BG Pulse Journal USA
ISSN:1947-2536 http://www.bgpulseusa.com/index.php/bg

UDC 613.1:614.7-07:574.24

MODERN METHODS FOR STUDYING THE IMPACT OF PHYSICAL, CHEMICAL, AND BIOLOGICAL ENVIRONMENTAL FACTORS ON THE HUMAN BODY

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doi:https://doi.org/10.5281/zenodo.24050891

Abstract: Rapid urbanization and industrialization in the Fergana Valley have intensified human exposure to complex combinations of environmental hazards. Assessing the isolated and synergistic impacts of physical, chemical, and biological environmental factors on human physiology requires transitioning from conventional sanitary observation to high-precision biomonitoring and molecular diagnostics. This article presents a comparative clinical-hygienic study conducted at Andijan State Medical Institute. Using the IMRAD framework, the research evaluates modern instrumental, toxicochemical, and molecular-immunological methods for detecting early preclinical alterations in individuals exposed to multifactorial environmental stressors compared to residents of ecologically favorable areas. The study involved 200 adult participants and utilized digital multiparameter dosimetry, inductively coupled plasma mass spectrometry (ICP-MS), alkaline comet assay, real-time PCR bioaerosol profiling, and multiplex ELISA. The results demonstrate a statistically higher prevalence of xenobiotic bioaccumulation, lymphocyte DNA strand breaks, autonomic dysregulation, and mucosal immune suppression in the exposed group. The study concludes that integrating human biomonitoring with molecular and cytogenetic assays enables early detection of environmentally induced homeostatic exhaustion prior to irreversible organ pathology.

Keywords: environmental health, physical factors, chemical xenobiotics, biological factors, human biomonitoring, ICP-MS, comet assay, biomarkers.

Современные методы изучения влияния физических, химических и биологических факторов внешней среды на организм человека

Аннотация: Стремительная урбанизация и индустриализация в Ферганской долине усилили воздействие на человека сложных комбинаций неблагоприятных факторов окружающей среды. Оценка изолированного и синергического влияния физических, химических и биологических факторов внешней среды на физиологию человека требует перехода от традиционного санитарного наблюдения к высокоточному биомониторингу и молекулярной диагностике. В данной статье представлено сравнительное клинико-гигиеническое исследование, проведенное в Андижанском государственном медицинском институте. Используя структуру IMRAD, исследование оценивает современные инструментальные, токсико-химические и молекулярно-иммунологические методы

выявления ранних донозологических изменений у лиц, подвергающихся воздействию многофакторных средовых стрессоров, по сравнению с жителями экологически благоприятных районов. В исследовании приняли участие 200 взрослых обследуемых, применялись цифровая многопараметрическая дозиметрия, масс-спектрометрия с индуктивно-связанной плазмой (ИСП-МС), метод ДНК-комет, ПЦР-профилирование биоаэрозолей в реальном времени и мультиплексный ИФА. Результаты демонстрируют статистически более высокую частоту биоаккумуляции ксенобиотиков, разрывов цепей ДНК лимфоцитов, вегетативной дисрегуляции и супрессии мукозального иммунитета в основной группе. Исследование делает вывод, что интеграция биомониторинга человека с молекулярными и цитогенетическими тестами позволяет выявлять средовое истощение гомеостаза до развития необратимой органной патологии.

Ключевые слова: гигиена окружающей среды, физические факторы, химические ксенобиотики, биологические факторы, биомониторинг человека, ИСП-МС, метод ДНК-комет, биомаркеры.

Tashqi muhitning inson organizmiga fizik, kimyoviy va biologik omillarini o‘rganishning zamonaviy metodlari

