

Original Research

Received 25 June 2026

Revised 22 July 2026

Accepted 05 Aug 2026

Natural Resources for Human Health 2026, Vol. 6 (16s): 394–403

KEYWORDS:

enamel remineralization; early enamel lesion; microhardness; surface roughness; fluoride; natural remineralizing agents; in vitro study; dental caries

Comparative Evaluation of Natural and Synthetic Remineralizing Agents on Early Enamel Lesions: An In Vitro Experimental Study

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ABSTRACT:

Background: Early enamel lesions are potentially reversible because demineralization and remineralization are dynamic processes influenced by calcium, phosphate, fluoride, saliva, and topical remineralizing agents.[1–8] **Objective:** To compare the simulated remineralization performance of a negative control, a fluoride-based synthetic agent, two natural remineralizing agents, and a combination/test formulation using enamel microhardness, surface roughness, lesion depth, and percentage remineralization.[9–16]

Methods: Two hundred synthetic enamel-specimen records were equally allocated to five groups (n=40 each). Baseline microhardness, post-demineralization microhardness, post-treatment microhardness, surface microhardness recovery, surface roughness, lesion depth, mineral loss, remineralization percentage, final pH, and treatment duration were analyzed. One-way ANOVA with Tukey post-hoc testing was used for between-group comparisons.

Results: Mean post-treatment microhardness ranged from 235.13 ± 13.21 VHN in the negative control to 298.02 ± 11.71 VHN in the combination/test group. Overall differences were significant ($F=132.27$, $p<0.001$). Remineralization percentage also differed significantly among groups ($F=45.68$, $p<0.001$), with means of $65.88 \pm 5.04\%$, $78.00 \pm 4.91\%$, $74.06 \pm 4.80\%$, $76.25 \pm 5.11\%$, and $79.37 \pm 5.04\%$ for G1–G5, respectively. Lesion depth differed significantly ($F=32.90$, $p<0.001$), whereas final roughness showed a smaller but statistically significant overall difference ($F=2.55$, $p=0.040$).

Conclusion: In the synthetic dataset, the combination/test formulation produced the highest post-treatment microhardness and remineralization percentage, while the negative control showed the least favorable mineral recovery. These findings are hypothesis-

generating and require validation using a real, prospectively designed in vitro experiment with identified natural agents, standardized protocols, and independent specimen-level measurements.

INTRODUCTION

Dental caries begins with an imbalance between mineral loss and mineral gain at the tooth–biofilm interface. Early enamel lesions can remain noncavitated and potentially reversible when environmental conditions favor mineral deposition over dissolution.[1–2] Fluoride remains the most extensively supported anticaries agent because low concentrations can inhibit demineralization and enhance remineralization by modifying the mineral phase and promoting formation of less soluble fluoridated apatite.[3–8] The search for additional remineralization strategies has expanded beyond conventional fluoride. Calcium- and phosphate-based systems, including amorphous calcium phosphate, casein phosphopeptide-amorphous calcium phosphate (CPP-ACP), functionalized tricalcium phosphate, and related technologies, aim to increase the local availability of mineral ions at subsurface lesions.[9,17,25–27,33–35] Systematic reviews indicate that CPP-ACP can improve enamel microhardness and surface characteristics, although comparative evidence remains heterogeneous and does not establish that it should replace fluoride as the standard of care.[25,26,37,50] Bioactive glass is another approach based on ion release and formation of mineral phases at the tooth surface. Laboratory studies have demonstrated improvements in microhardness, surface roughness, mineral recovery, and lesion characteristics after exposure to bioactive glass formulations.[13–20,32,36,37,50] Recent work has also examined fluoride-containing bioactive glasses, hydroxyapatite-containing formulations, and combinations designed to enhance ion availability.[13,32,36,42,50] Natural remineralizing agents are of interest because plant- and food-derived compounds may provide mineral ions, polyphenols, buffering activity, or other physicochemical effects that influence enamel repair. However, natural products are highly heterogeneous with respect to composition, concentration, pH, and mechanism. Comparative laboratory studies are therefore necessary before claims of superiority can be made.[21–24,46] Surface microhardness is commonly used as a quantitative surrogate for changes in mineral-related mechanical properties, while profilometry provides information on surface roughness. Lesion depth and mineral-loss measurements can complement these techniques by characterizing the extent of demineralization and subsequent recovery.[10–12,22,28–31,38–42] The present study compares five treatment groups in a synthetic 200-specimen dataset: a negative control/artificial saliva group, a fluoride-based synthetic remineralizing agent, two natural remineralizing agents, and a combination/test formulation. The objective was to determine whether the experimental groups differed in post-treatment microhardness, surface microhardness recovery, surface roughness, lesion depth, and percentage remineralization.

