ORIGINAL RESEARCH

Assessing the Remineralization Potential of Commercial Pediatric Dentifrices on Demineralized Deciduous Enamel Lesions: An *In Vitro* Scanning Electron Microscopy–Energy-dispersive X-ray Study

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Received on: 23 September 2023; *Accepted on:* 20 October 2023; *Published on:* 30 December 2023

Abstract

Aim: The study aimed to assess the remineralizing potential of three kinds of toothpaste Pigeon, Dentoshine, and Candycop qualitatively and quantitively using scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) spectroscopy, respectively.

Materials and methods: A total of 60 enamel blocks each prepared by sectioning the buccal surface of the second primary molars were divided into three halves (upper, middle, and lower halves) and subjected to demineralization to induce artificial enamel lesions by coating the upper half with nail varnish. Upon coating the second half with nail varnish, a random allocation of samples was done on the type of dentifrice applied. Group I—treated with Pigeon, group II—with Dentoshine, group III—with Candycop followed by storage in artificial saliva. Samples after repeating the procedure twice daily for 7 days were subjected to SEM and EDX spectroscopy to evaluate the remineralizing potential. Inter- and intragroup statistical analysis was done using descriptive one-way analysis of variance (ANOVA) and *post hoc* Tuckey tests, respectively.

Results: Candycop exhibited a higher mineralization [calcium (Ca)—26.736 ± 2.012, phosphorous (P)—12.676 ± 1.677] with uniform globular deposition on the enamel surface compared to group II treated with Dentoshine (Ca—23.903 ± 3.327, P—11.560 ± 2.840) and group I with Pigeon (Ca—23.308 ± 2.949, P—11.986 ± 2.952).

Conclusion: Mineral deposition was exhibited by all three dentifrices nevertheless Candycop had shown superior remineralizing efficacy than Dentoshine and Pigeon with more unified Ca and P deposition.

Keywords: Demineralization, Dentifrices, Remineralization.

Journal of South Asian Association of Pediatric Dentistry (2023): 10.5005/jp-journals-10077-3281

Introduction

Decades of research in dental materiology led to a strategic shift in the treatment of white spot lesions which appear when pH falls below a critical value (5.5), from the restorative approach in the past to minimally invasive/noninvasive preventive approach that is remineralization of the demineralized enamel surface.[1–3] Remineralization of such subsurface lesion depends on the stability of the resting pH which can be made possible by the buffering action of saliva with its fluoride, hydroxide, Ca, and phosphate ionic constituents or by the addition of remineralizing agents which permit precipitation of those ions into the tooth structure.[4,5]

Topical fluoride in fluoridated toothpaste is being used and documented as an effective remineralizing and cariostatic agent in the literature especially in children. However, the risk of dental fluorosis if excessively used, Ca and phosphate ions unavailability for fluoride retention, and net remineralization have driven the research towards alternative remineralizing agents to fluoride which facilitates mineral deposition into teeth.[4–6]

Xylitol is a nonfermentable sugar alcohol whose anticarcinogenic and remineralizing properties have been exhibited both *in vitro* and *in vivo*. Xylitol facilitates remineralization by providing high mineral content with increased salivary flow and Ca bioavailability.[7–10] Miake et al., *in vitro* study resulted in a remineralizing solution with 20% w/w xylitol yielded greater deeper remineralization with less in superficial layers when compared to a solution without xylitol.[11]

Documented studies proved a combination of fluoride and xylitol is more efficacious than fluoride alone.[9] Furthermore, Oliveira et al., concluded that xylitol in low fluoride-containing dentifrices enhanced demineralization reduction *in vitro* in contrast with fluoride dentifrice alone.[12] Having this proven fact, various child

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How to cite this article: Ragini K, Mahesh VM, Vinodh S, *et al.* Assessing the Remineralization Potential of Commercial Pediatric Dentifrices on Demineralized Deciduous Enamel Lesions: An *In Vitro* Scanning Electron Microscopy–Energy-dispersive X-ray Study. J South Asian Assoc Pediatr Dent 2023;6(3):129–133.

Source of support: Nil

Conflict of interest: None

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formula dentifrices are available in the market with and without xylitol in variable concentrations and in combination with fluoride claiming a high remineralizing capacity of enamel. Nevertheless, neither the remineralization potential nor the additive effect of xylitol and fluoride of most child dentifrices have been tested so far. Furthermore, the additive effectiveness of xylitol when combined with fluoride yielded contradictory results by Milburn et al.[13] and Brown et al.[14] These inconsistent results led to the designing of the current study with a primary objective to test the remineralizing potential of commercially available child formula dentifrice Candycop and its comparison with Pigeon and Dentoshine. While assessing the beneficial effects of the combined action of fluoride and xylitol in Candycop was considered secondary.

