Framework

The theoretical framework of this study integrates the CASA paradigm, Human–Machine Communication HMC, AI-mediated communication, relational-agent research, and studies of self-disclosure and AI companionship. The CASA perspective demonstrates that individuals may apply social rules and expectations to technological agents even when they understand that they are interacting with machines, which helps explain why generative AI can be perceived as a socially meaningful interlocutor (Nass et al., 1994). Building on this, Human–Machine Communication conceptualises AI as an increasingly active participant in communicative exchanges rather than merely a technical channel (Guzman & Lewis, 2020), while AI-mediated communication theory highlights its role in modifying, generating, and augmenting interpersonal communication (Hancock et al., 2020). Research on relational agents further shows that repeated interaction with computational systems can generate trust, familiarity, engagement, and friendship-like

perceptions (Bickmore & Picard, 2005; Bickmore et al., 2005). Recent studies extend these ideas to contemporary AI systems, demonstrating associations between human–AI relationships, perceived social support, companionship, and subjective well-being (Zhang et al., 2024). Self-disclosure is particularly important in this context: Social Penetration Theory emphasises the role of increasing breadth and depth of disclosure in relational development (Altman & Taylor, 1973), and empirical research shows that users may disclose personal and emotional information to conversational agents and develop changing disclosure patterns over time (Croes & Antheunis, 2023; Warren-Smith et al., 2025). AI may also be perceived as relatively non-judgmental, encouraging users to discuss sensitive issues and seek advice or emotional reassurance (Warren-Smith et al., 2025). At the same time, AI companionship has been associated with temporary reductions in loneliness, especially when users feel heard and supported (De Freitas et al., 2024). On this basis, the present study conceptualises the transformation of interpersonal interaction through two complementary mechanisms: interaction substitution, in which AI partially replaces human advice, emotional support, or problem discussion, and interaction augmentation, in which AI helps users clarify thoughts, prepare for conversations, and improve subsequent communication with others. These mechanisms are not mutually exclusive and together capture the broader reconfiguration of communicative resources and relational practices associated with the growing integration of generative AI into everyday social life.

Literature Review

From computer-mediated communication to human–AI interaction. The digital transformation of social interaction predates the emergence of generative artificial intelligence. Research on computer-mediated communication has long demonstrated that communication technologies alter the conditions under which interpersonal relationships are initiated, maintained, and experienced. Early CMC research frequently emphasised the limitations created by the reduced availability of non-verbal and contextual cues in technologically mediated environments (Walther, 1992). Subsequent scholarship, however, challenged the assumption that mediated communication is necessarily socially impoverished. Walther's (1996) hyperpersonal model demonstrated that under particular conditions computer-mediated interaction may become highly selective, intimate, and relationally meaningful. This shift was theoretically important because it established that the social quality of interaction depends not simply on the physical presence of another person but on the ways users interpret and adapt to technological environments. Generative AI introduces a further transformation. Whereas conventional communication technologies predominantly connect human actors, conversational AI can generate content, interpret requests, provide feedback, and sustain dialogue. Guzman and Lewis (2020) argue that such systems challenge traditional communication models because AI can no longer be understood exclusively as a neutral channel through which human communication occurs. Human–Machine Communication (HMC) therefore treats communication between humans and computational agents as a legitimate object of communication research. Similarly, Hancock et al. (2020) conceptualise AI-mediated communication as a process in which intelligent systems modify, augment, or generate messages in pursuit of interpersonal and communicative goals. These perspectives point to an important conceptual transition.

The social character of human–AI interaction. The possibility that humans respond socially to technological agents is not entirely new. The Computers Are Social Actors (CASA) paradigm demonstrated that individuals can apply interpersonal conventions to computers even when they know that the systems are non-human (Nass et al., 1994). Such responses may include politeness, attribution of personality, reciprocity, and other social expectations. Contemporary conversational AI substantially extends these possibilities because natural-language interaction creates a stronger appearance of responsiveness and conversational continuity than earlier computer interfaces. Research on relational agents anticipated some of these developments. Bickmore and Picard

(2005) demonstrated that computational systems could be designed to establish and maintain longer-term social-emotional relationships with users. In research involving older adults, Bickmore et al. (2005) found that interaction with relational agents could be interpreted through familiar interpersonal categories, including friendship-like communication.

AI as an adviser and conversational partner. Advice-seeking represents one of the clearest examples of this shift. Generative AI provides immediate, personalised-looking responses without requiring coordination with another person's time or availability. The absence of conventional interpersonal costsincluding fear of embarrassment, concern about burdening another person, or anticipation of negative judgementmay make AI particularly attractive for questions that users perceive as sensitive. This characteristic distinguishes conversational AI from traditional online information retrieval. Searching for information through a search engine does not ordinarily constitute a sustained conversational relationship. Generative AI, by contrast, allows users to describe circumstances, provide additional context, challenge responses, ask follow-up questions, and iteratively refine advice. Consequently, information seeking can gradually acquire characteristics of interpersonal consultation. The role attributed to AI is therefore important. Users may approach the same system as a search tool in one situation, a writing assistant in another, and an adviser or conversational partner in another. Zhang et al. (2024) demonstrate that different perceived types of user–AI relationships are associated with different outcomes and that perceived social support represents an important mechanism linking relationships with AI assistants to subjective well-being. This suggests that frequency of use alone is insufficient for understanding the social consequences of generative AI. The purpose and relational meaning of use must also be considered. This distinction is particularly relevant for general-purpose generative AI systems. Much existing research on emotionally meaningful human–AI interaction has focused on applications explicitly designed for companionship.