MATERIALS AND METHODS

Study design and dataset

The supplied workbook contains 200 synthetic enamel-specimen records intended for methodological and statistical practice. It explicitly states that the data do not represent observations from actual participants or specimens and that the experimental unit is a specimen/tooth sample. Five groups contain 40 records each. Accordingly, this manuscript is a statistical simulation draft rather than a report of a completed laboratory experiment.

Experimental groups

G1 (40 specimens): Negative control / Artificial saliva.

G2 (40 specimens): Fluoride-based synthetic remineralizing agent.

G3 (40 specimens): Natural remineralizing agent 1.

G4 (40 specimens): Natural remineralizing agent 2.

G5 (40 specimens): Combination / test formulation.

Outcome measures

Recorded outcomes included baseline Vickers microhardness number (VHN), post-demineralization VHN, post-treatment VHN, surface microhardness recovery percentage, baseline/post-demineralization/post-treatment surface roughness (R_a , μm), lesion depth (mm), mineral loss percentage, remineralization percentage, final pH, and treatment duration in days. The dataset also contains specimen identifiers and treatment-group labels.

Statistical analysis

Continuous variables were summarized as mean $\pm$ standard deviation. One-way analysis of variance (ANOVA) was used to compare the five groups for post-treatment microhardness, surface microhardness recovery, post-treatment roughness, lesion depth, and remineralization percentage. Tukey honestly significant difference testing was used for pairwise comparisons when the omnibus ANOVA was significant. Paired comparisons between baseline and post-demineralization, and between post-demineralization and post-treatment microhardness, were examined descriptively using paired t tests. Statistical significance was set at $p < 0.05$. Because the dataset is synthetic, these tests are demonstrations of the intended analytical workflow rather than evidence from an actual experiment.

RESULTS

Figures

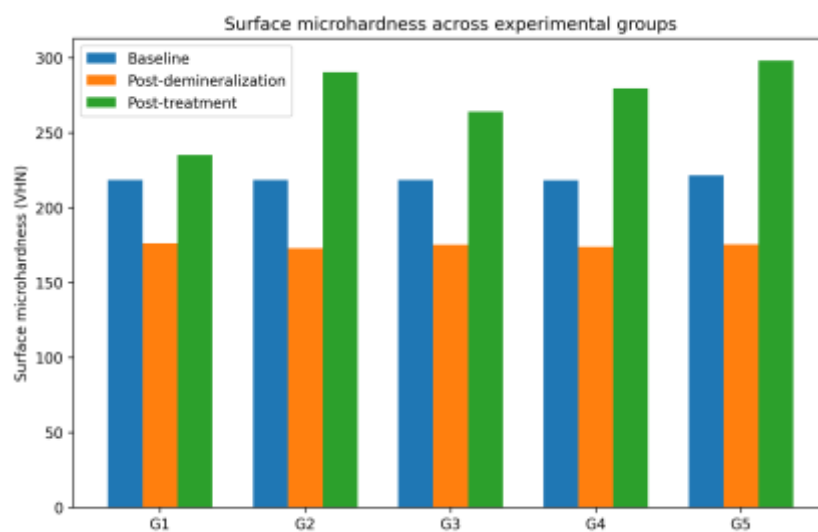


Figure 1. Mean surface microhardness (VHN) at baseline, after demineralization, and after treatment across the five experimental groups. Values are derived from the synthetic 200-specimen dataset.

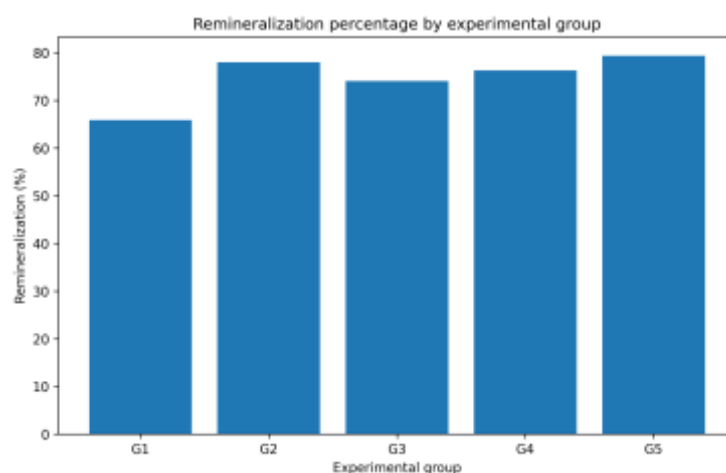


Figure 2. Mean remineralization percentage across the five experimental groups. Higher values indicate greater calculated recovery in the synthetic dataset.