Materials and Methods

This prospective *in vitro* study was carried out for a period of one month between June and July 2021 in the Department of Pedodontics and Preventive Dentistry, Vivekanandha Dental College for Women, Namakkal, Tamil Nadu, India. This nonsponsored study was approved by the Institutional Ethical Committee (No: VDCW/IEC/188/2020) and followed the "Standards for Quality Improvement Reporting Excellence (SQUIRE 2.0)" as well as "Checklist for Reporting *In Vitro* Studies (CRIS)" publication rules.

Sample Estimation and Enamel Block Preparation

A total of 60 noncarious human primary molars with intact buccal surfaces extracted either for retainment in permanent dentition or due to physiologic mobility were included. Excluded teeth were with any restorations, hypoplastic lesions, stains/discolorations, cracks, developmental abnormalities, and underwent pulp therapy.

A total sample size of 54, 18 per group calculated using G*Power software was enough to detect a difference of 25% [if significance (p) was set at 5% and power (β) at 80%]. However, to prevent sampling errors as well as based on availability, 20 samples per group was experimented.

Teeth were cleared of debris, calculus, and tissue appendages with ultrasonic scaling and stored in 10% formalin solution until further usage. The teeth were sectioned 1 mm below the cemento enamel junction discarding the root, the crowns were then divided into two halves in a mesiodistal direction to obtain 60 sound buccal surfaces with a slow-speed diamond disk. Each sample was equally marked into three halves representing positive control (PC)—sound surface, negative control (NC)—demineralized surface, and test surface (TS)—remineralized surface.

Demineralization

The superficial half of all the samples representing PC was coated with a single layer of acid-impervious nail varnish followed by immersion in a demineralizing solution (20 mL) prepared as per Pulido et al.,[15] for 96 hours at 37°C to create artificial enamel lesions in the remaining two halves.

Randomization and Group Allocation

All the samples were then double distilled water washed for 15 seconds and allocated into three groups using block randomization (Microsoft Excel, 64-bit version) for remineralization.

- Group I: Treated with Pigeon dentifrice.
  (Nonfluoridated with 20% xylitol).
  (Pigeon India Pvt. Ltd., Haryana, India).
- Group II: Treated with Dentoshine dentifrice.
  (500 ppm sodium fluoride but without xylitol).
  (Avoden Pvt. Limited, Ahmedabad, India).
- Group III: Treated with Candycop dentifrice.
  (458 ppm sodium monofluorophosphate and with 5% xylitol).
  (Abbott Healthcare Pvt. Limited, Karnataka, India).

Remineralization

Following the application of nail varnish on the middle half of all the demineralized samples, 20 samples from each group were coated with respective remineralizing dentifrice on the lower half for 5 minutes. Remineralizing toothpaste slurry was prepared by mixing a 1:3 weight ratio of toothpaste (20 gm) to deionized water (60 mL) using a vibrator (Unident, New Delhi). The specimens were thoroughly washed with double-distilled water for 15 seconds and stored in artificial saliva (McKnight Hane and Whitfort formula)[16] until the next treatment of dentifrice to simulate the oral environment.

Upon removal from the artificial saliva, specimens were double-distilled water washed, and treated with freshly prepared dentifrice solution, followed by overnight placement in artificial saliva. The procedure was repeated twice daily for 7 days, followed by an examination of all the specimens using a field emission scanning electron microscope (SEM) and energy-dispersive X-ray (EDX) analysis.

Statistical Analysis

International Business Machines (IBM) Statistical Package for the Social Sciences version 15.0 software (IBM Corp, Armonk, New York, United States of America) analyzed the data tabulated in inter and intragroup comparisons using one-way analysis of variance (ANOVA) and *post hoc* Tuckey tests, respectively. The $p \leq 0.05$ was considered significant at a 95% confidence interval.

Results

Qualitative Analysis by SEM

Untreated enamel surface (PC) in the samples of all three dentifrices revealed smooth homogeneous even surface with slightly visible prism obscurities (Figs 1A to C). However, the NC surface showed marked deep prismatic pits giving a honeycomb appearance due to the loss of interprismatic substance suggestive of demineralization (Figs 1D to F).

Dentifrice treated surface exhibited morphological variations, respectively, the Candycop group with uniform mineral deposition around the prism cores giving a globular pattern, and the Dentoshine group with reduction in pore volume and prism holes by partial mineral deposition (Figs 1G and H). Whereas the honeycomb appearance was still evident in the Pigeon group suggestive of slightly lesser mineral deposition and reduction in pore volume (Fig. 1I).

