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Original Article

Impact of Swimming on Enamel Integrity: An In Vitro Analysis of Dental Erosion and Preventive Strategies

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ABSTRACT

This in vitro investigation explored the protective potential of high-concentration fluoride and remineralizing agents (F-APC) against dental erosion in the context of competitive swimming. Forty-eight extracted teeth were collected, stored in saline, and assigned to three experimental conditions. In the control group (G1), teeth were half-submerged in chlorinated pool water. In the fluoride group (G2), teeth were fully immersed in chlorinated water, with one half of each tooth surface treated once weekly with a concentrated fluoride preparation. In the remineralization group (G3), teeth were also fully immersed, and half of each surface received a F-APC application after each exposure. Immersions lasted 4 hours per day over a 4-week period.
In G1, erosion was significantly more pronounced on submerged surfaces compared to non-submerged ones at week 3 ($p = 0.019$) and week 4 ($p = 0.0007$), affecting four and eight surfaces, respectively. In G2, untreated portions displayed higher wear at week 4 ($p = 0.039$), with three surfaces affected by erosive tooth wear (ETW). Similarly, in G3, untreated areas showed greater ETW at week 4 ($p = 0.019$), with four surfaces affected. These results suggest that chlorinated pool water can contribute to dental erosion, particularly when pH levels approach critical thresholds. Application of high-concentration fluoride once weekly for 5 minutes or routine F-APC treatment effectively mitigates erosion and preserves tooth integrity.

Keywords: Dental erosion, Competitive swimmers, Preventive oral care, Athlete dentistry

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Introduction

Erosive tooth wear (ETW) is characterized as the progressive and irreversible loss of dental hard tissue due to exposure to acids of non-bacterial origin [1, 2]. Epidemiological studies indicate that approximately 30% of Europeans aged 18–35 exhibit at least one tooth affected by ETW [3]. This condition can affect both primary and permanent dentition, involving enamel alone or both enamel and dentin, and may present as localized or generalized lesions. The palatal surfaces of maxillary anterior teeth and the occlusal surfaces of mandibular first molars are most commonly impacted. Early-stage ETW is often asymptomatic and difficult to detect visually or tactilely, as it does not initially cause discoloration or softening. Morphological changes become evident at more advanced stages, with tooth surfaces appearing opaque, flattened, and slightly polished; posterior teeth may develop cusp concavities, while anterior teeth often exhibit wider depressions on smooth surfaces. The cervical third near the gingival margin typically remains unaffected, and in severe cases, pulp exposure can occur, particularly in incisors [4]. Patients may experience hypersensitivity, pain, and functional or aesthetic concerns.

Over a lifetime, teeth are continuously exposed to chemical and mechanical challenges that contribute to ETW. When acids lower salivary pH below the critical threshold of 5.5, enamel demineralization occurs due to calcium and phosphate loss, weakening the tissue and increasing susceptibility to mechanical stress [5]. Acidic challenges can originate intrinsically or extrinsically [6]. Intrinsic sources include gastroesophageal reflux, eating disorders such as

anorexia or bulimia, and pregnancy [7–9]. Extrinsic sources are primarily dietary acids, including fruit juices, soft drinks, energy drinks, wine, certain medications, and occupational exposure [10].

Competitive swimmers are particularly at risk of ETW due to prolonged exposure to chlorinated pool water [2, 11]. While chlorination is essential for pathogen control, dissolved chlorine can alter water pH, potentially lowering it to decalcifying levels if not properly buffered [1, 2, 12]. Chlorine gas in pools reacts with water to form hypochlorous acid (HOCl), the primary germicidal agent, and hydrochloric acid (HCl) as a byproduct [1]. The World Health Organization recommends maintaining pool water pH between 7.2 and 7.8, but these levels are not always achieved. Enamel dissolution is influenced both by solution pH and the mineral content of enamel (calcium, phosphate, fluoride), with critical pH thresholds reported to begin around 6.5 [13].

Swimmers commonly experience dental staining from pool disinfectants and enamel erosion due to acidic exposure (pH 2.8–4.5), which dissolves hydroxyapatite crystals and releases calcium ions [2]. High consumption of acidic beverages by athletes may further exacerbate the risk of ETW [14].

