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HORMONAL AND SEXUAL DYSFUNCTIONS IN MEN RESIDING IN ENVIRONMENTALLY UNFAVORABLE CONDITIONS: A CLINICAL–FUNCTIONAL ANALYSIS USING THE ICF FRAMEWORK

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ГОРМОНАЛЬНЫЕ И СЕКСУАЛЬНЫЕ ДИСФУНКЦИИ У МУЖЧИН, ПРОЖИВАЮЩИХ В ЭКОЛОГИЧЕСКИ НЕБЛАГОПРИЯТНЫХ УСЛОВИЯХ: КЛИНИКО-ФУНКЦИОНАЛЬНЫЙ АНАЛИЗ С ИСПОЛЬЗОВАНИЕМ КЛАССИФИКАЦИИ ICF

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Abstract. Male reproductive health is increasingly recognized as a sensitive indicator of environmental and population health. The aim of this study was to comprehensively assess hormonal status and sexual function in men of reproductive age living in regions with various types of adverse environmental exposure, with functional interpretation of the findings within the framework of the International Classification of Functioning, Disability and Health (ICF). A comparative cross-sectional study was conducted involving 216 men aged 25–45 years who were permanent residents of either environmentally favorable regions or areas predominantly affected by pesticide use, heavy metal contamination, or radionuclide exposure. Hormonal assessment included measurements of total testosterone, sex hormone–binding globulin (SHBG), and luteinizing hormone (LH). Sexual function was evaluated using the International Index of Erectile Function (IIEF), with a focus on erectile and orgasmic domains. Within the ICF framework, environmental exposure is considered an adverse environmental factor leading to impairments in endocrine body functions and subsequent limitations in activity and participation, clinically manifested as sexual dysfunction. The findings support the interpretation of sexual dysfunction as an early functional marker of environmentally mediated endocrine disruption and highlight the value of integrating hormonal and functional outcomes in environmental and reproductive health research. Men residing in environmentally unfavorable regions exhibited significantly lower total testosterone levels and elevated SHBG concentrations

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compared with controls, while LH levels did not differ significantly between groups. These hormonal alterations were accompanied by marked reductions in erectile and orgasmic function scores. The observed combination of decreased androgen bioavailability in the absence of compensatory LH elevation indicates functional hypogonadism rather than primary testicular failure.

Аннотация. Мужское репродуктивное здоровье всё больше признаётся чувствительным индикатором состояния окружающей среды и здоровья населения. Целью настоящего исследования было комплексное изучение гормонального статуса и сексуальной функции у мужчин репродуктивного возраста, проживающих в регионах с различными типами неблагоприятного экологического воздействия, с функциональной интерпретацией результатов в рамках Международной классификации функционирования, ограничений жизнедеятельности и здоровья (МКФ). Было проведено сравнительное поперечное исследование с участием 216 мужчин в возрасте 25–45 лет, постоянно проживающих либо в экологически благоприятных регионах, либо в зонах, преимущественно подверженных воздействию пестицидов, тяжелых металлов или радионуклидов. Гормональное обследование включало определение общего тестостерона, глобулина, связывающего половые гормоны (ГСПГ), и лютеинизирующего гормона (ЛГ). Сексуальная функция оценивалась с помощью Международного индекса эректильной функции (IIEF), с акцентом на эректильную и оргазмическую сферы. В рамках МКФ экологическое воздействие рассматривается как неблагоприятный фактор окружающей среды, приводящий к нарушениям эндокринных функций организма и последующим ограничениям в активности и участии, клинически проявляющимся сексуальной дисфункцией. Полученные результаты подтверждают возможность интерпретации сексуальной дисфункции как раннего функционального маркера экологически обусловленного эндокринного дисбаланса и подчёркивают ценность интеграции гормональных и функциональных показателей в исследованиях окружающей среды и репродуктивного здоровья. Мужчины, проживавшие в экологически неблагоприятных регионах, демонстрировали значительно более низкий уровень общего тестостерона и повышенные концентрации ГСПГ по сравнению с контрольной группой, в то время как уровни ЛГ существенно не различались между группами. Эти гормональные изменения сопровождались выраженным снижением показателей эректильной и оргазмической функции. Наблюдаемая комбинация сниженной биодоступности андрогенов при отсутствии компенсаторного повышения ЛГ указывает на функциональный гипогонадизм, а не на первичную тестикулопатию.