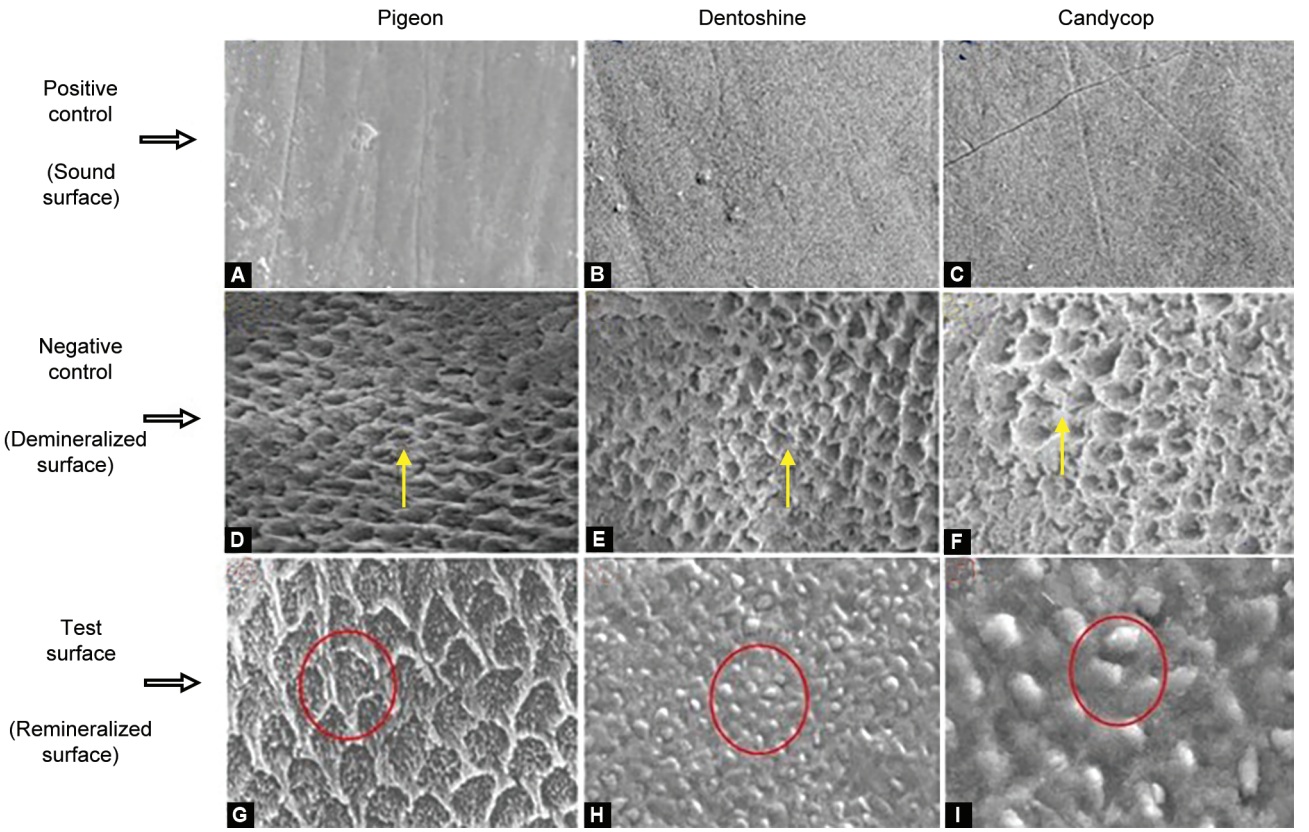
Quantitative Analysis by SEM–EDX

Calcium (Ca) and phosphorous (P) weight percentages were analyzed by EDX spectrometry. It revealed a significant difference in Ca and P weight percentages between PC and NC ($p = 0.000$ and $p = 0.000$), NC and TS ($p = 0.000$ and $p = 0.001$) of each sample in Group I respectively while no significant difference was observed between PC and TS ($p = 0.808$ and $p = 0.384$). A similar trend was also observed within the samples of group II ($p = 0.000$ and $p = 0.000$ for PC vs NC, $p = 0.000$ and $p = 0.001$ for NC vs TS, and $p = 0.033$ and $p = 0.169$ for PC vs TS). However, group III showed a significant difference between all the surfaces ($p = 0.000$ and $p = 0.000$ for PC

vs NC, $p = 0.000$ and $p = 0.000$ for NC vs TS, and $p = 0.001$ for PC vs TS) except P Wt% between PC and TS ($p = 0.044$) (Table 1).

