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NARRATIVE REVIEW

Dry Eye Disease in Physically Active Individuals: The Role of Environmental Factors – A Narrative Review

HIGHLIGHTS

- ▶ DED prevalence is significantly influenced by environmental stressors such as low humidity, air pollution, and UV radiation.
- ▶ Systemic dehydration increases tear osmolarity, directly exacerbating ocular surface dysfunction.
- ▶ Physically active individuals face compounded risks due to combined environmental exposure and exercise-induced fluid loss.
- ▶ Preventive strategies should integrate hydration management and environmental protection to

mitigate DED in active populations.

- ▶ Future research requires targeted studies on athletes to establish evidence-based ocular health guidelines.

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ABSTRACT

BACKGROUND: Dry eye disease (DED) is a multifactorial disorder of the ocular surface characterized by tear film instability, hyperosmolarity, inflammation, and neurosensory abnormalities. Environmental stressors and systemic factors play a significant role in its development. Physically active individuals are likely to be exposed to such conditions.

AIM: To summarize current evidence on the impact of environmental factors and hydration on the development and severity of dry eye disease, with emphasis on physically active populations.

MATERIALS AND METHODS: A narrative review was conducted using literature indexed in PubMed and Google Scholar databases, including studies published between 2001 and 2024. The publications were selected based on their relevance to epidemiology and pathophysiology.

RESULTS: DED affects a substantial proportion of the population worldwide. Environmental factors such as low humidity, air pollution, temperature variations, ultraviolet radiation and dehydration contribute to ocular surface stress. These factors influence tear osmolarity and may exacerbate symptoms, particularly in physically active individuals exposed to increased environmental and physiological stress.

CONCLUSIONS: Environmental exposure and hydration status are important contributors to dry eye disease. Physically active individuals may be at increased risk due to combined exposure to environmental conditions and fluid imbalance, highlighting the importance of preventive strategies in this population.

KEYWORDS

dry eye disease; tear film; environmental factors; hydration; tear osmolarity; physical activity

GRAPHICAL ABSTRACT

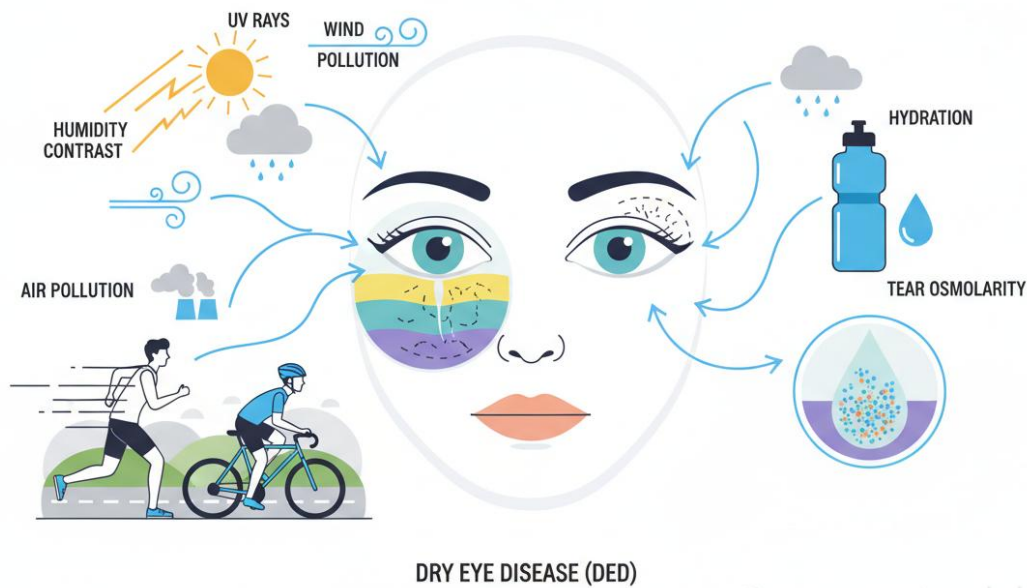


Figure 1. Graphical overview of environmental stressors (low humidity, pollution, UV), dehydration, tear film instability, and preventive strategies for physically active individuals.

PLAIN LANGUAGE SUMMARY

Dry eye disease is a common condition that causes eye discomfort, redness, and blurred vision. It is often triggered or worsened by environmental factors such as dry air, pollution, wind, and sunlight. This review shows that people who exercise outdoors or engage in intense physical activity are at higher risk because they are more exposed to these environmental stressors and often lose more body fluids through sweat. When the body is dehydrated, the tear film on the eyes becomes less stable and more irritated. To protect eye health, physically active individuals should drink enough water, wear protective eyewear, and avoid exercising in harsh environmental conditions when possible. More research is needed to develop specific guidelines for athletes and active individuals.