Annotatsiya: Farg‘ona vodiysidagi jadal urbanizatsiya va sanoatlashuv jarayonlari inson organizmiga tashqi muhitning murakkab omillari majmuasi ta’sirini kuchaytirdi. Tashqi muhitning fizik, kimyoviy va biologik omillarining inson fiziologiyasiga alohida hamda sinergik ta’sirini baholash an’anaviy sanitariya kuzatuvlaridan yuqori aniqlikdagi biomonitoring va molekulyar diagnostika usullariga o‘tishni taqozo etadi. Ushbu maqolada Andijon davlat tibbiyot institutida o‘tkazilgan qiyosiy klinik-gigiyenik tadqiqot natijalari keltirilgan. IMRAD tuzilmasiga asoslangan ushbu ish ko‘p omilli ekologik stressorlar ta’siridagi shaxslarda erta donozologik (kasallik oldi) o‘zgarishlarni aniqlashning zamonaviy instrumental, toksiko-kimyoviy va molekulyar-immunologik metodlarini ekologik toza hudud aholisi bilan qiyosiy baholaydi. Tadqiqotda 200 nafar katta yoshli ishtirokchi qatnashdi hamda raqamli ko‘p parametrli dozimetriya, induktiv bog‘langan plazmali mass-spektrometriya (ICP-MS), ishqoriy DNK-kometalar metodi, bioaerozollarni real vaqt rejimida PZR-profillash va multipleks IFA usullaridan foydalanildi. Natijalar shuni ko‘rsatadiki, asosiy guruhda ksenobiotiklar bioakkumulyatsiyasi, limfotsitlar DNK zanjiri uzilishlari, vegetativ disregulyatsiya va shilliq qavat immuniteti susayishi statistik jihatdan ishonchli darajada yuqori uchraydi. Tadqiqot inson biomonitoringini molekulyar va sitogenetik testlar bilan integratsiya qilish a’zolarda qaytmas patologiyalar rivojlanishidan oldin tashqi muhit ta’sirida yuzaga keluvchi gomeostaz zo‘riqishini erta aniqlash imkonini beradi degan xulosaga keladi.

Kalit so‘zlar: atrof-muhit gigiyenasi, fizik omillar, kimyoviy ksenobiotiklar, biologik omillar, inson biomonitoringi, ICP-MS, DNK-kometalar metodi, biomarkerlar.

INTRODUCTION

Environmental health science faces unprecedented diagnostic challenges due to the growing complexity of anthropogenic exposures worldwide. In Uzbekistan, particularly in the densely populated and industrially active Fergana Valley, residents are simultaneously exposed to a diverse spectrum of external environmental stressors. While sanitary standards historically evaluated individual hazards against maximum permissible concentrations (MPC), real-world exposure involves a continuous, combined interaction of physical, chemical, and biological factors that act synergistically on the human body.

The physiological impact of these three factor groups operates through interconnected biological pathways. Physical factors—including chronic urban noise, non-ionizing electromagnetic fields (EMF), vibration, and thermal microclimatic extremes—directly dysregulate the hypothalamic-pituitary-adrenal (HPA) axis and autonomic nervous system, inducing systemic oxidative stress. Chemical factors—such as fine particulate matter (PM2.5), heavy metals (lead, cadmium, mercury), pesticides, and volatile organic compounds (VOCs)—penetrate physiological barriers, inhibit enzymatic systems, and generate genotoxic reactive oxygen species. Simultaneously, biological factors—comprising airborne bacterial pathogens, fungal mycotoxins, endotoxins, and pollen aeroallergens—sensitize the respiratory mucosa, disrupt the epithelial barrier, and trigger chronic systemic inflammation.

Despite advances in environmental hygiene, traditional assessment methods that measure only external ambient concentrations fail to reflect the actual internal biologically effective dose absorbed by human tissues. Conventional clinical examinations often detect pathology only after irreversible structural organ damage has already occurred.

At Andijan State Medical Institute, it was hypothesized that applying a triad of modern analytical methodologies—combining wearable biotelemetry for physical factors, high-resolution mass spectrometry and cytogenetics for chemical factors, and molecular-immunological profiling for biological factors—enables precise quantification of early preclinical health effects in exposed populations. This article aims to evaluate the diagnostic sensitivity and clinical utility of modern methods for studying physical, chemical, and biological environmental factors in residents of high-exposure urban zones compared to a control group from ecologically favorable areas.

METHODS

This comparative cross-sectional and case-control study was conducted at the Department of Hygiene, Public Health, and Infectious Diseases of Andijan State Medical Institute over a period of 12 months.