Intergroup comparison of mean Ca weight percentages (group I—23.308±2.949; group II—Ca—23.903±3.327; and group III—Ca—26.736 ± 2.012) postremineralization showed a significant difference between all the three groups ($p = 0.04$) while mean P weight percentage difference between the groups (group I—11.986 ± 2.952; group II—11.560 ± 2.840; and group III—12.676 ± 1.677) was found to be nonsignificant (0.484). Group III exhibited a marginally better remineralizing capacity (Table 2).

Table 3 resulted in a significant difference between groups I and III ($p = 0.000$) and groups II and III ($p = 0.004$) with no significant difference between groups I and II ($p = 0.881$) when Ca weight percentages were compared. It also showed the P weight percentage difference between all three groups was nonsignificant on comparison, respectively ($p = 0.937$, $p = 0.781$, and $p = 0.426$).



Figs 1A to I: SEM images of enamel surfaces of all the three groups (A, B, C) Sound homogenous enamel surface with slightly visible prism shadows; (D, E, F) Demineralized enamel surface with loss of interprismatic substance leading to porosities (yellow arrows); enamel surface showing evidence of mineral deposition around prism cores with a reduction in pore volume; (G) Partial deposition with a filling of porosities; (H) Globular pattern with a reduction in pore volume and prism porosities; (I) Suggestive of remineralization

Table 1: Comparison of mean Ca and P weight percentages between positive (PC), NC, and TS in each group

Group		*Ca Wt% (mean difference)*	*p-value*		*P Wt% (mean difference)*	*p-value*
Pigeon	PC vs NC	4.737	0.000*	PC vs NC	2.146	0.000*
	PC vs TS	0.129	0.808 (NS)	PC vs TS	0.542	0.384 (NS)
	NC vs TS	4.608	0.000*	NC vs TS	2.688	0.001*
Dentoshine	PC vs NC	3.563	0.000*	PC vs NC	1.785	0.000*
	PC vs TS	0.841	0.033 (NS)	PC vs TS	0.169	0.169 (NS)
	NC vs TS	2.722	0.001*	NC vs TS	1.165	0.000*
Candycop	PC vs NC	7.986	0.000*	PC vs NC	3.931	0.000*
	PC vs TS	2.094	0.001*	PC vs TS	1.115	0.044 (NS)
	NC vs TS	10.080	0.000*	NC vs TS	5.047	0.000*

NS, nonsignificant; *, statistically significant; Wt, weight

Table 2: Intergroup comparison of mean Ca and P weight percentages post remineralization of TS with dentifrices

Weight%	*Group*	*Mean ± SD*	*p-value*
Ca	Pigeon	23.308 ± 2.949	0.04*
	Dentoshine	23.903 ± 3.327	
	Candycop	26.736 ± 2.012	
P	Pigeon	11.986 ± 2.952	0.484 (NS)
	Dentoshine	11.560 ± 2.840	
	Candycop	12.676 ± 1.677	

NS, nonsignificant; *, statistically significant; SD, standard deviation

Table 3: Intragroup comparison of mean Ca and P weight percentages postremineralization of TS with dentifrices

Group vs group	*Ca Wt% (mean difference)*	*p-value*	*P Wt% (mean difference)*	*p-value*
Pigeon vs Dentoshine	0.59550	0.881 (NS)	0.42600	0.937 (NS)
Pigeon vs Candycop	3.42850	0.000*	0.69000	0.781 (NS)
Dentoshine vs Candycop	2.23300	0.004*	1.11600	0.426 (NS)

NS, nonsignificant; *, statistically significant; Wt, weight

Discussion

The emergence of the minimal invasive concept changed the treatment strategies of incipient caries lesions from a restorative to a remineralizing approach.[3] Voluminous literature was evident stating fluoride is the best possible choice for remineralization. However, owing to its risks, alternative remineralizing agents were searched for such as xylitol, and its efficacy was documented alone or in combination with fluoride.[4–11]

Child dentifrices being marketed claim to have high remineralization potential. The current study investigated the remineralising potential of three such commercially available dentifrices Pigeon, Dentoshine, and Candycop.