Self-disclosure, trust, and perceived non-judgement. Self-disclosure constitutes another major theme in the literature on human–AI relationships. In interpersonal relationships, disclosure of personal information, thoughts, and emotions contributes to the development of intimacy and trust (Altman & Taylor, 1973). Conversational AI complicates this traditionally human process by providing a non-human recipient capable of producing responses that can be interpreted as attentive, supportive, or empathetic. Research on human–chatbot interaction indicates that users may disclose personal experiences to conversational systems and that patterns of disclosure can develop over repeated interactions. Croes and Antheunis (2023), for example, examined self-disclosure longitudinally in human–chatbot relationships and demonstrated that communication with a chatbot can encompass a wide range of personal topics. Such findings suggest that disclosure to AI is not necessarily limited to isolated experimental interactions but can become embedded in continuing communicative practices. Several mechanisms may explain why users disclose personal information to AI.

Emotional support, companionship, and loneliness. The relationship between AI interaction and loneliness has become one of the most rapidly developing areas of human–AI research. Conversational agents are particularly relevant in this context because loneliness is not simply physical isolation; it concerns perceived deficiencies in desired social relationships. An artificial conversational partner capable of responding immediately and maintaining dialogue may therefore provide at least some of the subjective characteristics associated with social contact. De Freitas et al. (2025) provide particularly important evidence in this area. Across multiple studies, they found that interaction with AI companions can reduce momentary loneliness, with the perception of being heard playing an especially important role. Their findings are theoretically significant because they suggest that the effects of conversational AI may depend less on whether the interaction partner is objectively human and more on whether the interaction generates particular subjective social experiences. Nevertheless, short-term alleviation of loneliness and

long-term transformation of social relationships are not equivalent outcomes. An AI system may provide immediate comfort while simultaneously changing the ways in which users activate human support networks. Jacobs (2024) therefore approaches AI companionship through the broader concept of digital loneliness and social recognition, questioning whether artificial forms of recognition can reproduce the relational qualities associated with meaningful human relationships. This tension is also reflected in discussions of companion AI more broadly. Malfacini (2025) argues that AI companionship may generate both benefits and risks for human relationships. Potential benefits include availability, accessibility, and support for individuals who experience difficulties establishing or maintaining social connections.

Substitution of human interaction. One of the most consequential but still insufficiently resolved questions concerns whether AI-based interaction substitutes for human contact. A substitution mechanism can occur when individuals transfer communicative or supportive functions from their interpersonal networks to AI. For example, rather than asking a friend for advice, an individual may consult AI; rather than discussing a difficult personal situation with a relative, the individual may describe it to a chatbot; rather than approaching another person for reassurance, the individual may repeatedly seek feedback from an artificial system. Such substitution need not involve complete withdrawal from human relationships. It can occur incrementally and at the level of specific social functions. A person may maintain an active social network while increasingly outsourcing particular forms of advice, emotional processing, or decision preparation to AI. For this reason, measuring only the amount of social contact may fail to capture changes in the functional composition of social interaction. The availability of AI makes this possibility particularly important. Human support involves reciprocity and social obligations: friends and family members have their own needs, schedules, emotions, and expectations. AI interaction appears to remove many of these constraints. The user does not have to wait for an appropriate moment, reciprocate emotional labour, or worry about tiring the conversational partner. These affordances may make AI attractive precisely in situations in which interpersonal support is perceived as difficult to access. However, existing evidence does not justify assuming that greater AI use necessarily produces social withdrawal. Much of the current literature focuses either on users already engaging with companion systems or on relatively short-term experimental outcomes. Consequently, the direction of the relationship remains theoretically open. Individuals experiencing limited social support or loneliness may turn to AI more frequently, meaning that social conditions can predict AI use rather than simply result from it.

Augmentation of interpersonal interaction. An alternative perspective conceptualises AI as an augmentation mechanism. Instead of replacing interpersonal communication, generative AI may help individuals participate in it more effectively. Users can ask AI to help formulate a sensitive message, organise their thoughts before discussing a conflict, consider another person's perspective, or find appropriate language for expressing emotions. This process corresponds closely to Hancock et al.'s (2020) concept of AI-mediated communication, in which intelligent systems can augment communicative behaviour. Generative AI may therefore become part of an extended communicative sequence: *personal problem → interaction with AI → reflection/reformulation → interaction with another person*. Under this configuration, AI does not represent the endpoint of social interaction. It functions as a preparatory or interpretive resource embedded within human-to-human communication. The augmentation perspective is important because much public discussion implicitly assumes a zero-sum relationship between human and artificial interaction: more communication with AI is presumed to mean less communication with people. Empirically, however, the two may coexist. Individuals who frequently interact with other people may also use AI extensively as a communication aid. Similarly, a person may use AI as a substitute in one domain but as an augmentation tool in another. The distinction between substitution and augmentation consequently offers a more nuanced framework for analysing the

social consequences of generative AI than simple measures of frequency or attitudes towards technology. It shifts attention from how much AI is used to what happens to interpersonal interaction when AI is incorporated into everyday communicative practices.