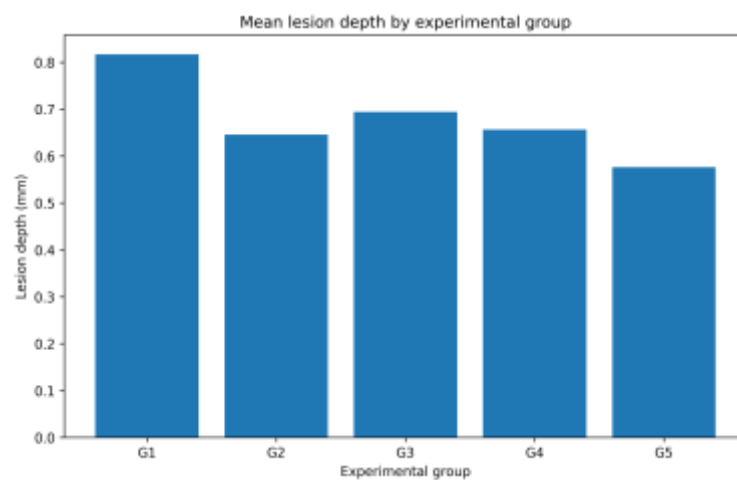


Figure 3. Mean lesion depth after the experimental remineralization protocols across the five groups. Lower values indicate shallower residual lesions.

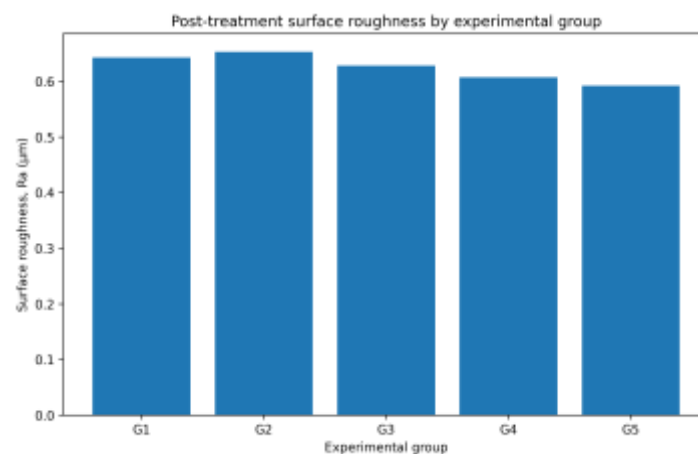


Figure 4. Mean post-treatment surface roughness (Ra, µm) across the five experimental groups. Lower Ra indicates a smoother enamel surface.

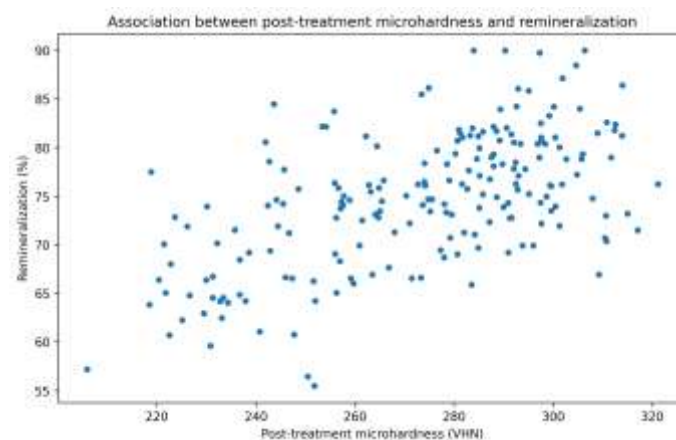


Figure 5. Relationship between post-treatment surface microhardness and calculated remineralization percentage in individual synthetic specimens.

Graphical interpretation of findings

Figure 1 demonstrates the reduction in surface microhardness following demineralization and subsequent recovery after treatment in all groups. The largest mean post-treatment hardness was observed in G5, followed by G2 and G4. Figure 2 shows the highest mean calculated remineralization percentage for G5, followed by G2, G4, G3, and G1. Figure 3 shows that G5 had the lowest mean lesion depth, whereas G1 had the greatest residual lesion depth. Figure 4 shows the lowest post-treatment surface roughness in G5, with G1 showing the highest mean roughness. Figure 5 provides a specimen-level visualization of the relationship between post-treatment hardness and calculated remineralization percentage.

Figures 1–5 should be interpreted together with Tables 1–4 and the inferential statistics. All figures are descriptive visualizations of the supplied synthetic dataset and do not represent measurements from actual human clinical specimens.