1. INTRODUCTION

Dry eye disease (DED) is a common and increasingly recognized disorder of the ocular surface, affecting millions of people worldwide. According to the TFOS DEWS II definition, DED is a multifactorial disease characterized by a loss of tear film homeostasis, accompanied by ocular symptoms, in which tear film instability, hyperosmolarity, inflammation, and neurosensory abnormalities play key roles [1,2].

The global prevalence of DED varies widely depending on diagnostic criteria and population characteristics, but it is estimated to affect a significant proportion of adults [3–5]. Recent epidemiological analyses highlight the importance of both internal and external risk factors, including age, sex, systemic health conditions, and environmental exposures [6,7].

Dry eye disease represents not only a clinical condition but also a significant public health concern due to its impact on quality of life and daily functioning. Patients with DED frequently report symptoms such as ocular discomfort, visual disturbances, and fatigue, which may impair productivity and overall well-being. The burden of disease is therefore not limited to clinical manifestations but extends to socioeconomic consequences.

In recent years, increasing attention has been paid to modifiable risk factors associated with dry eye disease. Among these, environmental exposures and lifestyle-related factors have emerged as particularly relevant. Urbanization, climate variability, and prolonged exposure to indoor, climate-controlled environments may contribute to the rising prevalence of DED. At the same time, behavioral factors, including screen use and reduced blinking frequency, may further exacerbate ocular surface stress.

Within this context, physically active individuals represent a unique subgroup characterized by increased exposure to environmental conditions and physiological stressors. Outdoor physical activity often involves sustained exposure to wind, sunlight, and fluctuating humidity, while intense exercise may lead to fluid loss

and dehydration. These factors may act synergistically, increasing the risk of tear film instability and ocular surface dysfunction.

The tear film is a complex, multilayered structure essential for maintaining ocular surface integrity and visual quality. Disruption of its stability, particularly due to meibomian gland dysfunction (MGD), is one of the leading mechanisms underlying evaporative dry eye [8–10]. Environmental conditions such as low humidity, air pollution, temperature changes, and ultraviolet radiation have been shown to significantly affect tear film dynamics and ocular surface health [11–14].

In addition to environmental stressors, systemic factors such as hydration status may influence tear film composition and osmolarity. Tear osmolarity is considered a key biomarker of DED severity, and its increase has been associated with both local and systemic dehydration [15–17].

Physically active individuals may be particularly exposed to a combination of these risk factors, including outdoor environmental conditions and fluid imbalance. Therefore, understanding the interaction between environmental stressors, hydration, and tear film stability is essential for identifying populations at increased risk and developing targeted preventive strategies.

Recent studies published in sport-oriented and interdisciplinary journals have highlighted the growing importance of environmental and lifestyle-related determinants of health in physically active populations. Research from *Quality in Sport* and *Journal of Education, Health and Sport* emphasizes the role of environmental exposure, training conditions, and hydration status as factors influencing overall well-being and performance in athletes [25–28].

The aim of this narrative review is to summarize current evidence on the role of environmental factors and hydration in dry eye disease, with particular emphasis on mechanisms relevant to physically active individuals. Moreover, the growing popularity of recreational and professional physical activity worldwide underscores the importance of understanding ocular health in active populations. As more individuals engage in outdoor sports and exercise, exposure to environmental risk factors becomes increasingly relevant. Recognizing dry eye disease as a condition influenced by both environmental and systemic determinants may support the development of more effective preventive strategies tailored to modern lifestyle patterns.

2. RESEARCH MATERIALS AND METHODS

This narrative review was conducted using a structured search of the literature available in PubMed and Google Scholar databases. The search included combinations of keywords such as "dry eye disease", "tear film", "environmental factors", "humidity", "air pollution", "ultraviolet radiation", "hydration", and "tear osmolarity", using Boolean operators (AND/OR).

The search covered studies published between 2001 and 2024. Priority was given to high-quality sources, including TFOS DEWS II reports, systematic reviews, and recent peer-reviewed articles. A total of 24 publications were selected based on their relevance to the epidemiology, pathophysiology, environmental determinants, and systemic influences on dry eye disease.