Kazakhstan and the underrepresentation of Central Asian contexts. Despite the rapidly expanding international literature on generative AI, the geographical distribution of research remains uneven. Much of the empirical literature on human–AI relationships has been generated in North American, Western European, and East Asian settings or through samples recruited from global online platforms. Central Asian societies remain considerably less visible in research examining the interpersonal consequences of conversational AI. This limitation is important because human–AI interaction does not occur independently of social and cultural context. Expectations concerning interpersonal support, family relations, privacy, advice-seeking, trust, and appropriate self-disclosure can influence the social functions assigned to AI. Findings obtained from users of dedicated companion applications in other national contexts cannot therefore automatically be generalised to adults using multipurpose generative AI in Kazakhstan. Kazakhstan represents a particularly relevant case because rapid digitalisation and increasing institutional attention to artificial intelligence coexist with social relationships shaped by family networks, educational transformations, linguistic diversity, and generational differences in technology use. Within this context, Almaty offers a valuable urban case for investigating emerging human–AI practices. As a major educational, professional, cultural, and technological centre, the city contains heterogeneous groups whose engagement with generative AI may differ considerably across the life course.

Materials and Methods

This study employed a quantitative cross-sectional survey design to examine how the use of generative artificial intelligence is associated with changes in interpersonal interaction among adult residents of Almaty, Kazakhstan. The target sample comprised 427 respondents aged 18 years and older. Age quotas were established in advance to ensure representation across six age groups: 18–24, 25–34, 35–44, 45–54, 55–64, and 65 years and older. The questionnaire was available in Kazakh and Russian and included socio-demographic characteristics, frequency and purposes of AI use, trust in AI, self-disclosure, emotional support, loneliness, perceived social support, and indicators of interaction substitution and interaction augmentation. The analytical framework distinguished between two key dimensions of AI-mediated social interaction. Interaction substitution reflected the extent to which respondents relied on AI instead of other people for advice, discussion of personal problems, or support, whereas interaction augmentation captured the use of AI to prepare for conversations, formulate thoughts and emotions, and facilitate subsequent communication with others. Most attitudinal items were measured using five-point Likert-type scales. Descriptive statistics, reliability analysis, correlation analysis, group comparisons, and regression modelling were planned to assess the relationships between AI-related practices and interpersonal interaction. The socio-demographic composition of the sample is presented in Table 1.

Table 1. Socio-demographic characteristics of the sample

Characteristic	Category	n	%
Age group	18–24 years	124	29.0
	25–34 years	109	25.5
	35–44 years	97	22.7
	45–54 years	63	14.8
	55–64 years	27	6.3
	65+ years	7	1.6
Sex	Female	224	52.5
	Male	203	47.5
Education	Secondary	45	10.5
	TVET/College	79	18.5
	Bachelor's degree	242	56.7
	Master's degree or higher	61	14.3
Employment status	Student	81	19.0
	Employed	247	57.8
	Self-employed	47	11.0
	Unemployed	38	8.9
	Retired	14	3.3
Marital status	Single	169	39.6
	Married/partnered	217	50.8
	Divorced/widowed	41	9.6
Survey language	Kazakh	127	29.7
	Russian	127	29.7
	Kazakh and Russian equally	173	40.5
Total		427	100.0

The sample was dominated by respondents aged 18–44 years, while older age groups were represented to a lesser extent. At the same time, the distribution by sex, education, employment, marital status, and language provided sufficient socio-demographic variation for examining differences in patterns of AI use and interpersonal interaction.

Results

The analysis first examined the descriptive characteristics and internal consistency of the main study constructs (Table 2). Among the AI-related dimensions, interaction augmentation showed a higher mean score (M = 2.50, SD = 1.22) than interaction substitution (M = 1.66, SD = 0.74), suggesting that AI was more strongly represented as a complementary resource for interpersonal communication than as a direct replacement for human interaction. Personal AI use was moderate-to-low (M = 2.32, SD = 1.16), while the mean AI disclosure score was comparatively low (M = 1.96, SD = 0.95). Perceived social support (M = 2.98, SD = 0.79) exceeded the mean level of loneliness (M = 2.56, SD = 0.85). All multi-item measures demonstrated acceptable to excellent internal consistency, with Cronbach's α ranging from .756 to .931. The highest reliability was observed for the AI Trust Index (α = .931), Interaction Augmentation Index (α = .917), and Personal AI Use Index (α = .905), while the Interaction Substitution Index also demonstrated good internal consistency (α = .824). These results support the use of the composite indices in subsequent analyses.

