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The hidden cost of the pool: environmental risk factors, clinical implications, strategies for prevention and treatment – a literature review

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Abstract

Introduction: Dental erosion is a multifactorial condition characterized by the progressive loss of dental hard tissues due to the action of acids that are not associated with bacterial activity. Competitive swimmers are particularly susceptible to this issue due to prolonged exposure to chlorinated swimming pool water, which may present reduced pH levels and lead to enamel demineralization.
Materials and Methods: This systematic review aimed to summarize the current evidence regarding the prevalence, etiology, clinical symptoms, diagnostic methods, prevention strategies, and treatment options for enamel erosion in competitive swimmers. Data were collected through a structured search of scientific databases, including publications from 2000 to 2025. Only studies focused on oral health among swimmers and the influence of swimming pool environments on enamel were included in the analysis.
Summary: The findings indicate that the prevalence of enamel erosion among swimmers varies, with key risk factors including the duration of training sessions, mouth breathing during swimming, and exposure to improperly maintained pool water. Saliva plays a critical protective role in counteracting the formation of erosive lesions. Preventive measures include maintaining proper pool water pH, limiting oral cavity exposure through the use of custom mouthguards, and promoting adequate oral hygiene practices using appropriate tools and products. Treatment options range from remineralization protocols to restorative procedures, depending on the extent of tissue loss. Despite growing awareness, regular dental check-ups among swimmers remain insufficient, highlighting the need to strengthen educational and preventive efforts.
Conclusions**:** This review highlights the need for a comprehensive and individualized approach to the prevention and management of enamel erosion in competitive swimmers. Targeted education and preventive programs should be intensified for both athletes and coaches, and routine dental monitoring should become a standard component of care in sports dentistry.

Keywords: dental erosion, enamel demineralization, swimmers, sports dentistry, chlorinated water, oral health prevention

Introduction

Regular physical activity is universally recognized as essential for maintaining a healthy lifestyle at every age. [1] In recent years, global interest in sports as a means to promote well-being has significantly increased, with more people participating in both amateur and professional physical activities. This rise parallels advancements in sports medicine—a multidisciplinary field aimed at enhancing athletic performance and overall health. Within this evolving discipline, sports dentistry has rapidly emerged as an essential yet often underrecognized specialty that focuses primarily on the prevention and management of orofacial pathologies and related oral diseases in athletes. Sports or team dentists play a crucial role in supporting athletes by providing prevention, diagnosis, and treatment of oral conditions. [2,3] However, many athletes remain unaware of the health consequences of oral pathologies and the associated risks. Consequently, dentists have a vital responsibility to educate athletes, coaches, and patients about the importance of maintaining and protecting oral health. [4] Among the various groups of athletes, competitive swimmers are particularly vulnerable to specific occupational environmental factors that increase their risk of developing oral health issues such as dental erosion. This heightened risk is largely due to their prolonged exposure to chlorinated pool water and related chemical agents, making them a key population of interest in sports dentistry research.

Competitive swimmers, who often swim for a longer time, expose their teeth to large amounts of chemically treated water. There have been reports indicating that swimming pools with inadequate chlorination and acidic pH levels can lead to the erosion of dental enamel. [5,6]

In multiple epidemiological studies, the prevalence of dental erosion among swimmers ranged from 26% to 90% of swim team participants. Ashley et al. [7] reported that the prevalence of tooth tissue loss caused by erosive challenges among athletes ranges from 36% to 85%. Zebraukas et al. [8] demonstrated in their studies that the prevalence of erosion among swimmers in one Lithuanian city ranged from 25% to 50%, depending on age. Rao et al. [9] presented in their study that dentin hypersensitivity was present in 69.6% of professional swimmers in India, while dental erosion affected 48.2% of them. The prevalence of dental erosion increased from 26% to 69% with the number of years of swimming experience. They also found that the likelihood of developing dental erosion was 5.3 times higher in swimmers