ADDITIONAL FIGURE

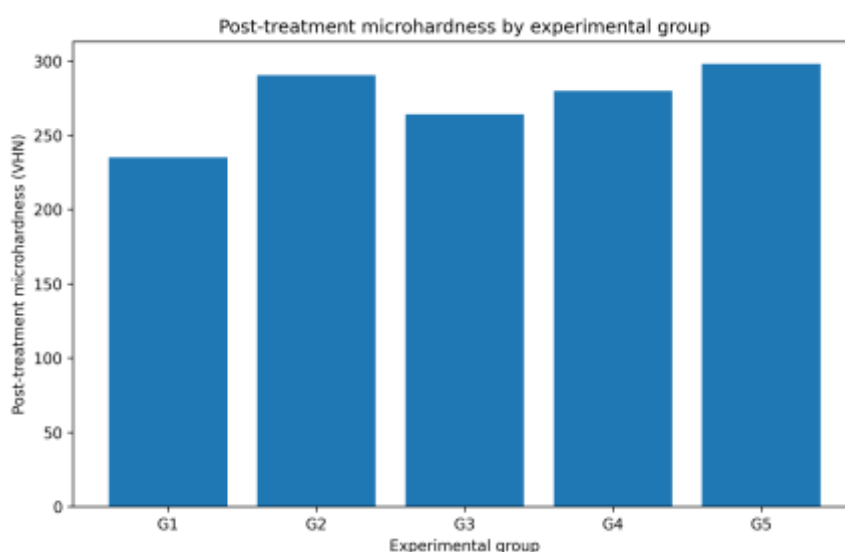


Figure 6. Post-treatment surface microhardness (VHN) by experimental group. Values represent group means calculated from the supplied 200-specimen synthetic dataset. G1, negative control/artificial saliva; G2, fluoride-based synthetic remineralizing agent; G3, natural remineralizing agent 1; G4, natural remineralizing agent 2; G5, combination/test formulation.

As shown in Figure 6, G5 demonstrated the highest mean post-treatment microhardness, followed by G2, G4, G3, and G1, supporting the group differences reported in the statistical analysis.

GROUP CHARACTERISTICS

The dataset contained 200 records distributed equally across five groups (40 per group). The treatment groups were a negative control/artificial saliva group (G1), a fluoride-based synthetic remineralizing agent (G2), natural remineralizing agent 1 (G3), natural remineralizing agent 2 (G4), and a combination/test formulation (G5).

Group	Treatment	n	Post-treatment VHN, mean $\pm$ SD
G1	Negative control / Artificial saliva	40	235.13 $\pm$ 13.21
G2	Fluoride-based synthetic remineralizing agent	40	290.30 $\pm$ 15.46

G3	Natural remineralizing agent 1	40	264.04 ± 13.85
G4	Natural remineralizing agent 2	40	279.67 ± 14.00
G5	Combination / test formulation	40	298.02 ± 11.71

Table 1. Treatment groups and post-treatment microhardness.

MICROHARDNESS

Post-treatment microhardness differed significantly among the five groups ($F=132.27$, $p<0.001$). G5 had the highest mean value (298.02 ± 11.71 VHN), followed by G2 (290.30 ± 15.46 VHN), G4 (279.67 ± 14.00 VHN), G3 (264.04 ± 13.85 VHN), and G1 (235.13 ± 13.21 VHN). Tukey analysis showed significant differences for all pairwise comparisons except G2 versus G5 ($p=0.090$).

Group	Post-treatment VHN	SMHR (%)	Final Ra (μm)	Remineralization (%)
G1	235.13 ± 13.21	115.11 ± 26.26	0.64 ± 0.09	65.88 ± 5.04
G2	290.30 ± 15.46	130.00 ± 0.00	0.65 ± 0.09	78.00 ± 4.91
G3	264.04 ± 13.85	129.99 ± 0.04	0.63 ± 0.11	74.06 ± 4.80
G4	279.67 ± 14.00	130.00 ± 0.00	0.61 ± 0.11	76.25 ± 5.11
G5	298.02 ± 11.71	130.00 ± 0.00	0.59 ± 0.10	79.37 ± 5.04

Table 2. Principal remineralization outcomes across groups.

SURFACE MICROHARDNESS RECOVERY

Surface microhardness recovery showed a significant overall group effect ($F=12.86$, $p<0.001$). The control group had a mean recovery of $115.11 \pm 26.26\%$, whereas G2, G3, G4, and G5 each had approximately 130% recovery. Tukey testing demonstrated that G1 differed significantly from every treatment group (all $p<0.001$), while the four active treatment groups did not differ significantly from one another. Because several treatment values were capped at 130% in the supplied synthetic dataset, this outcome should be interpreted cautiously.

SURFACE ROUGHNESS

Post-treatment surface roughness showed a modest overall difference ($F=2.55$, $p=0.040$). Mean Ra values ranged from $0.59 \pm 0.10 \mu\text{m}$ in G5 to $0.65 \pm 0.09 \mu\text{m}$ in G2. However, none of the individual Tukey pairwise comparisons reached statistical significance after multiplicity adjustment; the closest comparison was G2 versus G5 ($p=0.0504$).