Table 2. Descriptive statistics and internal consistency of the study constructs

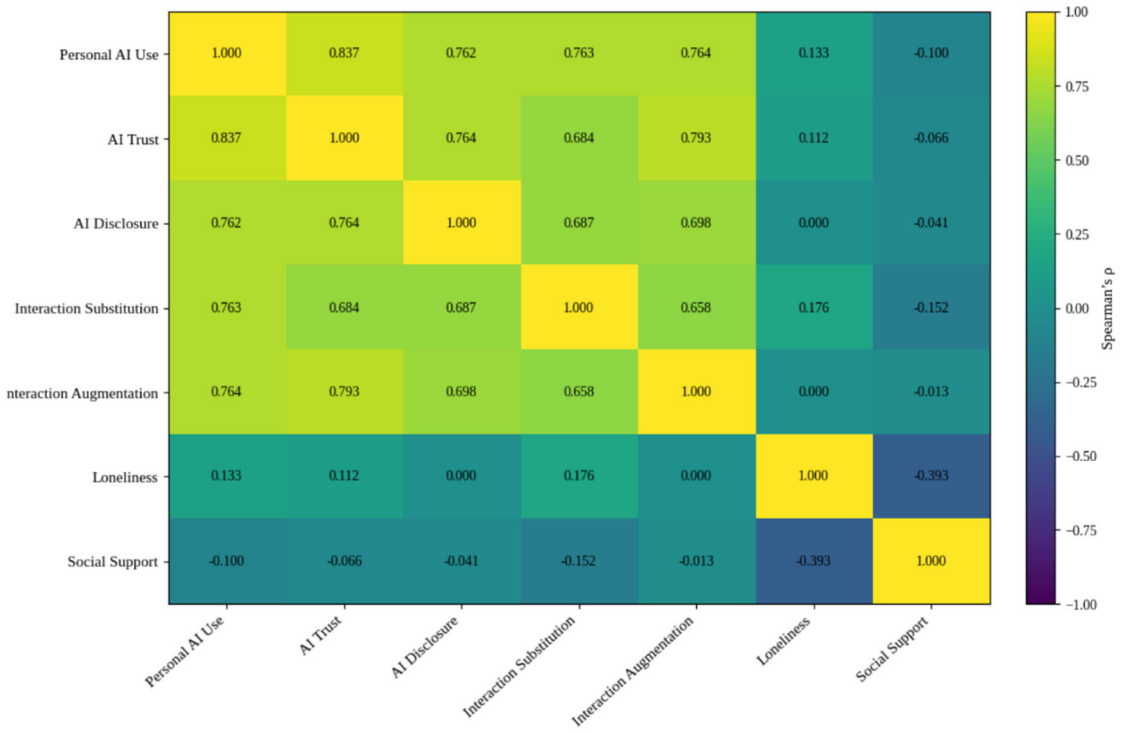
Construct	No. of items	M	SD	Min–Max	Cronbach's α
Personal AI Use	3	2.32	1.16	1.00–5.00	.905
AI Trust	3	2.50	1.23	1.00–5.00	.931
AI Disclosure	2	1.96	0.95	1.00–4.50	.756
Interaction Substitution	3	1.66	0.74	1.00–4.67	.824
Interaction Augmentation	3	2.50	1.22	1.00–5.00	.917
Loneliness	3	2.56	0.85	1.00–5.00	.774
Social Support	3	2.98	0.79	1.00–5.00	.763

Note. All constructs were measured on scales ranging from 1 to 5; higher scores indicate higher levels of the respective construct. N = 427.

Spearman correlation analysis revealed strong positive associations between personal AI use and both dimensions of interpersonal transformation. Personal AI use was positively associated with interaction substitution (ρ = .763, $p < .001$) and interaction augmentation (ρ = .764, $p < .001$). AI trust was also strongly related to augmentation (ρ = .793, $p < .001$) and substitution (ρ = .684, $p < .001$), while AI disclosure was positively associated with both substitution (ρ = .687, $p < .001$) and augmentation (ρ = .698, $p < .001$). Importantly, substitution and augmentation themselves were positively correlated (ρ = .658, $p < .001$), indicating that these processes were not mutually exclusive.

The social-context variables showed a different pattern. Loneliness was positively, although more weakly, associated with interaction substitution (ρ = .176, $p < .001$), whereas perceived social support was negatively associated with substitution (ρ = −.152, $p = .002$). Loneliness and social support were moderately negatively correlated (ρ = −.393, $p < .001$). Thus, stronger reliance on AI as an alternative to human interaction tended to coexist with greater loneliness and lower perceived interpersonal support (Figure 1). Group comparisons revealed statistically significant age differences in both dimensions of interpersonal transformation. The Interaction Substitution Index differed significantly across age groups, Kruskal–Wallis $H(5) = 46.83$, $p < .001$. The highest mean level of substitution was observed among respondents aged 18–24 years ($M = 1.94$, $SD = 0.84$), followed by those aged 25–34 ($M = 1.70$, $SD = 0.69$) and 35–44 years ($M = 1.60$, $SD = 0.67$). Lower scores were recorded among respondents aged 45–54 ($M = 1.35$, $SD = 0.63$), 65 years and older ($M = 1.33$, $SD = 0.64$), and 55–64 years ($M = 1.22$, $SD = 0.41$). Age differences were even more pronounced for interaction augmentation, $H(5) = 89.67$, $p < .001$. Respondents aged 18–24 reported the highest level of AI-assisted augmentation of interpersonal communication ($M = 3.13$, $SD = 1.11$), followed by those aged 25–34 ($M = 2.65$, $SD = 1.14$) and 35–44 years ($M = 2.41$, $SD = 1.18$).