Study Population - The study enrolled 200 adult participants aged 20 to 55 years residing in the Andijan region for at least 5 consecutive years. The participants were divided into two equal groups based on the ecological characteristics of their residential and occupational environments: Main Group (n=100): Individuals residing and working within 1.5 km of high-traffic transport hubs and industrial processing zones characterized by elevated physical, chemical, and biological environmental loads. Control Group (n=100): Individuals residing in ecologically favorable

suburban green zones with environmental parameters consistently within hygienic norms. Individuals with congenital genetic syndromes, occupational poisoning history, chronic infectious diseases (HIV, viral hepatitis), or active malignancy were excluded.

Data Collection and Modern Analytical MethodsAssessment of Physical Factors and Physiological Response: External physical loads were quantified using portable digital sound level meters, broadband EMF spectrum analyzers (50 Hz to 3 GHz), and microclimate data loggers. The internal physiological response to physical stressors was evaluated via 24-hour wearable heart rate variability (HRV) biotelemetry (assessing the Baevsky Stress Index and LF/HF ratio) and serum malondialdehyde (MDA) quantification as a lipid peroxidation marker.Assessment of Chemical Factors and Human Biomonitoring (HBM): Ambient air PM2.5 and VOC levels were monitored using laser nephelometry and gas chromatography. Internal chemical bioaccumulation of heavy metals (lead, cadmium) in whole blood and urine was determined via Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Genotoxic effects of chemical xenobiotics on peripheral blood lymphocytes were evaluated using the alkaline single-cell gel electrophoresis (Comet Assay), measuring the percentage of DNA in the comet tail (%Tail DNA).Assessment of Biological Factors and Molecular-Immunological Profiling: Environmental bioaerosols were sampled using impinger filtration and analyzed via quantitative Real-Time Polymerase Chain Reaction (qPCR) for bacterial 16S rRNA, fungal internal transcribed spacer (ITS) regions (Aspergillus, Alternaria), and Limulus Amebocyte Lysate (LAL) assay for airborne endotoxins. Host biological response was evaluated via multiplex ELISA for serum total IgE, interleukin-1 beta (IL-1 beta), tumor necrosis factor-alpha (TNF-alpha), and nasal mucosal secretory IgA (sIgA).

Statistical Analysis - Data were analyzed using SPSS 25.0 software. Differences in abnormality prevalence between groups were assessed using the Chi-square test, and continuous biomarker levels were compared via Student's t-test. Correlations between internal xenobiotic/physical load indices and biological effect markers were analyzed using Pearson's correlation coefficient. A p-value of <0.05 was considered statistically significant.

RESULTS

The integrated application of modern hygienic, analytical, and molecular diagnostic methods revealed substantial preclinical differences between the two groups across all three environmental domains.

Impact of Physical Factors and Autonomic-Oxidative Status - Digital dosimetry confirmed that the Main Group experienced mean daily noise levels of 68.4 dBA and elevated radiofrequency EMF background compared to 44.2 dBA in the Control Group. Wearable HRV biotelemetry demonstrated pronounced sympathetic overactivation in the Main Group: an elevated Baevsky Stress Index (>150 conventional units) was recorded in 62 percent of the Main Group compared to 21 percent of the Control Group. Concurrently, mean serum malondialdehyde (MDA) concentrations were 1.8 times higher in the Main Group (5.42 micromol/L vs. 2.98 micromol/L), indicating physical stress-induced oxidative membrane damage.

Chemical Biomonitoring (ICP-MS) and Genotoxicity (Comet Assay) - Human biomonitoring via ICP-MS revealed significant subclinical bioaccumulation of toxic trace elements in the Main

Group despite the absence of overt clinical poisoning. Mean blood lead (Pb) levels in the Main Group reached 54.6 microg/L compared to 18.2 microg/L in the Control Group, while urinary cadmium (Cd) levels were 2.3 times higher in the Main Group. The alkaline Comet Assay demonstrated a statistically significant increase in lymphocyte DNA damage: mean %Tail DNA in the Main Group was 14.8 percent versus 4.6 percent in the Control Group. Furthermore, micronucleus cytome assay abnormalities were detected in 34 percent of exposed participants compared to 9 percent of controls.