Keywords: environmental exposure; male reproductive health; testosterone; sex hormone–binding globulin (SHBG); sexual dysfunction; International Classification of Functioning (ICF); functional hypogonadism.

Ключевые слова: воздействие факторов окружающей среды, мужское репродуктивное здоровье, тестостерон, глобулин, связывающий половые гормоны (ГСПГ), сексуальная дисфункция, международная классификация функционирования, ограничений жизнедеятельности и здоровья (МКФ), функциональный гипогонадизм.

Male reproductive health is increasingly recognized as a sensitive indicator of environmental and population health [1–3].

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In recent decades, growing evidence has linked chronic exposure to environmental pollutants with adverse reproductive outcomes, including declining fertility rates, impaired spermatogenesis, and increased prevalence of sexual dysfunction [2, 3].

While semen quality has traditionally served as the primary marker of male reproductive health, emerging data suggest that endocrine regulation represents a critical intermediary pathway through which environmental factors exert their biological effects [6–8].

A wide range of environmental pollutants - including pesticides, heavy metals, radionuclides, and air contaminants - are known or suspected endocrine disruptors [5–11].

These agents may interfere with androgen synthesis, transport, and signaling, thereby altering hormonal homeostasis even at low or environmentally relevant exposure levels [6, 10, 11].

Experimental and epidemiological studies have demonstrated associations between environmental exposure and reduced testosterone levels, altered sex hormone - binding globulin (SHBG) concentrations, and disruption of hypothalamic – pituitary - gonadal regulation [12–15]. Such endocrine alterations may precede overt infertility and manifest clinically as disturbances of sexual function [16, 17].

Sexual function, encompassing erectile and orgasmic domains, is tightly regulated by androgen-dependent neurovascular and metabolic mechanisms [16–19].

Testosterone deficiency, whether absolute or functional, has been consistently associated with erectile dysfunction, reduced libido, and impaired orgasmic response [17–19].

Importantly, elevation of SHBG may further decrease androgen bioavailability despite testosterone concentrations remaining within reference ranges, contributing to a functional hypogonadal state [19].

However, sexual dysfunction is rarely integrated into environmental health research as a functional outcome reflecting endocrine disruption [20].

The International Classification of Functioning, Disability and Health (ICF) provides a comprehensive framework for integrating environmental exposure, biological impairment, and functional outcomes [4].

Within the ICF model, environmental pollutants are conceptualized as environmental factors (domain e) that contribute to impairments of body functions (domain b), including endocrine regulation, which in turn may lead to limitations in activity and participation (domain d), such as sexual activity and reproductive behavior.

Materials and methods

A comparative cross-sectional study was conducted to assess hormonal and sexual functioning in men residing in regions with different environmental conditions in the Kyrgyz Republic. Data collection was performed continuously during the study period using a unified research protocol. The study included 216 men of reproductive age (25–45 years) who had been permanent residents of the respective regions for at least five years.

Participants were stratified into four groups according to the predominant environmental exposure in their region of residence: a control group from environmentally favorable areas (n = 62), a pesticide exposure group from agricultural regions with intensive agrochemical use (n = 54), a heavy metals exposure group from industrial areas (n = 52), and a radionuclide exposure group from regions affected by radioactive contamination (n = 48).

Inclusion criteria were male sex, age 25–45 years, permanent residence in the study region for at least five years, and provision of written informed consent. Exclusion criteria included acute inflammatory diseases of the urogenital tract, known genetic causes of infertility, oncological diseases, and severe decompensated somatic disorders.