Figure 1. Heatmap of Spearman Correlations Between the Principal Study Variables



The corresponding means declined to 1.73 (*SD* = 1.00) among respondents aged 45–54, 1.40 (*SD* = 0.65) among those aged 55–64, and 1.43 (*SD* = 0.74) among respondents aged 65 years and older. The results therefore indicate substantial age differentiation in the incorporation of generative AI into interpersonal practices, particularly in its use as a resource for facilitating communication with other people. Employment status was also significantly associated with both interaction substitution, $H(4) = 36.52$, $p < .001$, and interaction augmentation, $H(4) = 49.71$, $p < .001$. Students demonstrated the highest mean scores for both substitution ($M = 2.06$, $SD = 0.81$) and augmentation ($M = 3.26$, $SD = 1.01$). Among employed respondents, the corresponding means were 1.63 ($SD = 0.73$) and 2.37 ($SD = 1.20$), respectively. Retired respondents demonstrated particularly low augmentation scores ($M = 1.38$, $SD = 0.64$). Educational differences were not statistically significant for interaction substitution, $H(3) = 7.76$, $p = .051$, but were significant for interaction augmentation, $H(3) = 9.99$, $p = .019$. Respondents with a master's degree or higher reported the highest augmentation score ($M = 2.70$, $SD = 1.17$), followed by respondents with a bachelor's degree ($M = 2.59$, $SD = 1.24$), secondary education ($M = 2.28$, $SD = 1.11$), and technical or vocational education ($M = 2.19$, $SD = 1.20$). Differences according to marital status were statistically significant for both substitution, $H(2) = 7.60$, $p = .022$, and augmentation, $H(2) = 11.06$, $p = .004$. Single respondents reported higher mean levels of substitution ($M = 1.79$, $SD = 0.82$) and augmentation ($M = 2.71$, $SD = 1.23$) than married or partnered respondents ($M = 1.57$, $SD = 0.66$ and $M = 2.41$, $SD = 1.21$, respectively). Respondents who were divorced or widowed reported mean scores of 1.56 ($SD = 0.77$) for substitution and 2.11 ($SD = 1.08$) for augmentation. In contrast, no statistically significant sex differences were identified. Male and female respondents reported comparable levels of interaction substitution ($M = 1.67$ vs. 1.65, $p = .972$) and interaction augmentation ($M = 2.51$ vs. 2.49, $p = .966$). Survey language was similarly unrelated to either substitution, $H(2) = 1.82$, $p = .403$, or augmentation, $H(2) = 1.79$, $p = .409$. The relationship between specific forms of AI use and interpersonal transformation was examined further using Spearman correlations. AI use for message drafting demonstrated a particularly strong positive association with interaction augmentation ($\rho = .857$, $p < .001$). Augmentation was also strongly associated with AI use for information searching ($\rho = .829$, $p < .001$), work or study purposes (ρ

= .821, $p < .001$), personal advice (ρ = .729, $p < .001$), emotional support (ρ = .722, $p < .001$), and decision-making (ρ = .714, $p < .001$). Personal and emotionally oriented uses were simultaneously related to substitution: emotional-support use showed the strongest association with the Interaction Substitution Index (ρ = .745, $p < .001$), followed by decision-making (ρ = .699, $p < .001$) and personal advice (ρ = .699, $p < .001$).

Multiple linear regression analysis was subsequently conducted to identify the independent associations of personal AI use, AI trust, AI disclosure, loneliness, and perceived social support with interaction substitution and augmentation (Table 3). The model predicting interaction substitution was statistically significant, $F(5, 421) = 87.42$, $p < .001$, and explained 50.9% of the variance in the dependent variable ($R^2 = .509$; adjusted $R^2 = .504$). Personal AI use emerged as the strongest independent correlate of substitution (β = .513, $p < .001$). AI disclosure was also positively associated with substitution (β = .144, $p = .007$), as was loneliness (β = .121, $p = .001$). By contrast, perceived social support showed a significant negative association (β = −.092, $p = .014$). AI trust did not retain an independent association with substitution after the other variables were included in the model (β = .047, $p = .492$).

Table 3. Multiple regression models predicting interaction substitution and interaction augmentation

Predictor	Interaction Substitution β	*p*	Interaction Augmentation β	*p*
Personal AI Use	.513	< .001	.235	< .001
AI Trust	.047	.492	.597	< .001
AI Disclosure	.144	.007	.069	.081
Loneliness	.121	.001	−.052	.064
Social Support	−.092	.014	.014	.601
R^2	.509		.728	
Adjusted R^2	.504		.724	
F	87.42*		225.00*	
*Note. Standardised regression coefficients (β) are reported. N = 427. **p < .001.*				

The regression model predicting interaction augmentation demonstrated substantially greater explanatory power, $F(5, 421) = 225.00$, $p < .001$, accounting for 72.8% of the variance in augmentation ($R^2 = .728$; adjusted $R^2 = .724$). AI trust emerged as the strongest independent correlate (β = .597, $p < .001$), followed by personal AI use (β = .235, $p < .001$). AI disclosure did not reach the conventional threshold for statistical significance after adjustment for the other predictors (β = .069, $p = .081$). Neither loneliness (β = −.052, $p = .064$) nor perceived social support (β = .014, $p = .601$) was independently associated with augmentation in the multivariable model. Multicollinearity diagnostics indicated variance inflation factors ranging from 1.19 to 4.07 across the five predictors. The highest values were observed for AI Trust (VIF = 4.07) and Personal AI Use (VIF = 3.73), followed by AI Disclosure (VIF = 2.38), Loneliness (VIF = 1.20), and Social Support (VIF = 1.19).