Biological Factor Profiling (qPCR) and Immunological Shifts - Molecular aerobiological monitoring (qPCR) of the Main Group's environment identified a 3.2-fold higher concentration of fungal spores and gram-negative bacterial endotoxins compared to the Control zone, largely driven by organic dust adsorption onto PM2.5 particles. Immunologically, chronic exposure to bioaerosols resulted in mucosal barrier depletion and allergic sensitization in the Main Group: mean nasal secretory IgA (sIgA) levels were reduced by 1.7 times (0.42 g/L vs. 0.71 g/L in controls), whereas elevated serum total IgE (>100 IU/mL) was found in 48 percent of the Main Group versus 16 percent of the Control Group. Pro-inflammatory serum IL-1 beta levels were also 2.1 times higher in the Main Group.

Synergistic Correlations - Correlation analysis highlighted strong synergistic interactions between the studied environmental factors. There was a strong positive correlation (r=0.79) between blood heavy metal concentrations (ICP-MS) and lymphocyte DNA strand breaks (%Tail DNA on Comet Assay). Additionally, ambient PM2.5-bound endotoxin levels strongly correlated (r=0.74) with elevated serum IgE and depressed mucosal sIgA levels, confirming that chemical particulates act as vectors that potentiate biological sensitization.

DISCUSSION

The findings from Andijan State Medical Institute demonstrate that modern analytical and biomonitoring methods provide a decisive diagnostic advantage over classical sanitary-hygienic approaches.

From External Monitoring to Internal Exposome Assessment Traditional hygiene evaluates external air, water, or physical field parameters in isolation. However, the concept of the human "exposome" requires measuring internal biological responses. In our study, ICP-MS detected subclinical heavy metal accumulation at nanomolar concentrations, while the Comet Assay revealed early DNA single-strand breaks long before hematological or renal pathology became clinically apparent. These biomarkers of exposure and effect allow preventive intervention at the reversible preclinical stage.

Synergism of Physical, Chemical, and Biological Factors A critical insight gained from multi-method profiling is the mutual potentiation of environmental hazards. Physical factors (noise and EMF-induced autonomic stress) increase respiratory rate and blood-brain barrier permeability, accelerating the uptake of chemical xenobiotics. In turn, chemical pollutants (PM2.5 and VOCs) damage respiratory ciliated epithelium and suppress local sIgA production, facilitating the penetration of biological agents (bacterial endotoxins and fungal allergens). Assessing only one group of factors overlooks this pathogenic synergy.

Diagnostic Precision of Molecular and Biotelemetric Tools The combination of qPCR bioaerosol detection with multiplex ELISA resolves the limitations of classical microbiological culture, which detects less than 10 percent of viable airborne microorganisms. Similarly, 24-hour HRV biotelemetry objectively quantifies neurovegetative exhaustion caused by chronic physical noise and thermal stress, eliminating the subjectivity of self-reported fatigue questionnaires.

Implications for Preventive Medicine and Public Health The high prevalence of cytogenetic and immunological shifts identified in clinically asymptomatic residents of the Main Group indicates that regional sanitary surveillance protocols should be modernized. Incorporating targeted human biomonitoring (ICP-MS, oxidative stress markers, mucosal immunity panels) into periodic medical examinations of high-risk urban populations will substantially improve primary disease prevention.

CONCLUSION

The comparative clinical-hygienic study conducted at Andijan State Medical Institute leads to the following conclusions regarding modern methods for studying physical, chemical, and biological environmental factors on the human body:

Firstly, modern assessment of environmental health hazards must combine external instrumental monitoring with internal human biomonitoring (HBM) utilizing biomarkers of exposure, effect, and individual susceptibility.

Secondly, high-precision analytical methods—specifically ICP-MS for chemical bioaccumulation, the alkaline Comet Assay for genotoxicity (r=0.79), wearable HRV biotelemetry for physical stress, and qPCR/multiplex ELISA for biological sensitization—accurately detect preclinical homeostatic disturbances in exposed populations.

Thirdly, combined exposure to urban physical, chemical, and biological factors produces a synergistic pathogenic effect characterized by autonomic sympathetic overactivation (62 percent), lymphocyte DNA damage, and mucosal immunodeficiency accompanied by allergic sensitization (48 percent).

Therefore, it is recommended that public health specialists, hygienists, and clinicians integrate human biomonitoring and molecular-cytogenetic screening into regional environmental health monitoring programs to enable early preclinical diagnosis and targeted ecological rehabilitation.

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