Given the limited number of studies directly investigating physically active populations, evidence from general populations was also included and interpreted in the context of physical activity.

Only articles published in English were included. Due to the narrative nature of the review, no formal meta-analysis was performed.

The search strategy was supplemented by manual screening of the reference lists of relevant articles.

3. RESULTS

3.1. Epidemiology

Dry eye disease (DED) is currently defined as a multifactorial disorder of the ocular surface characterized by a loss of tear film homeostasis, accompanied by ocular symptoms, in which tear film instability, hyperosmolarity, inflammation, and neurosensory abnormalities play etiological roles [1,2].

Epidemiological data indicate that DED is highly prevalent worldwide, although estimates vary due to differences in diagnostic criteria and study populations. The TFOS DEWS II Epidemiology Report highlights that prevalence may range from approximately 5% to over 50% in certain populations [3]. A Bayesian meta-analysis further supports the wide variability in global prevalence, emphasizing methodological heterogeneity across studies [4].

Recent systematic reviews and meta-analyses confirm that DED represents a significant public health burden. For instance, data from the United States suggest both high prevalence and substantial incidence rates, particularly in older populations and women [5]. In addition to demographic factors, multiple modifiable and non-modifiable risk factors have been identified, including systemic diseases, medication use, and environmental exposure [6,7].

3.2. Pathophysiology

The tear film plays a critical role in maintaining ocular surface integrity, optical quality, and protection against environmental insults. It consists of a complex structure including a lipid layer, aqueous component, and mucin layer, which together ensure stability and minimize evaporation [8,10].

One of the central mechanisms in DED is tear film instability, often associated with increased evaporation. Meibomian gland dysfunction (MGD) is considered the leading cause of evaporative dry eye, as it disrupts the lipid layer responsible for reducing tear evaporation [9,11]. Structural and functional alterations of the meibomian glands lead to qualitative and quantitative changes in lipid secretion, further destabilizing the tear film [10].

Hyperosmolarity is a key feature in DED pathophysiology and represents a unifying mechanism linking various etiological factors. Increased tear osmolarity promotes inflammation and epithelial damage, creating a self-perpetuating cycle of ocular surface dysfunction [2].

Additionally, behavioral factors such as incomplete blinking may exacerbate tear film instability by reducing lipid layer distribution and increasing exposure of the ocular surface [13].

3.3. Environmental Factors

Environmental conditions are among the most important modifiable contributors to dry eye disease. Exposure to low humidity has been shown to significantly increase tear evaporation and reduce tear film stability [12,18]. Controlled experimental studies demonstrate that dry environments can directly impair the ocular surface and exacerbate symptoms of DED [12].

Air pollution is another major environmental risk factor. Both particulate matter and gaseous pollutants have been associated with ocular surface irritation, inflammation, and increased prevalence of dry eye symptoms [16,17]. These effects are particularly relevant in urban environments and areas with poor air quality.

Temperature and humidity fluctuations further influence tear film dynamics. Higher temperatures and low humidity levels have been correlated with increased DED severity, likely due to enhanced evaporation and ocular surface stress [19].

Ultraviolet (UV) radiation represents an additional environmental stressor. Excessive UV exposure may induce phototoxic damage to the cornea and conjunctiva, contributing to ocular surface inflammation and dysfunction [14,15].

The TFOS Lifestyle Report emphasizes that environmental conditions play a crucial role in ocular surface health, highlighting the cumulative impact of multiple stressors such as wind, dry air, pollution, and light exposure [20]. Environmental factors rarely act in isolation. In real-life conditions, individuals are typically exposed to multiple environmental stressors simultaneously. For example, outdoor physical activity may involve concurrent exposure to wind, low humidity, ultraviolet radiation, and airborne pollutants. The combined effect of these factors may have a synergistic impact on tear film stability and ocular surface integrity.

Differences between indoor and outdoor environments should also be considered. While outdoor environments are associated with natural stressors such as wind and UV radiation, indoor settings often involve artificial conditions, including air conditioning, heating systems, and reduced humidity levels. Both environments may therefore contribute to ocular surface stress through different mechanisms. Understanding the cumulative and context-dependent nature of environmental exposure is essential for accurately assessing the risk of dry eye disease and developing effective preventive strategies.

3.4. Hydration

Hydration status is an important systemic factor influencing ocular surface physiology. Adequate fluid balance is essential for maintaining tear production and osmotic equilibrium [21].