Taken together, the analyses supported both research hypotheses. Consistent with H1, higher levels of personal and emotionally oriented AI use were associated with greater interaction substitution. Personal AI use remained the strongest independent correlate of substitution in the multivariable model, while greater AI disclosure and loneliness were also positively associated with this outcome and perceived social support was negatively associated with it. Consistent with H2, communication-related AI use was strongly associated with interaction augmentation. The particularly strong association between AI use for message drafting and augmentation (ρ = .857, $p < .001$), together with the independent effects of AI trust and personal AI use in the regression

model, indicated that generative AI was frequently incorporated into practices oriented toward preparing, formulating, and facilitating subsequent interpersonal communication. The positive association between the Interaction Substitution and Interaction Augmentation indices (ρ = .658, $p < .001$) further demonstrated that the two processes coexisted rather than forming opposite ends of a single behavioural pattern. Respondents reporting greater substitution of selected interpersonal functions by AI also tended to report greater use of AI to facilitate communication with other people. Within the analysed data, generative AI was therefore incorporated into interpersonal practices through both substitutional and augmentative patterns, with the relative prominence of these patterns varying according to age, employment status, marital status, AI-related practices, loneliness, perceived social support, and trust in AI.

Discussion

The present study examined how generative artificial intelligence is becoming incorporated into interpersonal interaction among adults in Almaty, with particular attention to two analytically distinct processes: interaction substitution and interaction augmentation. The findings provide support for both mechanisms and, importantly, demonstrate that they should not be understood as mutually exclusive. Rather than indicating a straightforward displacement of human communication by artificial systems, the results suggest a more complex reconfiguration of communicative practices in which AI can simultaneously assume selected functions previously performed within interpersonal relationships and facilitate subsequent communication with other people. One of the most important findings is the substantially higher mean level of interaction augmentation compared with interaction substitution. This pattern suggests that, within the studied sample, generative AI was more commonly incorporated into interpersonal life as a supplementary communicative resource than as a direct alternative to human interaction. Such a finding is consistent with the concept of AI-mediated communication proposed by Hancock et al. (2020), according to which intelligent systems can modify, generate, and augment communication in pursuit of interpersonal goals. The present findings extend this perspective by demonstrating that augmentation may occur before direct human-to-human interaction. Individuals may use AI to formulate messages, clarify their thoughts, organise emotional experiences, or prepare for difficult conversations before communicating with another person. Generative AI can therefore occupy an intermediate position within a broader communicative sequence rather than functioning exclusively as the final recipient of communication. This interpretation is particularly supported by the strong association between AI use for message drafting and interaction augmentation. The relationship indicates that one of the important social functions of generative AI may lie in reducing the cognitive and communicative demands associated with interpersonal expression. AI can provide users with a space in which language is rehearsed, reformulated, and evaluated before being introduced into an interpersonal setting. In this respect, the findings expand the conventional understanding of technologically mediated communication. Whereas earlier forms of computer-mediated communication primarily altered the channel through which people interacted, generative AI can participate in the construction of the communication itself. This development corresponds to the broader Human–Machine Communication perspective, which conceptualises computational agents as increasingly active participants in communicative processes rather than passive technological intermediaries (Guzman & Lewis, 2020).

At the same time, the results provide clear evidence of interaction substitution. Personal AI use was strongly associated with the tendency to rely on AI instead of other people for selected communicative and supportive functions and remained the strongest independent correlate of substitution in the multivariable model. Particularly notable were the relationships between substitution and the use of AI for emotional support, personal advice, and decision-making. These patterns indicate that generative AI is entering domains that have traditionally been embedded within interpersonal networks. Seeking reassurance, discussing a personal difficulty, or asking for