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Hormonal status was evaluated using venous blood samples collected in the morning hours (08:00–10:00) after an overnight fast. Serum concentrations of total testosterone, sex hormone–binding globulin (SHBG), and luteinizing hormone (LH) were measured using enzyme-linked immunosorbent assay (ELISA) techniques according to the manufacturers' instructions. All analyses were performed in the same certified laboratory to minimize inter-assay variability.

Hormonal measurements were interpreted using standard reference ranges for adult men. No pharmacological or hormonal interventions were administered prior to or during the study period.

Sexual function was assessed using the International Index of Erectile Function (IIEF), a validated multidimensional self-administered questionnaire widely applied in clinical and epidemiological research. For the purposes of the present study, two domains were analyzed: erectile function and orgasmic function. Domain scores were calculated according to standard scoring algorithms, with lower scores indicating greater functional impairment.

Functional interpretation using the ICF framework. The International Classification of Functioning, Disability and Health (ICF) was used as a conceptual framework for the interpretation of study findings. Environmental exposures were considered environmental factors (domain *e*), while alterations in hormonal regulation and sexual function were interpreted as impairments of body functions (domain *b*), potentially leading to limitations in activity and participation related to sexual and reproductive life (domain *d*). Formal ICF coding was not applied.

Statistical analysis. Statistical analyses were performed using nonparametric methods. Quantitative variables were expressed as mean ± standard error (M ± SE). Group comparisons were conducted using the Mann–Whitney U test for continuous variables and the chi-square (χ^2) test for categorical variables. A p-value < 0.05 was considered statistically significant.

Ethical considerations. The study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol was approved by the local ethics committee, and written informed consent was obtained from all participants prior to inclusion.

Results and discussions

Assessment of hormonal status revealed significant alterations in androgen regulation among men residing in environmentally unfavorable regions (Table 1).

Table 1

HORMONAL PROFILE OF MEN RESIDING
IN REGIONS WITH DIFFERENT ENVIRONMENTAL CONDITIONS (M±SE)

Hormonal parameter	*Control group (n=62)*	*Pesticide exposure (n=54)*	*Heavy metals exposure (n=52)*	*Radionuclide exposure (n=48)*
Total testosterone (ng/mL)	4.9±0.4	3.1±0.5*	2.9±0.7*	3.4±0.2*
Sex hormone–binding globulin (SHBG), nmol/L	30.6±3.4	43.4±2.7*	39.5±2.3*	37.8±0.9*
Luteinizing hormone (LH), mIU/mL	6.9±1.2	5.8±0.8	6.5±0.6	7.1±1.4

Data are presented as mean ± standard error (M±SE). * $p < 0.05$ compared with the control group (Mann–Whitney U test)

Mean total testosterone levels were significantly lower in all exposure groups compared with the control group (4.9±0.4 ng/mL). The most pronounced reduction was observed in men exposed to heavy metals (2.9±0.7 ng/mL), followed by the pesticide exposure group (3.1±0.5 ng/mL) and the radionuclide exposure group (3.4±0.2 ng/mL) ($p < 0.05$ for all comparisons).

Concurrently, sex hormone–binding globulin (SHBG) concentrations were significantly elevated in all environmentally exposed groups relative to controls (30.6±3.4 nmol/L). Increased SHBG levels were

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observed in the pesticide (43.4±2.7 nmol/L), heavy metals (39.5±2.3 nmol/L), and radionuclide (37.8±0.9 nmol/L) groups (p <0.05), suggesting a reduction in androgen bioavailability.

Luteinizing hormone (LH) concentrations did not differ significantly between exposed and control groups. The absence of compensatory LH elevation in the context of reduced testosterone levels indicates the presence of a functional hypogonadal state without overt activation of the hypothalamic–pituitary–gonadal axis.