Tear osmolarity is widely recognized as a key biomarker of dry eye disease severity. Elevated osmolarity reflects tear film instability and is associated with increased ocular surface inflammation [23,24]. Notably, systemic dehydration has been shown to increase tear osmolarity, suggesting a direct link between hydration status and ocular surface health.

Experimental studies indicate that tear osmolarity may serve as a potential marker of whole-body hydration status, particularly in physically active individuals [22]. This relationship underscores the relevance of fluid balance in conditions associated with increased fluid loss, such as physical exertion and exposure to heat.

The relationship between systemic hydration and ocular surface health highlights the importance of considering dry eye disease within a broader physiological context. While tear film alterations are often assessed locally, they may reflect systemic changes affecting fluid balance and homeostasis. From a clinical perspective, tear osmolarity represents not only a diagnostic marker of dry eye disease but also a potential indicator of overall hydration status. This dual role suggests that assessment of tear osmolarity may provide valuable information regarding both ocular and systemic conditions. In physically active individuals,

maintaining adequate hydration may be particularly important due to increased fluid loss associated with exercise. Failure to compensate for fluid loss may lead to subclinical dehydration, which can contribute to increased tear osmolarity and exacerbate dry eye symptoms.

3.5. Implications for Physically Active Individuals

Physically active individuals may be exposed to a unique combination of risk factors for dry eye disease. Outdoor activities often involve prolonged exposure to environmental stressors such as wind, sunlight, variable humidity, and air pollution, all of which can negatively affect tear film stability [16,19,20].

In addition, physical exertion may lead to dehydration and electrolyte imbalance, particularly in conditions of high temperature or insufficient fluid intake. As dehydration has been associated with increased tear osmolarity, this may further exacerbate ocular surface dysfunction [22–24].

The combined effect of environmental exposure and fluid imbalance may place physically active individuals at increased risk of developing or worsening DED symptoms. Although direct evidence in athletic populations is limited, the underlying mechanisms suggest a plausible and clinically relevant association.

Therefore, preventive strategies in physically active populations should include both environmental protection (e.g., eyewear, UV filters) and adequate hydration to support tear film stability and ocular surface health.

Table 1. Environmental and systemic risk factors in dry eye disease

Factor	Type	Mechanism	Effect on ocular surface
Low humidity	Environmental	Increased tear evaporation	Tear film instability
Air pollution	Environmental	Inflammation, oxidative stress	Ocular surface damage
UV radiation	Environmental	Phototoxicity	Epithelial injury
High temperature	Environmental	Increased evaporation	Tear film disruption
Wind exposure	Environmental	Mechanical stress, evaporation	Increased tear loss
Dehydration	Systemic	Increased tear osmolarity	Inflammation, instability
Incomplete blinking	Behavioral	Reduced lipid distribution	Increased evaporation

4. DISCUSSION

The present review highlights the multifactorial nature of dry eye disease, emphasizing the interplay between environmental stressors and systemic factors such as hydration. The findings confirm that tear film instability and hyperosmolarity represent central mechanisms linking various risk factors involved in DED pathogenesis [2].

Environmental conditions appear to play a particularly significant role in ocular surface disruption. Low humidity, air pollution, temperature variability, and ultraviolet radiation have all been shown to negatively affect tear film stability and promote ocular surface inflammation [12,14–19]. These factors often coexist, and their cumulative effect may be greater than that of individual exposures alone.

In addition to environmental influences, hydration status emerges as an important yet frequently underestimated contributor to dry eye disease. Increased tear osmolarity, a hallmark of DED, has been associated not only with local tear film dysfunction but also with systemic dehydration [22–24]. This suggests that ocular surface health may be influenced by whole-body fluid balance to a greater extent than previously recognized.

It is worth noting that the interaction between environmental exposure and hydration may be particularly relevant in physically active individuals. Physical activity, especially in outdoor settings, is commonly associated with increased exposure to environmental stressors and a higher risk of fluid loss. Although direct studies focusing on athletes are limited, the available evidence supports a plausible link between these factors and increased susceptibility to DED.

These findings are consistent with previous reports from sport science and health-related journals, which underline the impact of environmental conditions and hydration on physiological balance and performance. Studies published in *Quality in Sport* and *Journal of Education, Health and Sport* indicate that physically active individuals are particularly susceptible to environmental stressors and fluid imbalance, which may influence not only systemic but also ocular health [25–28].

From a clinical perspective, these findings underscore the importance of a holistic approach to dry eye disease. In addition to conventional treatments targeting tear film stability and inflammation, attention should be given to modifiable lifestyle factors, including environmental exposure and hydration habits. Preventive strategies such as protective eyewear, optimization of environmental conditions, and adequate fluid intake may play a supportive role in reducing DED risk.