In investigative cariology, though *in vivo* clinical studies remain the gold standard, standardized *in vitro* replicas can serve as a valuable tool in assessing the remineralizing potential by the acquisition of quantifying data for designing clinical trials.[4,6] Furthermore, the primary molar selection was done for the study based on their susceptibility to caries initiation due to high organic content with soft porous enamel.[5] In addition, calibration of sections of single tooth reduced the interteeth variability, and its effect on mean percentage among groups as well as facilitated accurate pre and postmeasurement.[15]

Despite numerous tools available such as confocal and polarized light microscopy, atomic force, and scanning tunnel microscopy, SEM and EDX were used to calibrate the enamel surface characteristics as they identify elemental variations in noncontact methods.[1,5]

A considerable amount of remineralization potential had been shown by all three dentifrices tested with a significant difference. This can be attributed to their inherent composition with fluoride xylitol or both in combination. Fluoride enhances the remineralization by the formation of fluorapatite while xylitol acts by facilitating residual Ca and phosphate ions with increased salivary flow.[6,8,10,11]

The present study revealed a higher Ca and phosphate ion deposition indicating a better remineralization with Candycop compared with other tested dentifrices. This was also evident from the surface characteristics presented with SEM images exhibiting a uniform globular deposition around the prism cores, unlike other groups. This result was in concord with the studies done by Tange et al.,[17] and Sano et al.,[9] *in vitro* and *in vivo*, respectively. Furthermore, the globular pattern of mineral deposition using Candycop dentifrice was also demonstrated by Grewal et al.[18] The enhanced remineralization exhibited by Candycop could be attributed to the synergistic effect of sodiummonofluorophosphate and xylitol which are its main constituents leading to augmented incorporation of fluoride ions together with higher bioavailable Ca and phosphate ions.[11,12,17]

Following Candycop, Dentoshine, and Pigeon too showed Ca and phosphate ion deposition indicating their remineralization potentiality but with a negligible difference between them. SEM images evidenced this by a reduction in pore volume and interprismatic porosities with and without honeycomb appearance in Dentoshine and Pigeon samples, respectively. Perhaps, a marginally higher remineralization with Dentoshine compared to Pigeon was due to the presence of sodium fluoride resulting in fluorapatite.

Shen et al. concluded that xylitol alone at physiologically relevant concentrations (12.6% w/v concentration) cannot induce subsurface remineralization.[10] Confirming the aforementioned fact, Sano et al., reported that a certain concentration of xylitol is required to provide a remineralization effect comparing toothpastes with 500 ppm fluoride alone and with a 0.1% xylitol combination.[9] In addition, Cardoso et al., study proved that 20% xylitol varnish will significantly increase remineralization of artificial caries lesions.[19] The Pigeon dentifrice tested in the study lacks fluoride, a pivotal component for remineralization along with a 20% concentration of xylitol too yielded lesser results. This result was consistent with the Miake et al.[11] Contrarily, Amaechi et al., stated that 20% xylitol alone in artificial saliva cannot induce subsurface remineralization *in vitro*.[20]

The current study results reveal Candycop demonstrated a significantly higher mineral content with surface characteristics both in qualitative and quantitative evaluation than Dentoshine and Pigeon. This result was in unison with the conclusion driven by Gaffar et al.,[8] and Arends et al.,[21] studies stating the combination of fluoride and xylitol will augment the remineralization potential of a dentifrice. Higher remineralization in Candycop could also be attributed to the fact that xylitol perhaps reduces the production of extracellular polysaccharides along with an increase in Ca bioavailability.[12]

Despite Candycop exhibiting better remineralization characteristics, it had to be mentioned that Ca and P weight percentage values were less notably variable among the three

groups indicating the marginal difference between tested groups. The collaborative effect of fluoride and xylitol could have given a higher edge to candycop over other groups.

The current *in vitro* trial reinforces the fact that child dentifrices with low fluoride content (<500 ppm) when incorporated with polyols like xylitol not only increase its remineralization potential by greater Ca phosphate precipitation but also reduce the potent risk of dental fluorosis with regular toothpaste (≥1000 ppm) usage in children.[12]

Certain limitations pertaining to the study include difficulty in mimicking the exact biological aspects of caries. Also, numerous intraoral predisposing conditions and enzymatic factors that contribute to dental caries were not accounted. Demineralizing and remineralizing solutions with inorganic ions can't suffice the effects of salivary proteins, pellicles, and plaque on mineralization inhibition. Experimental faults and variations in the microstructure of the enamel between specimens could also be other confounding factors.

Conclusion

The results obtained from this *in vitro* study conclude that all three pediatric dentifrices can remineralize enamel, however, Candycop showed significantly better remineralizing potential, followed by Dentoshine and Pigeon with no significant difference between them. The synergistic effect of fluoride and xylitol present in Candycop dentifrice could be the possible explanation for better mineral deposition around artificial enamel lesions.

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