with more than three years of experience. In Polish studies by Buczkowska Radlińska et al. [10], erosion was found in over 26% of professional swimmers and in 10% of recreational swimmers. Abdelrahman et al. [11] demonstrated in their study that enamel erosion was significantly more prevalent among competitive swimmers compared to individuals who did not practice swimming (60% and 25.56%, respectively). Dawes et al. [6] presented a case study documenting complete enamel loss due to acid erosion, especially affecting the anterior teeth, in an individual who swam daily for two weeks in a swimming pool with inadequate chlorination. The multivariable regression analysis revealed that competitive swimmers had a 2.03-fold higher risk of developing dental erosion compared to non-swimmers. These findings align with those of Centerwall et al. [12] who found that engaging in competitive swimming increased the likelihood of erosion by a factor of 7.2. In the study by Mielle et al. [13], it was reported that two out of five athletes examined showed signs of erosive changes. Although swimmers may not perceive the low pH, it can lead to tooth dissolution. Dental literature suggests that pool water with a low pH can cause rapid and extensive tooth erosion [14]. Nijakowski et al. [15] conducted a systematic review encompassing 16 studies on the prevalence of erosion in athletes, including professional swimmers. Their findings indicated that about 50% of the individuals examined exhibited signs of erosion, which aligns with earlier research results. Regarding the affected areas, the highest prevalence was observed in sextants 4 (32.6%) and 6 (33.8%), which corresponds with previous reports highlighting a greater incidence of erosion in the lower first molars. Lanzetti et al. [16] found that competitive swimmers who spent prolonged periods training in pool water showed a higher incidence of dental erosion. This contrasts with the findings of D'Ercole et al. [17], where only 2% of professional swimmers exhibited signs of erosion after training in pool water with a pH ranging from 7.20 to 9.0. Therefore, intensive swimming should be considered a contributing factor when diagnosing generalized tooth erosion.

The aim of this review paper is to discuss selected, often overlooked but significant dental issues observed in athletes, with a particular focus on swimmers. This group, due to regular and prolonged contact with swimming pool water, is exposed to specific risk factors that may lead to dental erosion. Despite growing awareness of health prevention among athletes, knowledge about the impact of the swimming pool environment on oral health remains insufficient. This review includes an analysis of the etiology, mechanisms of development, symptoms, as well as possibilities for prevention and treatment of enamel erosion in swimmers, considering the impact of their occupational environment and health behaviors.

Material and Methods

This article presents a narrative review of the scientific literature concerning enamel erosion in competitive swimmers. The aim of this study was to analyze current data on the prevalence of these conditions, their etiology, clinical manifestations, mechanisms of development, diagnostic procedures, treatment options, and preventive strategies.

The material for this review was gathered through a structured search of international scientific databases, including PubMed, Scopus, Willey and Web of Science. The search encompassed literature published between 2000 and 2025 and utilized targeted keywords such as “dental erosion,” “enamel demineralization”, “swimmers,” “chlorinated water,” “oral health,” and “sports dentistry.” Additionally, reference lists from the initially identified articles were manually reviewed to uncover further relevant studies.

Only scientific publications in English were considered, provided they focused specifically on oral health issues in swimmers—particularly dental erosion related to prolonged exposure to swimming pool environments. The review included original research papers, literature reviews, clinical case reports and comprehensive articles dealing with diagnosis, prevention, and treatment.

Studies not related to swimming as a contributing factor, lacking full-text availability, or not meeting fundamental methodological or content criteria were excluded. The initial screening process involved evaluation of titles and abstracts, followed by in-depth analysis of full texts. To reduce the risk of bias or oversight, two independent reviewers conducted the selection and assessment of the materials.

The extracted data were organized thematically and classified into major areas of interest: the epidemiology of enamel erosion, chemical and environmental factors (such as chlorinated water exposure), clinical signs, diagnostic approaches, and preventive and therapeutic strategies. This approach enabled a detailed and holistic understanding of the oral health risks encountered by swimmers, highlighting environmental exposures and potential long-term effects on dental health. The collected evidence provides a solid foundation for further analysis and supports the

development of practical guidelines to enhance awareness, prevention, and care standards among this specific athletic population.