This study aims to evaluate the protective efficacy of high-concentration fluoride products and remineralizing agents (F-APC) against erosive dental lesions in competitive swimmers using an in vitro model.

Materials and Methods

Sample collection

A total of 85 human permanent teeth were initially collected from individuals aged 18–30 undergoing extractions for orthodontic purposes at the Section of Stomatology, DISCO Department, Polytechnic University of Marche, Ancona, Italy. All procedures adhered to the 1964 Declaration of Helsinki and local ethical guidelines, with informed consent obtained for the use of extracted teeth in research.

Teeth included maxillary and mandibular central incisors, canines, premolars, and molars. Teeth with caries, fractures, restorations, or other pathological conditions were excluded. After screening, 48 teeth were selected and randomly divided into three groups of 16 teeth each.

Prior to the experiment, teeth were carefully cleaned to remove tartar and soft tissue using scalers, low-intensity ultrasonic tools, and a micromotor with yellow gum to minimize surface damage. The cleaned teeth were stored in physiological saline. Baseline assessment was performed by drying the teeth with an air-water syringe, and surfaces were classified according to the Basic Erosive Wear Examination (BEWE) index **(Table 1)** [15].

Table 1. Basic Erosive Wear Examination (BEWE) [16].

Score	Description
0	No erosive tooth wear (no surface loss)
1	Initial loss of enamel surface texture
2[a]	Distinct defect, hard tissue loss (dentine) <50% of the surface area
3[a]	Hard tissue loss >50% of the surface area

[a] in scores 2 and 3, dentine often is involved.

Exposure to chlorinated water

Following the initial baseline assessment (T0), the 48 teeth were allocated into three experimental groups and subjected to daily immersion in chlorinated water to simulate the typical exposure experienced by competitive swimmers. Over a period of 31 days, teeth were immersed for 4 hours per day, five days per week, resulting in a cumulative immersion time of 95 hours. The chlorinated water, sourced from a swimming pool in Vicenza, Italy, was replaced every two days to maintain consistent chemical parameters. The pH was monitored daily using litmus paper, generally maintained at 6.0, with four days reaching a lower pH of 5.0.

The experimental groups were structured as follows:

Control group (G1): Each tooth was positioned on a custom-made Splintline resin base to maintain uniform placement within the container. Teeth were half-submerged to allow comparison between exposed and non-exposed surfaces. Following the 4-hour immersion, teeth were rinsed and stored in a physiological saline solution supplemented with bicarbonate to simulate oral conditions. The pH of this solution was maintained at 7.0 and checked daily.

Remineralizing product group (G2): Teeth were fully immersed in chlorinated water for 4 hours. After rinsing, one half of the enamel surface was treated with Curasept Bioenamel Shock Action Mousse Caries Abrasion and Erosion (Curasept S.p.A., Saronno, VA, Italy), containing 1,450 ppm fluoride and Amorphous Calcium Phosphate (ACP). The mousse was applied according to the manufacturer's protocol: 2 minutes daily and 4 minutes once weekly. Treated teeth were then stored in a saline-bicarbonate solution at pH 7.0 to replicate the oral environment.

High-concentration fluoride group (G3): Teeth were fully immersed for 4 hours in chlorinated water. After rinsing, one half of each tooth surface was treated with Elmex® Dental Gel (Colgate-Palmolive Company,

New York, NY, USA), containing 12,500 ppm fluoride, for 5 minutes. Teeth were then rinsed to remove residual gel and stored in saline-bicarbonate solution at pH 7.0.

Statistical analysis

All data analyses were conducted using SPSS Statistics version 29.0.2.0. Descriptive statistics and frequency distributions were computed for the ETW indices. Comparisons between treated and untreated surfaces were performed using the Wilcoxon signed-rank test.

Results and Discussion

The BEWE scores for tooth surfaces at each time point—T1 (week 1), T2 (week 2), T3 (week 3), and T4 (week 4)—are summarized in **Tables 2–5**.

Table 2. BEWE classifications of teeth surfaces included in the study at T1 (1 week) divided by treatment groups.

