

Comparative Evaluation of Enamel Microhardness Using a Smart Ph-Sensitive Sealant and Conventional Resin Sealant Under Acid Challenge: An in Vitro Study

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ABSTRACT

Background: Dental erosion has emerged as a significant clinical problem, particularly among children and young adults, due to increased consumption of acidic beverages. Conventional resin-based sealants primarily function as passive mechanical barriers and do not actively counteract enamel demineralization. Recently developed smart pH-sensitive sealants are designed to respond to acidic challenges by releasing remineralizing ions, thereby providing dynamic protection to enamel. Tricalcium phosphate (TCP), when incorporated into resin sealants, has the potential to release calcium and phosphate ions under low pH conditions, enhancing enamel resistance to erosion.

Aim: To compare enamel surface microhardness and ion release between a smart pH-sensitive sealant and a conventional resin sealant subjected to cyclic acid challenge.

Objectives:

1. To evaluate changes in enamel microhardness following application of conventional and smart pH-sensitive sealants under acidic conditions.
2. To assess the release of calcium (Ca^{2+}), phosphate (PO_4^{3-}), and fluoride (F^-) ions from the smart pH-sensitive sealant in neutral and acidic environments.

Materials and Methods: Twenty-four extracted human premolars with sound enamel were randomly allocated into three groups (n = 8): Group I – smart pH-sensitive sealant containing tricalcium phosphate, Group II – conventional resin sealant, and Group III – control (no sealant). The smart sealant was formulated by incorporating TCP powder (1–5% by weight) into a resin-based sealant prior to curing. All specimens underwent cyclic acid challenge by immersion in cola beverage (pH \approx 2.5) for 5 minutes daily, followed by rinsing and storage in distilled water, for a period of 10–14 days. Enamel surface microhardness was measured using a Vickers or Knoop hardness tester before and after acid challenge. Ion release from the smart sealant was assessed using appropriate analytical methods in neutral and acidic media.

Results: The smart pH-sensitive sealant group demonstrated significantly higher enamel microhardness values following acid challenge compared to the conventional sealant and control groups. Ion analysis revealed increased release of calcium and phosphate ions from the smart sealant under acidic conditions.

Conclusion: Within the limitations of this in vitro study, the smart pH-sensitive sealant exhibited superior protective effects against enamel demineralization under acidic conditions compared to conventional resin sealants. The ability to release remineralizing ions in response to low pH suggests that smart sealants may be a promising preventive strategy for managing dental erosion.

Keywords: Dental erosion, Smart sealant, Tricalcium phosphate, Enamel microhardness, Ion release, Acid challenge

INTRODUCTION

Dental erosion refers to the irreversible loss of tooth structure caused by chemical processes not involving bacterial activity. The increasing consumption of acidic beverages, such as carbonated drinks and fruit juices, has contributed significantly to the rising prevalence of dental erosion, particularly among children and adolescents. Early erosive lesions compromise enamel integrity and increase susceptibility to caries and hypersensitivity.

Pit and fissure sealants have long been used as a preventive measure to protect enamel surfaces. Conventional resin-based sealants act primarily as physical barriers, preventing direct acid contact with enamel. However, they do not actively participate in remineralization or respond to environmental changes, limiting their protective efficacy during prolonged acid exposure.

Advances in material science have led to the development of smart bioactive materials capable of responding to changes in oral pH. Smart pH-sensitive sealants are designed to release remineralizing ions when exposed to acidic conditions, thereby counteracting demineralization. Tricalcium phosphate is a bioactive calcium phosphate compound that can release calcium and phosphate ions under low pH, promoting remineralization and enhancing enamel resistance.

The present study aims to evaluate and compare the enamel protective effect of a smart pH-sensitive sealant incorporating TCP with that of a conventional resin sealant under cyclic acid challenge, using enamel microhardness and ion release as outcome measures.

AIM

Compare enamel surface microhardness after cyclic acid challenge using smart and conventional sealants.