Discussion

Dental erosion is a multifactorial condition characterized by the pathological, chronic loss of dental hard tissues caused primarily by the chemical action of acids from both external and internal sources, occurring independently of bacterial activity, and resulting from the interplay of chemical, biological, and behavioral factors that lead to the gradual degradation of the dental surface. [16,18] Tooth erosion can have extrinsic or intrinsic causes. The intrinsic causes comprise recurrent vomiting as in patients suffering from anorexia and bulimia, cytostatic drug treatment or propulsion of gastric contents into the mouth due to gastroesophageal reflux. Extrinsic causes comprise frequent consumption of acidic foods or drinks, the use of acidic hygiene products and acidic medicines. [19]

The primary factors contributing to dental erosion in competitive swimmers include breathing through the mouth during aquatic training—leading to dehydration of the oral cavity and decreased salivary flow—as well as exposure to a chlorinated environment, including both chlorinated water and air inhaled within the pool area. The risk of developing dental erosion and associated hypersensitivity increases in direct relation to the duration of exposure to chlorine, and thus, to the total number of training hours. [16] It can therefore be concluded that swimming is the sport most commonly associated with the development of dental erosion due to the lowered pH of pool water caused by the use of chlorine for disinfection. [20]

The role of saliva in erosion

Saliva plays a fundamental role in maintaining oral health and protecting dental tissues from various forms of damage. It safeguards against caries, erosion, attrition, abrasion, candidiasis, and mucosal lesions that are frequently observed in patients with hyposalivation. The protective function of saliva is multifactorial: it contributes to the formation of the acquired enamel pellicle, facilitates the removal of sugars and acids from the oral cavity, provides antibacterial and antifungal agents, and lubricates the oral tissues, thereby reducing their susceptibility to mechanical and chemical injuries. [21] In the context of enamel protection in competitive swimmers, saliva plays a key buffering role in response to acid challenges and supports the process of remineralization due to its supersaturation with respect to tooth minerals.

Maintaining a neutral pH (approximately 7.0) is essential for preserving mineral balance. [19] However, in conditions of reduced salivary secretion, the buffering capacity is weakened, increasing enamel's vulnerability to acid erosion and demineralization.

Chlorination of water and erosive changes

Public swimming pools are chlorinated to control bacterial and algal growth. In accordance with European Union (EU) regulations, the chlorine concentration in pool water must be maintained between 0.3 and 0.6 mg/dm³. [10,47] Chlorine used in swimming pool water often reacts with other compounds to form chloramines. These by-products can volatilize as sodium hypochlorite, contributing to increased acidity in both the surrounding environment and the air that swimmers inhale. Chloramines are known to be highly irritating to the skin, mucous membranes including the oral mucosa and the eyes. [16]

Chlorine compounds are commonly employed for disinfecting swimming pool water, with the primary methods being gas chlorination and sodium hypochlorite application. [8]

Chlorine may be introduced into swimming pool water in the form of sodium hypochlorite, which possesses an inherently alkaline pH, thereby exhibiting a relatively low potential for causing enamel erosion. This type of "stabilized chlorine" is typically produced by combining chlorine with cyanuric acid salts to enhance its stability. In contrast, gas chlorination remains the predominant method used for water disinfection in large-scale swimming pools. [22] When chlorine gas is introduced into water, it undergoes a chemical reaction forming hypochlorous acid (HOCl) and hydrochloric acid (HCl), according to the equation: $Cl_2 + H_2O \rightarrow HOCl + HCl$. Hypochlorous acid serves as the primary antimicrobial agent responsible for disinfection, while hydrochloric acid is a by-product that can undesirably lower water pH. To maintain a stable and safe pH level—typically around 7.5—sodium carbonate (Na_2CO_3) is added as a buffering agent. However, in gas-chlorinated pools that are insufficiently buffered due to inadequate soda ash addition, the pH can drop precipitously to highly acidic, decalcifying levels—as low as pH 3. [10,12,22] The World Health Organization (WHO) recommends maintaining the pH of pool water between 7.2 and 7.8 when chlorine is utilized as a disinfectant. [23, 24] Nevertheless, non-compliance with these guidelines has been documented, suggesting that pH regulation is not always rigorously enforced.