G1		Immersed Surfaces	G2		Treated Surfaces	G3		Treated Surfaces
1	0	0	1	0	0	1	0	0
2	0	0	2	0	0	2	0	0
3	0	0	3	0	0	3	0	0
4	0	0	4	0	0	4	0	0
5	0	0	5	0	0	5	0	0
6	0	0	6	0	0	6	0	0
7	0	0	7	0	0	7	0	0
8	0	0	8	0	0	8	0	0
9	0	0	9	0	0	9	0	0
10	0	0	10	0	0	10	0	0
11	0	0	11	0	0	11	0	0
12	0	0	12	0	0	12	0	0
13	0	0	13	0	0	13	0	0
14	0	0	14	0	0	14	0	0
15	0	0	15	0	0	15	0	0
16	0	0	16	0	0	16	0	0

Table 3. BEWE classifications of teeth surfaces included in the study at T2 (2 weeks) divided by treatment groups.

G1		Immersed Surfaces	G2		Treated Surfaces	G3		Treated Surfaces
1	0	1	1	0	0	1	0	1
2	0	0	2	0	0	2	0	0
3	0	0	3	0	0	3	0	0
4	0	0	4	0	0	4	0	0
5	0	0	5	1	0	5	0	0
6	0	0	6	0	0	6	0	0
7	0	0	7	0	0	7	0	0
8	0	0	8	0	0	8	0	0
9	0	0	9	0	0	9	0	0
10	0	0	10	0	0	10	0	0
11	0	0	11	0	0	11	0	0
12	0	0	12	0	0	12	0	0
13	0	0	13	0	0	13	0	0
14	0	0	14	0	0	14	0	0
15	0	1	15	0	0	15	0	1
16	0	0	16	0	0	16	0	0

Table 4. BEWE classifications of teeth surfaces included in the study at T3 (3 weeks) divided by treatment groups.

G1		Immersed Surfaces	G2		Treated Surfaces	G3		Treated Surfaces
1	0	1	1	0	0	1	0	1
2	0	0	2	0	0	2	0	0
3	0	0	3	0	0	3	0	0
4	0	0	4	0	0	4	0	0
5	0	0	5	1	0	5	0	0
6	0	0	6	0	0	6	0	0
7	0	0	7	0	0	7	0	0
8	0	0	8	0	0	8	0	0
9	0	0	9	0	0	9	0	0
10	0	0	10	0	0	10	0	0
11	0	0	11	0	0	11	0	0
12	0	0	12	0	0	12	0	0
13	0	0	13	0	0	13	0	0
14	0	0	14	0	0	14	0	0
15	0	1	15	0	0	15	0	1
16	0	0	16	0	0	16	0	0

Table 5. BEWE classifications of teeth surfaces included in the study at T4 (4 weeks) divided by treatment groups.

G1		Immersed Surfaces	G2		Treated Surfaces	G3		Treated Surfaces
1	0	1	1	0	0	1	0	1
2	0	1	2	0	0	2	0	1
3	0	0	3	0	0	3	0	0

4	0	0	4	0	0	4	0	0
5	0	0	5	1	0	5	0	0
6	0	0	6	1	0	6	0	0
7	0	1	7	0	0	7	0	1
8	0	1	8	0	0	8	0	1
9	0	0	9	0	0	9	0	0
10	0	1	10	0	0	10	0	1
11	0	1	11	0	0	11	0	1
12	0	0	12	0	0	12	0	0
13	0	1	13	1	0	13	0	1
14	0	1	14	0	0	14	0	1
15	0	0	15	0	0	15	0	0
16	0	0	16	0	0	16	0	0

As illustrated in **Figure 1**, teeth in the control group (G1) began to exhibit notable signs of dental erosion on submerged enamel surfaces starting from week 3 (T3) ($p = 0.019$), while the non-submerged portions remained unchanged. By week 4 (T4), the number of eroded surfaces in the submerged teeth had further increased, showing a highly significant difference ($p = 0.0007$).

In the fluoride-treated group (G2) **(Figure 2)**, enamel surfaces exposed to high-concentration fluoride exhibited substantially lower erosion scores compared to G1. At T4, the fluoride-treated areas remained free of erosion, whereas the untreated portions developed erosion in three teeth, yielding a statistically significant difference ($p = 0.039$).