advice are not merely informational activities; they are social practices through which relationships are activated and maintained. When some of these functions are transferred to an artificial interlocutor, the structure of support-seeking may change even when the individual's broader interpersonal network remains intact. This finding is consistent with emerging research suggesting that conversational AI can acquire relational significance for users. Zhang et al. (2024) showed that relationships with AI assistants can be conceptualised in different relational terms and that perceived social support represents an important mechanism linking human AI relationships with subjective well-being. Research on social companion AI similarly indicates that users can develop attachment to artificial conversational partners and that this process is associated with perceived personification as well as the perceived benefits and costs of interaction (Hu et al., 2025). The present findings suggest that such relational processes are relevant not only to specialised companion applications but also to the broader incorporation of generative AI into everyday advice-seeking and personal communication. The association between AI disclosure and interaction substitution provides further evidence of this development. Self-disclosure is traditionally understood as an important mechanism through which interpersonal intimacy and relational closeness develop (Altman & Taylor, 1973). Previous research has demonstrated that disclosure can also occur in sustained interaction with conversational agents (Croes & Antheunis, 2023) and that characteristics attributed to AI may affect users' willingness to communicate personal information (Warren-Smith et al., 2025). The positive relationship identified in the present study suggests that greater willingness to disclose personal experiences to AI is associated with a greater tendency to transfer certain communicative functions away from human interlocutors. Importantly, this does not establish that AI disclosure causes withdrawal from interpersonal relationships. Given the cross-sectional design, the relationship may also operate in the opposite direction: individuals who experience barriers to interpersonal disclosure may be more inclined to use AI as an alternative conversational space. The findings concerning loneliness and perceived social support reinforce the importance of distinguishing association from causation. Loneliness was positively associated with interaction substitution, while perceived social support showed a negative association. Moreover, both variables retained independent relationships with substitution when other AI-related characteristics were taken into account. These results indicate that substitution is embedded not only in patterns of technology use but also in respondents' broader social circumstances. Individuals reporting greater loneliness and weaker perceived interpersonal support were more likely to use AI in ways that replaced selected forms of human interaction.

This pattern is consistent with research demonstrating that AI companions can provide users with an immediate subjective sense of being heard and can temporarily reduce feelings of loneliness (De Freitas et al., 2024). At the same time, it supports the caution expressed in more critical accounts of AI companionship. Jacobs (2024) distinguishes technologically mediated experiences of recognition from the broader relational structures through which meaningful social connectedness is produced, while Malfacini (2025) highlights both the potential benefits and risks associated with AI companionship for human relationships. The present results do not establish that AI use increases loneliness or weakens social support. Instead, they indicate that individuals experiencing lower levels of interpersonal resources may be especially likely to incorporate AI into functions otherwise associated with human support. This distinction is theoretically important because the observed association may reflect social selection into AI use as much as any effect of AI use itself. A particularly significant finding is the strong positive relationship between interaction substitution and interaction augmentation. Rather than representing opposite behavioural tendencies, the two processes frequently occurred together. Individuals who relied more heavily on AI as an alternative source of advice or support were also more likely to use it to facilitate communication with other people. This finding challenges a simple zero-sum model in which

increasing human AI interaction necessarily corresponds to decreasing human-to-human interaction. The same technological system may perform different social functions depending on the communicative situation. A user may disclose an issue to AI rather than to another person, subsequently use AI to clarify how the issue should be discussed, and finally engage in a human conversation informed by that prior interaction. This coexistence of substitution and augmentation also provides empirical support for treating generative AI as a new form of communicative resource rather than categorising it exclusively as either a social threat or a social benefit. The CASA perspective established that people may apply social conventions to computational systems even when they recognise their non-human character (Nass et al., 1994). Research on relational agents subsequently demonstrated that repeated interaction with computational agents can produce trust, familiarity, engagement, and friendship-like perceptions (Bickmore & Picard, 2005; Bickmore et al., 2005). Contemporary generative AI considerably extends these earlier dynamics because interaction is open-ended, linguistically flexible, and capable of moving across informational, practical, and emotional domains within the same conversation. The present findings suggest that this flexibility enables AI to occupy multiple positions within users' communicative environments simultaneously.

AI trust appears particularly important in understanding this process. Although trust was strongly correlated with both substitution and augmentation, it remained a strong independent correlate primarily of augmentation when the other variables were controlled. This distinction suggests that trust may play different roles across the two forms of interpersonal transformation. Substitution appears more closely connected with actual patterns of personal AI use, disclosure, loneliness, and available social support, whereas augmentation is particularly closely related to confidence in AI as a useful communicative resource. Users may therefore need to regard AI output as sufficiently reliable or useful before incorporating it into the preparation of communication with other people. The pronounced age differences provide an additional sociological dimension to these findings. Younger respondents reported substantially higher levels of both substitution and augmentation, with the strongest augmentation observed among those aged 18–24. Scores generally declined across older age groups. Employment differences followed a related pattern, with students reporting the highest levels of both outcomes. These findings point to a generationally differentiated incorporation of generative AI into everyday social practices. Younger adults are likely to encounter generative AI within a wider range of educational, informational, professional, and communicative activities, making movement between instrumental and relational uses comparatively fluid. The results should not, however, be interpreted as evidence that age itself directly determines human–AI relationships. Age is intertwined with educational environments, occupational position, digital experience, and exposure to emerging technologies, all of which may contribute to the observed differences. The absence of statistically significant sex differences is also noteworthy. Men and women reported highly similar levels of both interaction substitution and augmentation. In the context of this study, therefore, the social incorporation of generative AI appears to be differentiated more strongly by age, life-course position, and patterns of AI engagement than by sex. Educational differences were comparatively limited, although higher levels of education were associated with greater augmentation. This may reflect greater exposure to contexts in which generative AI is used for writing, professional communication, information processing, and other cognitively demanding activities, although this interpretation requires further investigation.

The Kazakhstan context adds an important geographical dimension to these findings. Existing research on relational AI and AI companionship has disproportionately concentrated on North American, Western European, East Asian, or global online populations. The present study demonstrates that relational forms of generative AI use are also observable in a Central Asian urban context. In Almaty, AI is not limited to instrumental applications associated with information

retrieval, education, or productivity; it is also becoming incorporated into advice-seeking, emotional processing, self-disclosure, decision-making, and preparation for interpersonal communication. These findings broaden the geographical scope of research on human–AI relationships and demonstrate the importance of examining how global technological systems become embedded within locally situated patterns of social interaction.