Sexual function. Evaluation of sexual function using the International Index of Erectile Function demonstrated significant impairment among men exposed to adverse environmental factors (Table 2). Both erectile and orgasmic function scores were significantly lower in all exposure groups compared with the control group (p<0.05).

Table 2

SEXUAL FUNCTION PARAMETERS ASSESSED BY THE INTERNATIONAL INDEX OF ERECTILE FUNCTION (IIEF) IN MEN RESIDING IN REGIONS WITH DIFFERENT ENVIRONMENTAL CONDITIONS

IIEF domain	*Control group (n = 62)*	*Pesticide exposure (n = 54)*	*Heavy metals exposure (n = 52)*	*Radionuclide exposure (n = 48)*
Orgasmic function score	7.7 ± 0.8	5.7 ± 0.6*	5.2 ± 0.3*	5.8 ± 0.3*
Erectile function score	16.2 ± 1.3	10.8 ± 1.6*	12.7 ± 1.9*	11.2 ± 2.3*

Data are presented as mean ± standard error (M±m). *p< 0.05 compared with the control group (Mann–Whitney U test)

Men residing in regions contaminated by pesticides and heavy metals exhibited the most pronounced reductions in erectile function, whereas impairments in orgasmic function were observed consistently across all exposure categories. Overall, sexual dysfunction was substantially more prevalent in environmentally exposed populations than in men from environmentally favorable regions.

Association between hormonal alterations and sexual dysfunction. Comparative analysis revealed a consistent convergence between hormonal alterations and sexual dysfunction. Groups characterized by reduced total testosterone levels and elevated SHBG concentrations demonstrated the lowest erectile and orgasmic function scores. In contrast, men from the control group, who exhibited higher testosterone levels and lower SHBG concentrations, showed significantly better sexual function.

The absence of significant differences in LH levels across groups suggests that sexual dysfunction was associated primarily with impaired androgen bioavailability rather than with primary testicular failure or pituitary dysregulation. These findings support the interpretation of sexual dysfunction as a functional clinical manifestation of environmentally mediated endocrine disruption.

Interpretation within the ICF framework. Within the ICF framework, chronic exposure to environmental pollutants represents an adverse environmental factor (domain e) contributing to impairments in endocrine body functions (domain b), particularly androgen regulation. Reduced androgen bioavailability, in turn, is associated with limitations in activity and participation (domain d), manifesting clinically as erectile and orgasmic dysfunction.

This functional pathway underscores the role of hormonal disturbances as an intermediary mechanism linking environmental exposure to clinically relevant impairments in sexual functioning, rather than representing isolated endocrine or urological abnormalities.

Principal findings. The present study demonstrates that men residing in environmentally unfavorable conditions exhibit a consistent pattern of endocrine and sexual dysfunction. Chronic

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environmental exposure was associated with reduced total testosterone levels, elevated SHBG concentrations, and impaired sexual function, while luteinizing hormone levels remained largely unchanged. This constellation of findings indicates the development of a functional hypogonadal state rather than primary testicular failure. Importantly, hormonal alterations and sexual dysfunction occurred in parallel, suggesting a shared pathophysiological basis mediated by environmental factors.

Environmental exposure and functional hypogonadism. Environmental pollutants such as pesticides, heavy metals, and radionuclides are increasingly recognized as endocrine-disrupting agents capable of altering androgen homeostasis. In the present study, the combination of decreased total testosterone and elevated SHBG suggests a marked reduction in androgen bioavailability, even in the absence of overt hypothalamic–pituitary compensation. This pattern is consistent with environmentally mediated functional hypogonadism, which differs from classical primary or secondary hypogonadism by its subtle regulatory nature and frequent absence of compensatory LH elevation.

Several mechanisms may underlie this phenomenon, including oxidative stress–induced impairment of steroidogenesis, chronic low-grade inflammation, and disruption of hepatic SHBG synthesis [21, 22].