Similarly, the remineralization product-treated group (G3) **(Figure 3)** demonstrated protective effects. Surfaces treated with the F-APC remineralizing mousse showed no evidence of erosion, while untreated surfaces displayed enamel loss in four teeth. This difference was statistically significant at T4 ($p = 0.019$).

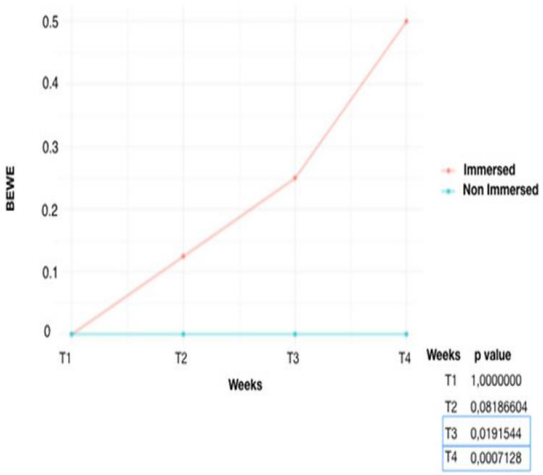

Figure 1. Average BEWE score over time, G1 (control group): comparison of immersed and non-immersed surfaces.

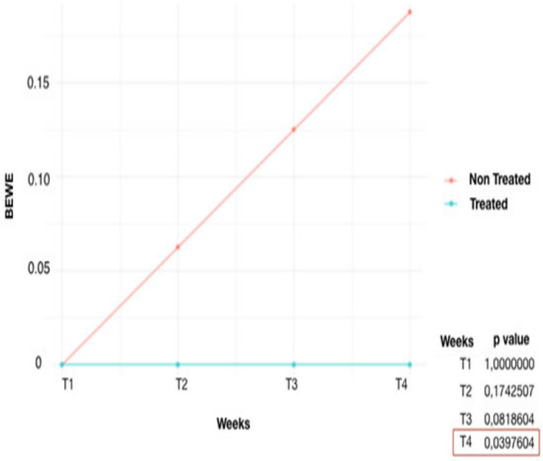

Figure 2. Average BEWE score over time, G2 (fluoride-treated group): comparison of treated and non-treated teeth.

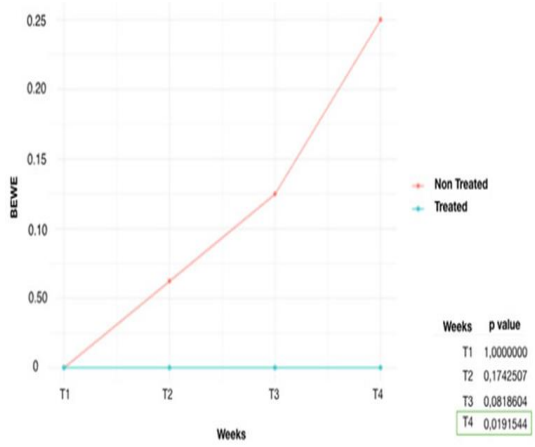

Figure 3. Average BEWE score over time, G3 (remineralization product-treated group): comparison of treated and non-treated teeth.

Swimming is recognized as a sport with a high risk of erosive tooth wear (ETW), largely due to decreased pH levels in chlorinated pool water [11]. This in vitro study investigated the impact of prolonged exposure to chlorinated water on enamel surfaces and assessed the protective effects of both high-concentration fluoride products and remineralizing agents (F-APC).

The anti-demineralization properties of fluoride, the active component in Elmex® Dental Gel, are well established. Fluoride contributes to the formation of fluorapatite, a less soluble and more acid-resistant mineral than hydroxyapatite, and can also inhibit acidogenic activity from oral bacteria. Similarly, synthetic hydroxyapatite and its derivatives, such as the F-ACP complex in Curasept Bioenamel Shock Action Mousse, promote enamel remineralization by delivering calcium, phosphate, and fluoride ions to areas of mineral loss, forming a protective interface that restores enamel integrity [17, 18].