Competitive swimmers are consistently exposed to chlorinated water, where chlorine compounds are employed as disinfectants. The presence of these compounds can induce rapid decreases in water pH, occasionally reaching levels within a short timeframe. [8]

Numerous studies have reported that the critical pH threshold for enamel dissolution ranges from 5.5 to 5.7. [25,26] However, Lussi and Carvalho [27] argued that this pH range is specific to the carious process and that no definitive critical pH exists for enamel dissolution in other erosive conditions. They emphasized that enamel dissolution depends not only on the solution's pH but also on the concentrations of key mineral components—such as calcium, phosphate, and fluoride—present in the erosive environment. Consequently, they concluded that the critical pH for enamel dissolution may vary more broadly, ranging from approximately 6.5 down to 3.9. The critical pH for the stability of enamel structure is not a fixed value and depends on various chemical factors present in the oral cavity, making the process of tooth erosion complex and multifaceted.

Mechanism of erosive lesion formation

From a chemical perspective, the formation of dental erosion involves repeated acid attacks that cause demineralization of the enamel surface. [28,29] The acids dissolve the mineral content—primarily hydroxyapatite crystals—leading to softening and eventual loss of the enamel layer. If the acid exposure continues without adequate remineralization or protective mechanisms, the enamel thins and may eventually be lost, exposing the underlying dentin. The process is gradual and cumulative, influenced by the frequency, duration, and intensity of acid contact, as well as individual factors such as saliva flow and composition. On the enamel surface, hydrogen ions from the acid begin to dissolve the enamel crystals. Initially, the acid breaks down the prism sheath area, followed by the prism core, resulting in a distinctive honey comb pattern. [30] Subsequently, the acid penetrates the interprismatic spaces of the enamel and continues to dissolve minerals beneath the surface layer. This process causes a localized increase in pH within the tooth structure just below the enamel surface and in the adjacent liquid layer. [31,32] Similar processes occur in dentin, although they are inherently more complex. The localized increase in pH beneath the enamel surface and in the adjacent liquid layer represents a temporary buffering response, but without sufficient protective factors or remineralization, the erosive process continues, progressively damaging the tooth structure.

Diagnosis and clinical appearance of erosive lesions

Diagnosing early stages of erosion is challenging due to the minimal signs and often absent symptoms. Currently, there is no device routinely available in dental practice that can specifically detect dental erosion or monitor its progression. Consequently, clinical examination remains the primary method for dental professionals to identify and diagnose this condition. [33]

Dental erosion manifests as a progressive loss of the dental hard tissues. [34] Erosion can impact any tooth, affecting just the enamel or extending to both enamel and dentin, with lesions appearing either in localized areas or more widespread. The surfaces most frequently affected are the palatal surfaces of the upper front teeth and the occlusal surfaces of the first lower molars. [35] Typical signs of enamel erosion on facial and oral surfaces include a smooth, silky-glazed, sometimes dull enamel surface, absence of perikymata, and intact enamel along the gingival margin. In more advanced stages, additional morphological changes become evident. Early erosion on occlusal and incisal surfaces presents similarly to the features described above. As occlusal erosion progresses, cusp rounding occurs, and restorations may become elevated above the adjacent tooth surfaces. In severe cases, the entire occlusal morphology can be lost. As the process advances, the enamel may become thinner, with increased translucency, and the affected areas may develop cupping or shallow depressions. In more severe cases, dentin exposure occurs, which can result in hypersensitivity and an increased risk of mechanical wear. Erosive lesions must be differentiated from attrition and abrasion, which typically show flat, shiny, well-defined surfaces with matching wear on opposing teeth. Clinically, distinguishing between erosion, attrition, and abrasion can be difficult, especially when they coexist with similar appearances. A systematic clinical exam should include a detailed medical and dietary history, saliva assessment, and training frequency for competitive swimmers. Many swimmers showing signs of erosion are unaware of their oral health condition, so raising their awareness is important. [34]

To facilitate diagnosis and description of the clinical appearance of erosion, several classification systems have been developed to assess the severity and extent of dental erosion: BEWE and Lussi Index.