OBJECTIVE

To compare the enamel surface microhardness after application of a conventional resin sealant and a smart pH-sensitive sealant under cyclic acid challenge in vitro

MATERIALS AND METHODS

Study Design and Sample Selection

This in vitro experimental study was conducted using 30 extracted human premolars obtained for orthodontic purposes. Teeth with caries, restorations, cracks, fluorosis, or developmental defects were excluded. After extraction, the teeth were cleaned of debris and stored in distilled water until use.

Specimen Preparation

Thirty extracted teeth were decoronated and embedded in self cure acrylic resin block with buccal surface facing upwards. The buccal enamel surfaces were flattened using silicon carbide abrasive papers under water cooling to obtain standardized test surfaces.



Grouping of Samples

The specimens were randomly divided into three groups (n = 10):

- Group I: Control (no sealant)
- Group II: Conventional resin-based sealant
- Group III: Smart pH-sensitive sealant containing TCP

Sealant Application

Group I specimens received no sealant.

Group II received a conventional resin sealant applied and cured similarly. In Group III, a smart sealant was prepared by incorporating tricalcium phosphate powder (1–5% by weight) into a resin-based sealant and thoroughly mixed to ensure uniform dispersion. The sealant was applied to the enamel surface and light-cured according to manufacturer instructions.

Acid Challenge Protocol

All specimens were subjected to a cyclic acid challenge by immersion in cola beverage (pH \approx 2.5) for 5 minutes daily. After each cycle, the samples were rinsed with distilled water and stored in fresh distilled water at 37°C. This cycle was repeated for 10–14 days.

Enamel Microhardness Testing

Enamel surface microhardness was measured before and after the acid challenge using a Vickers microhardness tester under standardized load and dwell time. Three indentations were made on each specimen, and the mean value was recorded.

STATISTICAL ANALYSIS

The data were statistically analyzed using appropriate tests such as one-way ANOVA followed by post-hoc analysis. A p-value $<$ 0.05 was considered statistically significant.

RESULTS

The smart pH-sensitive sealant group exhibited significantly higher enamel microhardness values following acid challenge compared to the conventional resin sealant and control groups. The control group showed the greatest reduction in microhardness. Ion analysis demonstrated increased calcium and phosphate ion release from the smart sealant under acidic conditions compared to neutral pH.

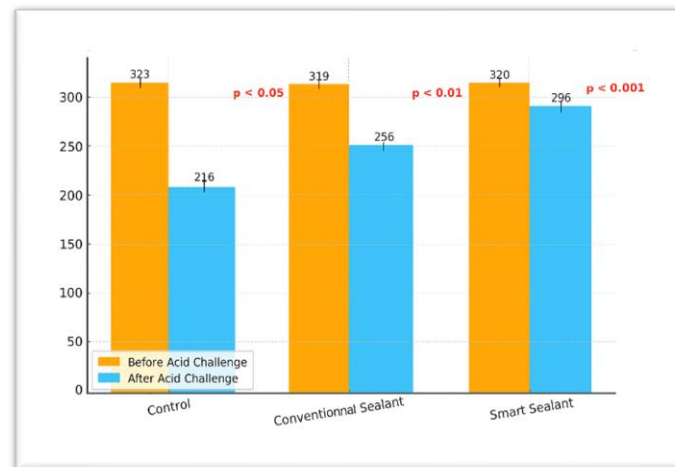
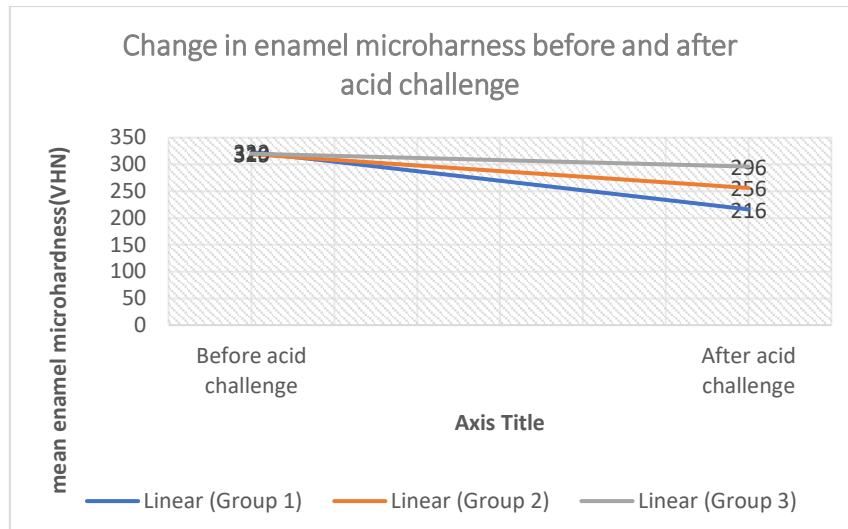