Distinct outcomes were observed among the experimental groups. In the control group, no enamel changes were detected after the first week (T1), suggesting that short-term exposure alone does not induce ETW. Minor erosive changes appeared by week 2 (T2) in two teeth, progressing to four teeth at week 3 (T3), and affecting eight teeth by week 4 (T4). These results align with previous findings indicating that both the duration and intensity of swimming correlate with ETW prevalence; swimmers training less than 2 hours per day had ~20% ETW, while those exceeding 4 hours daily exhibited up to 92% [19]. Longer durations of competitive swimming are also associated with increased enamel damage.

In the fluoride-treated group, weekly application of high-concentration fluoride prevented ETW on the treated surfaces throughout the study period. Untreated surfaces displayed minor erosion at T2 (one tooth), T3 (two teeth), and T4 (three teeth). The protective effect of fluoride is attributed to its ability to form a stable calcium fluoride layer, which deposits evenly across the enamel surface and provides prolonged resistance to acid attacks [20–22].

The remineralizing product-treated group showed similar trends. Treated enamel surfaces remained intact, while untreated surfaces exhibited minor erosion at T2 (one tooth), T3 (two teeth), and T4 (four teeth). This protective effect is likely due to daily application of the remineralizing mousse, which enhances the local mineral content and facilitates passive deposition onto adjacent, untreated enamel surfaces [23, 24].

These findings confirm that chlorinated pool water poses a risk for enamel erosion when the pH drops below critical levels. Preventive measures, including regular dental check-ups and the application of fluoride or remineralizing agents, are essential for mitigating ETW in competitive swimmers. Education of athletes and coaches on oral health maintenance is also critical, as adherence to preventive strategies is often inconsistent [25, 26]. Future research could expand this investigation in vivo, utilizing split-mouth designs to compare preventive and therapeutic effects of remineralizing agents across different swimming pools with varying chlorination levels. Such studies could help establish standardized protocols for the prevention and management of ETW in this population.

Conclusion

Chlorinated swimming pool water can induce tooth erosion when pH levels reach critical thresholds. The duration of exposure significantly influences enamel damage. Application of high-concentration fluoride products once weekly for 5 minutes effectively prevents ETW. Similarly, remineralizing agents such as F-APC, applied daily for 2 minutes and weekly for 4 minutes, provide significant protection against enamel erosion in competitive swimmers.

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References

1. Buczkowska-Radlińska J, Łagocka R, Kaczmarek W, Górski M, Nowicka A. Prevalence of dental erosion in adolescent competitive swimmers exposed to gas-chlorinated swimming pool water. Clin Oral Investig. 2013;17(2):579–83.
2. Abdelrahman HH, Ammar N, Hassan MG, Essam W, Amer H. Erosive tooth wear and salivary parameters among competitive swimmers and non-swimmers in Egypt: A cross-sectional study. Clin Oral Investig. 2023;27(10):7777–85.
3. Carvalho TS, Colon P, Ganss C, Huysmans MC, Lussi A, Schlueter N, et al. Consensus report of the European Federation of Conservative Dentistry: Erosive tooth wear—Diagnosis and management. Clin Oral Investig. 2015;19(7):1557–61.
4. Johansson AK, Omar R, Gunnar E, Carlsson GE, Johansson A. Dental erosion and its growing