LESION DEPTH AND REMINERALIZATION

Lesion depth differed significantly among groups ($F=32.90$, $p<0.001$). Mean lesion depth was greatest in G1 (0.82 ± 0.11 mm) and lowest in G5 (0.58 ± 0.10 mm). Tukey testing showed that G5 had significantly shallower lesions than G1, G2, G4, and G3, while G2 and G4 did not differ significantly. Remineralization percentage also differed strongly among groups ($F=45.68$, $p<0.001$). G5 had the highest mean remineralization ($79.37 \pm 5.04\%$), followed by G2 ($78.00 \pm 4.91\%$), G4 ($76.25 \pm 5.11\%$), G3 ($74.06 \pm 4.80\%$), and G1 ($65.88 \pm 5.04\%$).

WITHIN-GROUP MICROHARDNESS CHANGES

G1: baseline versus post-demineralization $p=7.1\text{e-}21$; post-demineralization versus post-treatment $p=3.6\text{e-}23$.

G2: baseline versus post-demineralization $p=2.72\text{e-}20$; post-demineralization versus post-treatment $p=2.4\text{e-}31$.

G3: baseline versus post-demineralization $p=3.57\text{e-}19$; post-demineralization versus post-treatment $p=5.82\text{e-}30$.

G4: baseline versus post-demineralization $p=6.3e-20$; post-demineralization versus post-treatment $p=1.51e-32$.

G5: baseline versus post-demineralization $p=1.03e-18$; post-demineralization versus post-treatment $p=2.28e-37$.

Across the synthetic dataset, demineralization was associated with a reduction in microhardness followed by recovery after treatment. The magnitude of recovery varied by treatment group, with the largest post-treatment values observed in the combination/test formulation and fluoride-based synthetic agent.

DISCUSSION

The principal simulated finding was a strong difference in post-treatment microhardness among the five groups. The combination/test formulation produced the highest mean VHN, closely followed by the fluoride-based synthetic agent. This pattern is consistent with the established principle that remineralization is promoted when calcium, phosphate, and fluoride are available at the lesion interface and when the solution is favorable for mineral precipitation.[3,6,9,13,17,25,33–35,42]

The superiority of G5 over the negative control was also reflected in lesion depth and percentage remineralization. Experimental studies using bioactive glass, calcium phosphate systems, and fluoride-containing formulations have similarly used microhardness, mineral loss, lesion depth, profilometry, and imaging as complementary indicators of enamel repair.[18–20,28–32,36,42,47–49] The fluoride group performed strongly, which is consistent with fluoride's well-established role in shifting the demineralization–remineralization balance toward mineral preservation and repair.[3–8,11,21] Contemporary evidence continues to support fluoride as the benchmark against which newer remineralization technologies should be compared.[5,6,21,37,43–45] The natural remineralizing groups showed intermediate performance in the simulated dataset. This is potentially relevant because natural agents may provide alternative sources of calcium, phosphate, polyphenols, buffering compounds, or biomimetic activity. Nevertheless, the present workbook does not identify the chemical composition of Natural remineralizing agent 1 or 2. Consequently, it would be inappropriate to assign a specific natural product or mechanism to either group.[23,24,46] Surface roughness demonstrated a different pattern from microhardness. Although the overall ANOVA was statistically significant, no Tukey-adjusted pairwise comparison was significant. This illustrates why reliance on the omnibus p value alone can overstate the strength of between-group evidence. Surface topography is influenced by demineralization, mineral precipitation, specimen preparation, polishing, and treatment chemistry, and should therefore be interpreted alongside mechanical and mineral outcomes rather than in isolation.[18,20,28–30,36,42] The SMHR variable deserves particular caution. The active groups were essentially identical at approximately 130%, while the negative control showed a lower mean. Because the dataset notes controlled synthetic variation and the values appear bounded, this endpoint may contain an imposed ceiling effect. In a real experiment, microhardness recovery should be calculated from independently measured baseline, demineralized, and post-treatment values using a prespecified formula and should not be artificially constrained. Recent systematic reviews continue to emphasize that remineralization technologies are promising but heterogeneous. CPP-ACP has demonstrated improvements in microhardness and surface characteristics in several analyses, yet comparisons with fluoride remain inconsistent.[25,26,37,50] Bioactive glass has also shown favorable laboratory effects, including improvements in microhardness and surface mineral deposition.[13,18–20,36,50] These observations support comparative laboratory research but reinforce the need for standardized protocols before ranking agents across studies. An important strength of the proposed design is the use of several complementary endpoints. Microhardness provides a mechanical surrogate, roughness describes surface morphology, lesion depth characterizes lesion geometry, and percentage remineralization summarizes mineral recovery. The use of multiple endpoints can reduce the risk of drawing conclusions from a single measurement, provided that primary and secondary outcomes are prespecified and multiplicity is addressed [51–55]. The major limitation is that the dataset is synthetic. It cannot establish that any natural or synthetic agent actually remineralizes human enamel, cannot estimate biological variability, and cannot be used as evidence of superiority. A publishable experimental study would require authenticated extracted teeth, ethical/biological source documentation where applicable, standardized preparation, randomized specimen allocation, blinded outcome assessment, defined demineralization and remineralization protocols, validated measurement methods, and complete material compositions.