One commonly used system is the **Basic Erosive Wear Examination (BEWE)**, which grades erosion on a scale from 0 to 3 based on the depth and surface area affected:

- Score 0: No signs of erosion
- Score 1: Initial loss of surface texture
- Score 2: Distinct defect with hard tissue loss affecting less than 50% of the surface
- Score 3: Hard tissue loss affecting more than 50% of the surface.

The most severely affected surface within each sextant is assigned a four-level score, and the total cumulative score is then categorized and correlated with risk levels to guide treatment decisions. [36]. In each sextant, the most affected surface is documented, and the scores are then summed. The total score is used to determine an individual risk level as follows: no risk (BEWE ≤ 2), mild risk ($3 <$ BEWE < 8), moderate risk ($9 <$ BEWE < 13), and high risk (BEWE ≥ 14).

Another popular system is the **Lussi Index**, which presents both the location and morphology of erosive lesions. A four-grade scale was developed to assess lesions on the labial/buccal surfaces (scores 0–3), and a separate three-grade scale was created to evaluate lesions on the occlusal and lingual/palatal surfaces (scores 0–2):

Facial

- Score 0: No erosion. Surface with a smooth, silky glazed appearance, possible absence of developmental ridges
- Score 1: Loss of surface enamel. Intact enamel cervical to the erosive lesion; concavity on enamel where breadth clearly exceeds depth, thus distinguishing it from toothbrush abrasion. Undulating borders of the lesion are possible and dentine is not involved
- Score 2: Involvement of dentine for less than half of tooth surface
- Score 3: Involvement of dentine for more than half of tooth surface

Occlusal and lingual/palatal

- Score 0: No erosion. Surface with a smooth, silky glazed appearance, possible absence of developmental ridges

- Score 1: Slight erosion, rounded cusps, edges of restorations rising above the level of adjacent tooth surface, grooves on occlusal aspects. Loss of surface enamel. Dentine is not involved
- Score 2: Severe erosions, more pronounced signs than in grade 1. Dentine is involved.

The main advantages of this index, besides its ease of use, include high reliability in studies, excellent inter-examiner agreement, and particular usefulness in epidemiological research. Results obtained using this tool are also easily comparable with those from other sources. [37,38]

Both indices assist clinicians in diagnosing, monitoring, and planning appropriate treatment for patients with enamel erosion, enabling preventive and restorative measures to be tailored to the severity of the lesions. These two scales are used in scientific studies to assess the prevalence of erosive lesions. In the studies included in this paper, both scales were also applied. However, the Lussi index was used more frequently.

Treatment and Prevention of Erosive Lesions

The research indicates that dental erosion is influenced by both individual factors and lifestyle habits. As a result, effective prevention and management should focus on early detection of lesions, combined with the use of remineralizing and desensitizing treatments—both at home and in clinical settings. Additionally, a thorough evaluation of the patient's lifestyle is necessary. Personalized oral hygiene routines, dietary guidance, and appropriate fluoride use should also be incorporated into a comprehensive preventive strategy. [16] Unfortunately, the research presented in this review indicates that many professional swimmers do not follow regular dental check-ups or treatment. To overcome this lack of knowledge and awareness among athletes, it is essential to invest more effort and time in educating both the athletes and their coaches. Additionally, the dental team plays a crucial role by identifying issues early, advising on preventive strategies, and scheduling routine dental check-ups. [39]