Importantly, these mechanisms may operate at exposure levels insufficient to produce acute toxicity, thereby contributing to subclinical but functionally significant endocrine alterations in exposed populations.

Hormonal alterations and sexual dysfunction. Sexual function is tightly regulated by androgen-dependent neurovascular and metabolic pathways. Reduced androgen bioavailability, whether due to decreased testosterone production or increased SHBG binding, has been consistently associated with erectile and orgasmic dysfunction [18]. In the present study, groups with the most pronounced hormonal alterations demonstrated the greatest impairment in sexual function, supporting the role of endocrine disruption as a key mediator of sexual dysfunction in environmentally exposed men.

The absence of significant differences in LH concentrations further supports the interpretation that sexual dysfunction in this population reflects functional endocrine dysregulation rather than irreversible gonadal damage. From a clinical perspective, this distinction is critical, as functional hypogonadism may represent a potentially modifiable condition if environmental and lifestyle factors are addressed.

Interpretation within the ICF framework. Application of the ICF framework provides a structured and clinically meaningful interpretation of the observed findings. Within this model, environmental pollutants act as adverse environmental factors (domain *e*), contributing to impairments in endocrine body functions (domain *b*), particularly androgen regulation. These impairments, in turn, lead to limitations in activity and participation (domain *d*), manifested as disturbances in sexual functioning.

By integrating hormonal and functional outcomes, the ICF framework facilitates a transition from isolated biochemical measurements to an understanding of how environmental exposure affects real-life functioning and quality of life. This approach is particularly relevant for environmental health research, where clinical relevance and population-level implications are central considerations.

Comparison with existing literature. The present findings are consistent with reports from international health organizations and epidemiological studies documenting associations between environmental exposure and alterations in male endocrine function. Previous studies have demonstrated reduced testosterone levels and increased SHBG concentrations in men exposed to endocrine-disrupting chemicals, as well as associations between androgen deficiency and sexual dysfunction. However, few studies have integrated hormonal assessment with standardized measures of sexual function within a unified functional framework.

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By combining endocrine evaluation, sexual function assessment, and ICF-based interpretation, the present study extends existing literature and highlights the importance of functional outcomes as clinically relevant indicators of environmentally mediated endocrine disruption.

Study limitations. Several limitations should be considered when interpreting the results. The cross-sectional design precludes causal inference and limits the ability to assess temporal relationships between environmental exposure and endocrine alterations. Hormonal assessment was limited to total testosterone, SHBG, and LH; measurement of free testosterone and additional pituitary hormones could provide further insight into regulatory mechanisms. Environmental exposure was inferred based on region of residence rather than individual exposure assessment, which may introduce exposure misclassification.

Clinical and public health implications. Despite these limitations, the findings have important clinical and public health implications. Sexual dysfunction may serve as an early functional marker of environmentally mediated endocrine disruption, preceding overt reproductive failure. Recognition of functional hypogonadism in environmentally exposed populations may facilitate earlier identification of at-risk individuals and support the development of preventive strategies aimed at reducing environmental exposure and mitigating endocrine consequences.

Conclusion

Men residing in environmentally unfavorable conditions exhibit a consistent pattern of endocrine and sexual dysfunction characterized by reduced total testosterone levels, elevated SHBG concentrations, and impaired erectile and orgasmic function. The absence of compensatory luteinizing hormone elevation suggests the development of a functional hypogonadal state rather than primary gonadal failure. Integration of hormonal and sexual function assessment within the ICF framework highlights environmental exposure as a key determinant linking endocrine impairment to clinically relevant limitations in sexual functioning. These findings support the interpretation of sexual dysfunction as an early functional manifestation of environmentally mediated endocrine disruption. Incorporating functional and endocrine outcomes into environmental health research may improve risk assessment and facilitate the development of preventive strategies aimed at mitigating the reproductive health consequences of chronic environmental exposure.

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