Several limitations should be considered when interpreting the findings. First, the cross-sectional design does not permit causal conclusions. Associations between loneliness, social support, and AI substitution may reflect multiple causal directions. Greater reliance on AI could potentially affect interpersonal practices, but individuals who already experience loneliness or limited social support may also be more likely to seek interaction with AI. Longitudinal research is therefore necessary to determine how these relationships develop over time. Second, the study relies on self-reported behaviour and perceptions. Respondents' accounts of AI use may differ from their actual frequency and patterns of interaction, particularly for practices involving emotional disclosure or substitution of human support. Future studies could combine survey measures with digital diaries, qualitative interviews, or longitudinal records of AI-use practices to capture the contextual circumstances under which individuals choose AI rather than human interlocutors. Third, the study was conducted among residents of Almaty and should not be interpreted as representative of Kazakhstan as a whole. Almaty is characterised by relatively high levels of educational, professional, technological, and digital activity, and patterns of AI adoption may differ in smaller cities and rural areas. Comparative research across regions of Kazakhstan would therefore provide a stronger basis for identifying the extent to which the patterns observed here reflect broader national transformations. Finally, the relatively small number of respondents in the oldest age groups limits the precision with which patterns among older adults can be estimated. Future research should deliberately oversample older populations and examine whether lower levels of relational AI use reflect differences in access, digital skills, perceived usefulness, trust, or preferences for interpersonal forms of support. Despite these limitations, the study contributes to the emerging sociology of human–AI interaction by demonstrating that the social consequences of generative AI cannot be adequately described through a simple opposition between technological use and human interaction. Generative AI can become simultaneously an alternative interlocutor and an instrument through which interpersonal communication is organised. The distinction between substitution and augmentation therefore provides a useful analytical framework for examining how conversational AI redistributes communicative functions across human and technological actors.

Conclusion

This study examined the relationship between generative artificial intelligence and changing patterns of interpersonal interaction among adults in Almaty, Kazakhstan. By distinguishing interaction substitution from interaction augmentation, the analysis moved beyond conventional measures of AI adoption and focused instead on the social functions that generative AI increasingly performs within everyday communication. The findings supported both proposed hypotheses. Higher levels of personal and emotionally oriented AI use were associated with a greater tendency to substitute AI for selected interpersonal practices, particularly advice-seeking, discussion of personal concerns, emotional support, and decision-making. At the same time, AI was extensively used as an augmentative communicative resource, helping respondents formulate messages, clarify thoughts and emotions, prepare for difficult conversations, and facilitate subsequent interaction with other people. Interaction augmentation was more prevalent overall than direct substitution, indicating that AI was more commonly incorporated as a complement to interpersonal communication than as its replacement. The simultaneous occurrence of substitution and augmentation represents the central empirical finding of the study. These processes were positively rather than negatively related, demonstrating that increased reliance

on AI in one area of social interaction does not necessarily imply withdrawal from human communication in another. Generative AI can replace a human interlocutor at one stage of a communicative process while facilitating human-to-human interaction at another. This pattern suggests that the emergence of conversational AI is producing a redistribution of communicative functions rather than a uniform displacement of interpersonal relationships. The results also demonstrate that this transformation is socially differentiated. Interaction substitution was associated with greater personal AI use and disclosure, higher loneliness, and lower perceived social support, whereas augmentation was particularly strongly associated with trust in AI and personal AI use. Younger adults and students reported substantially higher levels of both forms of interaction than older respondents, pointing to important generational differences in the integration of AI into everyday communicative practices. From a theoretical perspective, the findings support an understanding of generative AI as an emerging social and communicative actor whose significance cannot be reduced to technological functionality. The results extend the insights of CASA, Human–Machine Communication, AI-mediated communication, relational-agent research, and studies of self-disclosure by showing how conversational AI can occupy several relational positions simultaneously: tool, adviser, preparatory communication resource, source of support, and alternative interlocutor. The boundary between interpersonal and technologically mediated communication consequently becomes increasingly permeable as AI is incorporated into processes previously organised primarily through human relationships. The study also contributes empirical evidence from Kazakhstan to a literature in which Central Asian contexts remain underrepresented. The findings from Almaty demonstrate that the relational incorporation of generative AI is not confined to societies or applications previously examined in research on companion AI. As generative AI becomes embedded in everyday life, understanding its social consequences requires attention not only to adoption and frequency of use but also to the particular interpersonal functions that individuals delegate to, share with, or perform through artificial systems. Future research should therefore examine human–AI interaction longitudinally and across different social and geographical contexts, paying particular attention to the conditions under which augmentation develops into substitution and, conversely, the circumstances in which AI-mediated reflection strengthens subsequent human interaction. Such research will be essential for understanding whether the growing presence of artificial interlocutors ultimately changes the quantity of interpersonal contact, the quality of social relationships, or, more fundamentally, the distribution of communicative and supportive functions between human and technological actors.

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