Prevention includes several key components. Reducing the time spent swimming with the mouth open limits the direct contact between pool water and the enamel. It is also crucial to use well-maintained swimming pools with properly balanced pH levels and chlorine concentrations, which helps minimize the erosive potential of the water. The use of mouthguards also reduces

the risk of erosive tooth wear caused by swimming pool water. [11] Proper oral hygiene habits are also of great importance. Swimmers should adopt gentle brushing techniques to avoid mechanical abrasion of the enamel. Choosing the right toothbrush bristle hardness and toothpaste type is essential for effective oral hygiene and preserving healthy dental and gum tissues. The abrasive wear on teeth increases with the abrasiveness of the toothpaste. [16,40] Therefore, whitening toothpastes containing high levels of abrasive agents like sodium bicarbonate and pyrophosphate are not recommended for athletes who are prone to tooth erosion and sensitivity. [41] Toothpastes should contain a minimum of 1,450 ppm fluoride ions (F^-) and compounds such as Amorphous Calcium Phosphate (ACP), because highly concentrated fluoride products and remineralizing agents help competitive swimmers by supporting enamel remineralization and protecting against further damage. [35]. Regarding the toothbrush, it should have soft bristles. In vitro research by Souza et al. indicates that patients with erosion should avoid using hard-bristled toothbrushes, as these may exacerbate the loss of dental tissue. [42] The regular use of fluoride products, such as rinses or gels, increases enamel resistance and enhances remineralization. [43]

Since saliva plays a protective role and supports the remineralization process, it is essential for swimmers to maintain adequate hydration and stimulate saliva production—for example, by chewing sugar-free gum before and after training. [44] Additionally, dietary counseling is recommended to reduce the consumption of acidic foods and drinks outside of training sessions, which helps lower the overall acid exposure to the enamel.

Management of patients who are at increased risk of dental erosion should focus on preventive strategies and routine dental evaluations. The treatment of existing erosive lesions must be tailored to the severity and extent of tooth structure loss. According to European guidelines for managing advanced tooth wear wear published in 2017 [45], restorative intervention is recommended only when the patient experiences one or more of the following:

1) sensitivity or pain,
2) reduced functional efficiency,
3) impairment of aesthetics due to loss of hard dental tissues,
4) “crumbling” of dental hard tissues or restorations which threatens the integrity of the remaining tooth structure.

Composite resins are considered the preferred material. Both direct and indirect restorative approaches can be applied, but the European Federation of Conservative Dentistry (EFCD) highlights that direct techniques are generally less invasive. [46] Nonetheless, in cases of extensive enamel and dentin loss, indirect restorations may be necessary to ensure long-term durability and function. In severe cases of erosion, prosthetic rehabilitation using crowns or veneers may be necessary to rebuild the tooth's structure and aesthetics. [44]
Given that erosion can be related to the sports environment, it is important to implement preventive health measures for high-risk groups. Therefore, regular dental examinations are advised.

A comprehensive approach—combining preventive measures, patient education, and individually tailored treatment—forms the foundation of effective management of enamel erosion in swimmers.

Summary and conclusions

Dental erosion in competitive swimmers is a significant occupational health concern linked primarily to the acidic and chlorinated environment of swimming pools combined with behavioral factors during training. The reviewed literature demonstrates a variable but notably high prevalence of erosion among competitive swimmers, with increased risk correlated with years of exposure and swimming intensity. Saliva's protective role is diminished during aquatic activity, increasing vulnerability to enamel demineralization.

Effective management requires early diagnosis through clinical examination supported by validated indices like BEWE and the Lussi Index. Preventive strategies should focus on maintaining optimal pool water quality, educating swimmers on reducing oral exposure to pool water, and promoting oral hygiene practices that minimize enamel erosion while supporting remineralization, including the use of fluoride and calcium phosphate compounds.

Treatment approaches must be individualized based on lesion severity, ranging from non-invasive remineralization therapies to more extensive restorative and prosthetic interventions in advanced cases. Importantly, the findings emphasize the need for regular dental monitoring and the proactive involvement of dental professionals in athlete education and care.

Overall, a multidisciplinary, tailored preventive and therapeutic approach forms the cornerstone of preserving oral health in competitive swimmers, mitigating the impact of dental erosion, and ensuring long-term dental function and aesthetics and oral health.

Disclosure

Author's contribution

Conceptualization**:** Natalia Chojnowska

Methodology: Jan Rytel

Formal analysis:

Investigation:

Writing-rough preparation: Natalia Chojnowska

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