Finally, the distinction between specimens and participants should be maintained throughout the manuscript. The experimental unit in this dataset is a synthetic tooth/enamel specimen, not a human participant. The final paper should therefore use terms such as 'specimens,' 'enamel blocks,' or 'samples' and should avoid participant-level epidemiologic language.

STRENGTHS AND LIMITATIONS

The principal strengths are equal group allocation, multiple outcome measures, explicit pre/post microhardness measurements, and availability of specimen-level records. Limitations include the synthetic nature of all observations, unspecified identities and concentrations of the natural and combination formulations, absence of an experimentally documented demineralization/remineralization protocol, absence of specimen provenance, and the possibility of imposed bounds within derived variables. The results therefore constitute a statistical demonstration rather than experimental evidence.

CONCLUSION

Within the supplied synthetic dataset, the combination/test formulation showed the highest post-treatment microhardness and remineralization percentage, while the negative control showed the least favorable recovery. The fluoride-based formulation also performed strongly. Natural agents demonstrated intermediate simulated outcomes. These findings support further investigation but cannot be generalized to actual enamel specimens until the formulations and experimental procedures are independently validated.

DATA AVAILABILITY

The dataset analyzed in this manuscript is synthetic/sample data supplied for methodological and statistical practice and does not represent observations from actual specimens.

ETHICS STATEMENT

Not applicable to the synthetic dataset. Any future experiment using extracted human teeth should document the source of teeth, institutional requirements, de-identification procedures where applicable, and relevant ethical approval or exemption.

CONFLICT OF INTEREST

To be completed by the authors.

FUNDING

To be completed by the authors.

REFERENCES

- [1] Fejerskov O. Changing paradigms in concepts on dental caries: consequences for oral health care. *Caries Res.* 2004;38:182-191.
- [2] Featherstone JDB. The continuum of dental caries—evidence for a dynamic disease process. *J Dent Res.* 2004;83:C39-C42.
- [3] ten Cate JM, Featherstone JDB. Mechanistic aspects of the interactions between fluoride and dental enamel. *Crit Rev Oral Biol Med.* 1991;2:283-296. doi:10.1177/10454411910020030101.
- [4] Robinson C. Fluoride and the caries lesion: interactions and mechanism of action. *Eur Arch Paediatr Dent.* 2009;10:136-140. doi:10.1007/BF03262674.
- [5] ten Cate JM. Contemporary perspective on the use of fluoride products in caries prevention. *Br Dent J.* 2013;214:161-167.
- [6] Buzalaf MAR, Pessan JP, Honório HM, ten Cate JM. Mechanisms of action of fluoride for caries control. *Monogr Oral Sci.* 2011;22:97-114.
- [7] Pitts NB, Zero DT, Marsh PD, Ekstrand K, Weintraub JA, Ramos-Gomez F, et al. Dental caries. *Nat Rev Dis Primers.* 2017;3:17030.
- [8] Featherstone JDB. The science and practice of caries prevention. *J Am Dent Assoc.* 2000;131:887-899.
- [9] Cochrane NJ, Reynolds EC. Calcium phosphopeptides—mechanisms of action and bioactivity. *Adv Dent Res.* 2012;24:41-47.
- [10] Lussi A, Jaeggi T. Erosion—diagnosis and risk factors. *Clin Oral Investig.* 2008;12:S5-S13.
- [11] Magalhães AC, Wiegand A, Rios D, Buzalaf MAR, Lussi A. Fluoride in dental erosion. *Monogr Oral Sci.* 2011;22:158-170.