importance in clinical practice: From past to present. Int J Dent. 2012;2012:632907.
5. Lussi A, Schlueter N, Rakhmatullina E, Ganss C. Dental erosion—An overview with emphasis on chemical and histopathological aspects. Caries Res. 2011;45(1):2–12.
6. Lussi A, Jaeggi T. Erosion—Diagnosis and risk factors. Clin Oral Investig. 2008;12(Suppl 1):5–13.
7. Yanushevich OO, Maev IV, Krikheli NI, Andreev DN, Lyamina SV, Sokolov FS, et al. Prevalence and risk of dental erosion in patients with gastroesophageal reflux disease: A meta-analysis. Dent J. 2022;10(6):126.
8. Otsu M, Hamura A, Ishikawa Y, Karibe H, Ichijyo T, Yoshinaga Y. Factors affecting the dental erosion severity of patients with eating disorders. Biopsychosoc Med. 2014;8(1):25.
9. Hemalatha VT, Manigandan T, Sarumathi T, Aarthi Nisha V, Amudhan A. Dental considerations in pregnancy—A critical review on the oral care. J Clin Diagn Res. 2013;7(5):948–53.
10. Nijakowski K, Zdrojewski J, Nowak M, Podgórski F, Surdacka A. Regular physical activity and dental erosion: A systematic review. Appl Sci. 2022;12(3):1099.
11. Puleio F, Di Spirito F, Lo Giudice G, Pantaleo G, Rizzo D, Lo Giudice R. Long-term chromatic durability of white spot lesions through employment of infiltration resin treatment. Medicina (Kaunas). 2023;59(4):749.
12. Zebrauskas A, Birskute R, Maciulskiene V. Prevalence of dental erosion among the young regular swimmers in Kaunas, Lithuania. J Oral Maxillofac Res. 2014;5(2):e6.
13. Salem MN, Hafez S. Aesthetic management of erosive tooth wear in a young Egyptian swimmer: A case report. Clin Cosmet Investig Dent. 2021;13:201–9.
14. Sirimaharaj V, Brearley Messer L, Morgan MV. Acidic diet and dental erosion among athletes. Aust Dent J. 2002;47(3):228–36.
15. Bartlett D, Ganss C, Lussi A. Basic erosive wear examination (BEWE): A new scoring system for scientific and clinical needs. Clin Oral Investig. 2008;12(Suppl 1):S65–8.
16. A plea for the development of an universally accepted modular tooth wear evaluation system—Scientific figure on ResearchGate [Internet]. Available from: https://www.researchgate.net/figure/Basic-Erosive-Wear-Examination-BEWE-8_tbl3_309693771
17. Degli Esposti L, Ionescu AC, Brambilla E, Tampieri A, Iafisco M. Characterization of a toothpaste containing bioactive hydroxyapatites and in vitro evaluation of its efficacy to remineralize enamel and to occlude dentinal tubules. Materials (Basel). 2020;13(13):2928.
18. Sathish AK, Gopalkrishna P, Kumar S. In vitro evaluation of remineralizing agents on dentinal tubule occlusion: A scanning electron microscopic study. J Indian Soc Periodontol. 2023;27(4):362–7.
19. Baghele ON, Majumdar IA, Thorat MS, Nawar R, Baghele MO, Makkad S. Prevalence of dental erosion among young competitive swimmers: A pilot study. Compend Contin Educ Dent. 2013;34(6):e20–4.
20. Monterubbianesi R, Sparabombe S, Tosco V, Profili F, Mascitti M, Hosein A, et al. Can desensitizing toothpastes also have an effect on gingival inflammation? A double-blind, three-treatment crossover clinical trial. Int J Environ Res Public Health. 2020;17(24):8927.
21. Wiegand A, Bichsel D, Magalhães AC, Becker K, Attin T. Effect of sodium, amine and stannous fluoride at the same concentration and different pH on in vitro erosion. J Dent. 2009;37(7):591–5.
22. Mazzoleni S, Gargani A, Parcianello RG, Pezzato L, Bertolini R, Zuccon A, et al. Protection against dental erosion and the remineralization capacity of non-fluoride toothpaste, fluoride toothpaste and fluoride varnish. Appl Sci. 2023;13(3):1849.
23. Tosco V, Vitiello F, Monterubbianesi R, Gatto ML, Orilisi G, Mengucci P, et al. Assessment of the remineralizing potential of biomimetic materials on early artificial caries lesions after 28 days: An in vitro study. Bioengineering (Basel). 2023;10(4):462.
24. Ludovichetti FS, Zambon G, Cimolai M, Gallo M, Signoriello AG, Pezzato L, et al. Efficacy of two toothpastes in preventing tooth erosive lesions associated with gastroesophageal reflux disease. Appl Sci. 2022;12(2):1023.
25. Cardoso F, Monteiro AS, Fernandes A, Vilas-Boas JP, Pinho JC, Pyne D, et al. Oral health in young elite swimmers. Trends Sport Sci. 2020;27(1):49–55.
26. Engineer S, Tamgadge S, Rijhwani N, Choudhary N, Shukla G. Awareness of dental health in competitive and recreational swimmers: A comparative survey-based study. J Datta Meghe Inst Med Sci Univ. 2022;17(1):51–8.