Future research should focus on well-designed studies evaluating dry eye disease specifically in physically active populations. Such studies would help to better define risk profiles and develop targeted preventive and therapeutic strategies.

An additional aspect worth consideration is the potential role of individual susceptibility in the development of dry eye disease under environmental stress. Not all individuals exposed to similar environmental conditions develop clinically significant symptoms, suggesting that intrinsic factors such as tear film composition, ocular surface sensitivity, and genetic predisposition may modulate the response to external stressors. Variability in adaptive mechanisms, including reflex tearing and blinking patterns, may further influence the resilience of the ocular surface. For example, individuals with more stable lipid layer function or more efficient blinking may better compensate for increased evaporation. Conversely, those with subclinical meibomian gland dysfunction may be more vulnerable to environmental triggers. This inter-individual variability highlights the

importance of a personalized approach to both prevention and management of dry eye disease. Future research should aim to identify specific phenotypes or risk profiles that may predict increased susceptibility to environmental and systemic stressors. Such insights could contribute to more targeted interventions and improved clinical outcomes.

4.1. Preventive strategies in physically active individuals

Physically active individuals may be exposed to environmental conditions that promote tear film instability and ocular surface stress. Preventive strategies should therefore focus on minimizing exposure to adverse environmental factors and maintaining adequate hydration status. Appropriate fluid intake may help regulate tear osmolarity and support ocular surface homeostasis. Additionally, the use of protective eyewear can reduce exposure to wind, ultraviolet radiation, and airborne particles. Environmental modifications, such as avoiding prolonged activity in low-humidity or highly polluted conditions, may also be beneficial. Incorporating these preventive measures into routine practice may reduce the risk of dry eye symptoms and improve ocular comfort in physically active populations.

4.2. Mechanistic interaction between hydration and environmental stressors

Environmental and systemic factors influencing dry eye disease do not act independently but are closely interconnected through shared pathophysiological mechanisms. One of the key links between these factors is tear film evaporation, which is influenced both by external environmental conditions and internal hydration status. Low humidity and increased airflow are known to accelerate tear evaporation, leading to increased tear film instability. At the same time, systemic dehydration may reduce aqueous tear production and increase tear osmolarity. When these factors occur simultaneously, their effects may be amplified, resulting in a synergistic impact on ocular surface homeostasis. Increased tear osmolarity represents a central mechanism linking environmental exposure and hydration status. Hyperosmolar conditions promote inflammation, epithelial damage, and neurosensory alterations, contributing to a self-perpetuating cycle of dry eye disease. This suggests that both external and internal factors converge at the level of tear film composition and stability. Understanding these interactions is particularly relevant in populations exposed to both environmental stressors and physiological strain, such as physically active individuals. The combined effect of environmental exposure and fluid imbalance may significantly increase the risk of developing or exacerbating dry eye disease.

4.3. Clinical relevance and future directions

The findings of this review have important implications for clinical practice. Dry eye disease is often managed primarily through topical therapies; however, the role of environmental and systemic factors suggests that a more comprehensive approach may be beneficial. Clinicians should consider environmental exposure and hydration status as part of routine assessment in patients presenting with dry eye symptoms. Identifying modifiable risk factors may allow for more personalized management strategies, including lifestyle modifications and preventive interventions. Despite the growing body of evidence, data specifically addressing physically active populations remain limited. Most available studies are based on general populations, and direct research on athletes or individuals engaged in regular physical activity is scarce. This represents an important gap in the literature. Future research should focus on prospective studies evaluating the impact of environmental exposure and hydration in physically active individuals. Such studies may help to establish evidence-based guidelines for prevention and management of dry eye disease in this population. In addition, future studies should aim to incorporate objective measurements of both environmental exposure and hydration status in real-life conditions. The use of wearable sensors and continuous monitoring technologies

may provide more accurate and dynamic insights into how environmental and physiological variables influence the ocular surface. Interventional studies evaluating preventive strategies, such as optimized hydration protocols or protective measures during physical activity, would also be valuable. Such approaches could help to translate current knowledge into practical recommendations for individuals at increased risk of dry eye disease. Furthermore, multidisciplinary collaboration between ophthalmologists, sports medicine specialists, and environmental health researchers may facilitate a more comprehensive understanding of the factors contributing to dry eye disease in physically active populations.