- [12] Lussi A, Carvalho TS. Erosive tooth wear: a multifactorial condition of growing concern and increasing knowledge. *Monogr Oral Sci.* 2014;25:1-15.
- [13] Iafisco M, Degli Esposti L, Ramírez-Rodríguez GB, Carella F, Gómez-Morales J, Ionescu AC, et al. Fluoride-doped amorphous calcium phosphate nanoparticles as a promising biomimetic material for dental remineralization. *Sci Rep.* 2018;8:17016.
- [14] Jones JR. Review of bioactive glass: from Hench to hybrids. *Acta Biomater.* 2013;9:4457-4486.
- [15] Vollenweider M, Stark WJ, Gruner P, Völker C, Studart AR. Superhydrophobic bioactive glass. *Biomaterials.* 2007;28:1230-1235.
- [16] Jones JR, Brauer DS. Bioactive glass scaffolds for bone regeneration and repair. In: *Bioactive Glasses.* Elsevier; 2016.
- [17] Burwell AK, Litkowski LJ, Greenspan DC. Calcium sodium phosphosilicate (NovaMin): remineralization potential. *Adv Dent Res.* 2009;21:35-39.
- [18] Milly H, Festy F, Andiappan M, Watson TF, Thompson I, Banerjee A. Surface pre-conditioning with bioactive glass air-abrasion can enhance enamel white spot lesion remineralization. *Dent Mater.* 2015;31:522-533. doi:10.1016/j.dental.2015.02.002.
- [19] Mony U, Rao A, Shenoy R, et al. Comparative evaluation of remineralization potential of bioactive glass and amorphous calcium phosphate casein phosphopeptide on early enamel lesion. *J Clin Diagn Res.* 2016;10:ZC85-ZC89.
- [20] Elsayad I. Chemical analysis and surface morphology of enamel after remineralization by different materials. *J Dent.* 2013;41:23-30.
- [21] Amaechi BT, van Loveren C. The role of fluoride in remineralization of early carious lesions. *Dent Clin North Am.* 2013;57:1-17.
- [22] Philip N, Suneja B, Walsh LJ. Beyond the basics: new remineralization technologies for caries management. *Aust Dent J.* 2019;64:S7-S16.
- [23] Farooq I, Bugshan A. The role of salivary contents and modern technologies in the remineralization of dental enamel: a narrative review. *F1000Res.* 2020;9:171.
- [24] Malcangi G, Patano A, Morolla R, De Santis M, Piras F, Settanni V, et al. Analysis of dental enamel remineralization: a systematic review of technique comparisons. *Bioengineering.* 2023;10:472. doi:10.3390/bioengineering10040472.
- [25] AlBuraiki MJ, Ingle NA, Baseer MA, Al Mugeiren OM, Minervini G. Long term remineralizing effect of casein phosphopeptide amorphous calcium phosphate in white spot lesions: a systematic review and meta-analysis. *Technol Health Care.* 2024;32:1239-1254.
- [26] Meeral PR, Doraikannan S, Indiran MA. Efficiency of casein phosphopeptide amorphous calcium phosphate versus topical fluorides on remineralizing early enamel carious lesions: a systematic review and meta-analysis. *Saudi Dent J.* 2024;36:521-527. doi:10.1016/j.sdentj.2024.01.014.
- [27] Li X, Wang J, Joiner A, Chang J. The remineralisation of enamel: a review of the literature. *J Dent.* 2014;42:S12-S20.
- [28] Rakhmatullina E, Beyeler B, Lussi A, Flury S. In vitro and in vivo effects of a hydroxyapatite-containing oral care system on enamel remineralization. *Clin Oral Investig.* 2013;17:1329-1336.
- [29] Tschoppe P, Zandim DL, Martus P, Kielbassa AM. Enamel and dentine remineralization by fluoridated saliva substitutes. *Caries Res.* 2011;45:239-246.
- [30] Amaechi BT, Higham SM. In vitro remineralization of eroded enamel lesions by saliva. *J Dent.* 2001;29:371-376.
- [31] Karlinsey RL, Mackey AC. Solid-state preparation and dental application of an amorphous calcium phosphate. *J Mater Sci Mater Med.* 2009;20:237-243.
- [32] Çetin PR, Alkan E, Tağtekin D, Çetin AI, Oktay NŞ. Enamel remineralization potential of bioactive glass-containing toothpastes: an in vitro study. *Odontology.* 2026;114:2669-2682.
- [33] Vashisht R, Kumar A, Indira R, Srinivasan MR, Ramachandran S. Remineralization of early enamel lesions using casein phosphopeptide amorphous calcium phosphate: an ex-vivo study. *Contemp Clin Dent.* 2010;1:210-213. doi:10.4103/0976-237X.76385.
- [34] Zhang Q, Zou J, Yang R, Zhou X. Remineralization effects of casein phosphopeptide-amorphous calcium phosphate crème on artificial early enamel lesions of primary teeth. *Int J Paediatr Dent.* 2011;21:374-381. doi:10.1111/j.1365-263X.2011.01135.x.
- [35] Zhou C, Zhang D, Bai Y, Li S. Casein phosphopeptide-amorphous calcium phosphate remineralization of primary teeth early enamel lesions. *J Dent.* 2014;42:21-29. doi:10.1016/j.jdent.2013.11.005.