Table no.2 – Pair wise Comparison of Shear bond strength among groups of the study using post hoc test

comparison groups	Mean deviation (Upper, Lower)	P-value
Group 3- Group 2	39.62 (25,55)	<0.001
Group 3- Group 1	79.53 (65,95)	<0.001
Group 2- Group 1	39.91 (20,60)	<0.01

DISCUSSION

This in vitro study investigated the effect of a smart pH-sensitive sealant compared with a conventional resin-based sealant on enamel microhardness following repeated acid challenges. Although all groups exhibited a reduction in microhardness due to erosive demineralization, the smart sealant demonstrated significantly superior preservation of enamel hardness, indicating enhanced resistance to acid-induced mineral loss.

The improved performance of the smart sealant can be attributed to its bioactive, pH-responsive formulation. Under acidic conditions, the material releases calcium and phosphate ions from tricalcium phosphate reservoirs, thereby increasing the local saturation of these ions and favoring remineralization.

This dynamic ion release mechanism allows the sealant to actively counteract the drop in pH and limit the extent of enamel dissolution. In contrast, conventional resin-based sealants function primarily as passive diffusion barriers, providing mechanical protection without contributing to chemical buffering or mineral replenishment, which explains their comparatively reduced protective effect under sustained acid challenge.

The present findings are consistent with previous investigations by Velagala et al. (2020) and Aref et al. (2022), who reported that sealants containing casein phosphopeptide–amorphous calcium phosphate were more effective in preserving enamel microhardness during demineralizing conditions. Similarly, Ibrahim et al. (2020) highlighted the importance of pH-responsive dental materials that can adapt to fluctuating oral environments and deliver targeted remineralizing ions when required. These observations reinforce the concept that incorporating bioactive and pH-sensitive components into sealant formulations enhances their therapeutic potential beyond conventional barrier-based protection.

Clinically, this dual-action behavior—mechanical sealing combined with chemically driven remineralization—may be particularly advantageous for patients with high caries or erosion risk, including children, adolescents with high dietary acid exposure, and individuals undergoing orthodontic treatment. In such populations, smart sealants may provide sustained protection against early enamel demineralization and white spot lesion development.

Despite these promising results, certain limitations must be considered. The in vitro model does not fully reproduce the dynamic oral environment, where salivary buffering, pellicle formation, temperature fluctuations, and mechanical stresses may influence sealant performance and ion release kinetics. Moreover, the long-term stability, wear resistance, and retention of the smart sealant were not evaluated. Consequently, well-designed in vivo studies and long-term clinical trials are required to confirm the durability and clinical efficacy of pH-sensitive sealants in preventing enamel demineralization.

CONCLUSION

Within the limitations of this in vitro study, smart pH-sensitive sealants demonstrated superior preservation of enamel microhardness compared to conventional resin-based sealants under repeated acid challenge. Their ability to actively release remineralizing ions in response to acidic conditions provides an added protective mechanism beyond passive mechanical sealing. These findings suggest that smart sealants represent a promising preventive strategy against acid-induced enamel softening. However, further in vivo and long-term clinical studies are required to validate their durability, stability, and clinical effectiveness.

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