4.4. Limitations of the study

This narrative review has several limitations that should be acknowledged. First, due to its non-systematic design, the selection of studies may be subject to selection bias. Although efforts were made to include high-quality and relevant publications, the absence of a predefined protocol and formal screening process may limit the reproducibility of the findings. Second, the heterogeneity of the included studies represents an important limitation. Differences in diagnostic criteria for dry eye disease, variations in study populations, and inconsistencies in outcome measures may affect the comparability of results. As a consequence, drawing direct quantitative conclusions is challenging, and the findings should be interpreted within a qualitative framework. Another limitation is the relatively limited number of studies directly investigating physically active individuals. Most available data are derived from general populations, and extrapolation to athletes or highly active individuals may not fully capture the specific physiological and environmental conditions associated with physical activity. This highlights the need for targeted research in this subgroup. Additionally, environmental exposure is inherently complex and difficult to quantify. Individuals are typically exposed to multiple environmental stressors simultaneously, including variations in humidity, temperature, air quality, and light conditions. These factors may interact in a synergistic or cumulative manner, making it difficult to isolate the effects of individual variables on the ocular surface. Finally, hydration status is often assessed indirectly, and variability in measurement methods may influence the interpretation of results. While tear osmolarity is a valuable biomarker, it may be affected by both local ocular factors and systemic conditions, which should be considered when evaluating its clinical significance. Despite these limitations, the present review provides a comprehensive synthesis of current knowledge regarding the role of environmental and systemic factors in dry eye disease. It also identifies important gaps in the literature and offers a foundation for future research aimed at improving prevention and management strategies.

5. CONCLUSIONS

Dry eye disease is a multifactorial condition influenced by both environmental and systemic factors. Tear film instability, driven in part by meibomian gland dysfunction and hyperosmolarity, represents a central mechanism in disease development. Environmental stressors such as low humidity, air pollution, temperature changes, and ultraviolet radiation play a significant role in disrupting ocular surface homeostasis. Additionally, hydration status has emerged as an important factor influencing tear osmolarity and overall ocular surface health. Physically active individuals may be particularly vulnerable due to combined exposure to environmental conditions and fluid imbalance. Increased awareness of these factors may contribute to improved prevention and management of dry eye disease in this population. Integrating environmental awareness and hydration strategies into clinical practice may enhance both prevention and management of dry eye disease. A multidisciplinary approach that considers lifestyle, environmental exposure, and systemic factors may provide a more effective framework for addressing this increasingly prevalent condition. Furthermore, increasing awareness of environmental and hydration-related risk factors among physically active individuals may support early identification of symptoms and implementation of preventive strategies.

Education and simple behavioral interventions could play an important role in reducing the burden of dry eye disease in this population.

6. DISCLOSURE

6.1. Author Contributions

Conceptualization: N.M.; Methodology: N.M.; Literature search: N.M.; Data interpretation: N.M.; Writing – original draft preparation: N.M.; Writing – review and editing: N.M., K.Ś., W.W., D.Z., G.M., K.D., W.Wi., M.O., M.M., A.M.; Supervision: N.M. All authors have read and agreed to the published version of the manuscript.

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6.4. Informed Consent Statement

Not applicable.

6.5. Conflict of Interest

The authors declare no conflicts of interest.

6.6. Data Availability Statement

Not applicable.

6.7. Acknowledgements

Not applicable.

6.8. CRediT Author Contributions (taxonomy)

Mapped to the CRediT (Contributor Roles Taxonomy, NISO Z39.104-2022). Author initials: NM=Natalia Mordal; KŚ=Kacper Ściebura; WW=Weronika Walendziak; DZ=Damian Zienkiewicz; GM=Gabriela Makulec; KD=Karolina Domosud; WWi=Wiktoria Wiśniewska; MO=Magdalena Ostaszewska; MM=Milena Majchrzyk; AM=Anna Malczyk.

- Conceptualization: NM
- Methodology: NM
- Validation (Check): NM
- Formal analysis: NM
- Investigation: NM

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- Resources: NM
 - Data curation: NM
 - Writing – original draft: NM
 - Writing – review & editing: KŚ, WW, DZ, GM, KD, WWi, MO, MM, AM
 - Visualization: NM
 - Supervision: NM
 - Project administration: NM
 - Funding acquisition: Not applicable

Declaration of the use of generative AI and AI-assisted technologies in the writing process

AI tools were used solely for linguistic support and editing. All scientific content, interpretation, and conclusions were developed by the authors.

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