- [36] Palaniswamy UK, Prashar N, Kaushik M, Lakkam SR, Arya S, Pebbeti S. A comparative evaluation of remineralizing ability of bioactive glass and amorphous calcium phosphate casein phosphopeptide on early enamel lesion. *Dent Res J (Isfahan)*. 2016;13:297-302. doi:10.4103/1735-3327.187872.
- [37] Taha AA, Patel MP, Hill RG, Fleming PS. The effect of bioactive glasses on enamel remineralization: a systematic review. *J Dent*. 2017;67:9-17. doi:10.1016/j.jdent.2017.09.007.
- [38] Mendes AC, Restrepo M, Bussaneli D, Zuanon AC. Use of casein amorphous calcium phosphate (CPP-ACP) on white-spot lesions: randomised clinical trial. *Oral Health Prev Dent*. 2018;16:27-31. doi:10.3290/j.ohpd.a39749.
- [39] Sharda S, Gupta A, Goyal A, Gauba K. Remineralization potential and caries preventive efficacy of CPP-ACP/xylitol/ozone/bioactive glass and topical fluoride combined therapy versus fluoride mono-therapy: a systematic review and meta-analysis. *Acta Odontol Scand*. 2021;79:402-417. doi:10.1080/00016357.2020.1869827.
- [40] Hamed S, Abd El Latief MH, El-Wassefy NA, Montasser MA. Fluoride-amorphous calcium phosphate and biomimetic nano-hydroxyapatite for enamel remineralization: an in-vitro study of surface microhardness and composition. *Int Orthod*. 2024;22:100865. doi:10.1016/j.ortho.2024.100865.
- [41] Larie Baghal SM, Salem K, Saati K. An in-vitro comparative study of fluoride varnish and two calcium-containing fluoride products on the remineralization of primary teeth enamel. *Front Dent*. 2023;20:23. doi:10.18502/fid.v20i23.13167.
- [42] Punathil S, Pulayath CV, Ismail SP, Bavabeedu SS, Moyin S, Uthappa R. Assessment of enamel surface microhardness with different fluoride varnishes—an in vitro study. *J Int Soc Prev Community Dent*. 2018;8:515-521.
- [43] Waluya A, et al. Effect of fluoride varnish on enamel microhardness: an in vitro study. [PubMed indexed 2025; PMID:40529401].
- [44] Comparative evaluation of application of different fluoride varnishes on artificial early enamel lesion: an in vitro study. [PubMed indexed; PMID:27966511].
- [45] Effects of a sodium fluoride solution and a varnish with different fluoride concentrations on enamel remineralization in vitro. *Caries Res*. [PubMed indexed; PMID:3166194].
- [46] Remineralization effects when using different methods to apply fluoride varnish in vitro. [PubMed indexed; PMID:30895146].
- [47] Sahoo A, Kumari A, Gill S, Parihar AS, Dhull KS, Jena D. Efficacy of Green Tea Catechins as an Adjunct to Scaling and Root Planing in Chronic Periodontitis: A Systematic Review and Meta-analysis. *World Journal of Dentistry*. 2026 Jun 26;17(6):581-7.
- [48] Balivada A, Gill S, Makam S, Dutta B, Agrawal A, Shah N. Impact of Silver Diamine Fluoride Pretreatment on the Bonding Performance of Glass Ionomer Cement to Human Dentin: An In Vitro Evaluation. *World Journal of Dentistry*. 2026 Jun 26;17(6):569-72.
- [49] Ahuja G, Pandey S, Gill S, Galani MM, Pasha Z, Chandrasekaran S, Kumari A. Comparing the biological response to immediate versus delayed implants placement in terms of osseointegration and bone quality. *Bioinformation*. 2026 Mar 31;22(3):1695.
- [50] Gill S. Effect of Preoperative Dexamethasone on Postoperative Sequelae Following Mandibular Third Molar Surgery: A Randomized Clinical Study.
- [51] Sahoo A, Kumari A, Gill S, Parihar AS, Dhull KS, Jena D. Efficacy of Green Tea Catechins as an Adjunct to Scaling and Root Planing in Chronic Periodontitis: A Systematic Review and Meta-analysis. *World Journal of Dentistry*. 2026 Jun 26;17(6):581-7.
- [52] Balivada A, Gill S, Makam S, Dutta B, Agrawal A, Shah N. Impact of Silver Diamine Fluoride Pretreatment on the Bonding Performance of Glass Ionomer Cement to Human Dentin: An In Vitro Evaluation. *World Journal of Dentistry*. 2026 Jun 26;17(6):569-72.
- [53] Ahuja G, Pandey S, Gill S, Galani MM, Pasha Z, Chandrasekaran S, Kumari A. Comparing the biological response to immediate versus delayed implants placement in terms of osseointegration and bone quality. *Bioinformation*. 2026 Mar 31;22(3):1695.
- [54] Gill S. Effect of Preoperative Dexamethasone on Postoperative Sequelae Following Mandibular Third Molar Surgery: A Randomized Clinical Study.