

Micro computed tomography analysis of abrasivity of toothpaste tablets compared to conventional toothpaste

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ABSTRACT: Purpose: To evaluate with microCT dentin and enamel abrasion depth caused by toothpaste tablets when compared to conventional toothpastes. **Methods:** Dentin (N= 64) and enamel blocks (N=64) were randomized into four experimental groups of 16 specimens each for dentin and enamel. CP: Colgate Cavity Protection, served as the low abrasive toothpaste; AW: Colgate Total Advanced Whitening was used to represent a highly abrasive toothpaste. Two different types of toothpaste tablets were used. DT: Denttabs and BT: Bite tabs. To prepare the slurries, 40 mL of water was added to 25 g of each toothpaste and 4.4 g of each toothpaste tab. Blocks were brushed for a total of 10,000 and 40,000 strokes for dentin and enamel, respectively following ISO standard 11609. On completion of brushing, specimens were scanned with a microCT system. Tomographic 3D reconstruction followed by abrasion depths measurements were performed. Kruskal-Wallis procedure tested abrasion depths among the different groups. Tests of hypotheses were two-sided with an alpha level at 0.05. **Results:** There was a statistically significant difference in dentin abrasion depth among the groups ($P < 0.001$). The mean dentin/enamel abrasion depths in microns were 25.3/4.4, 36.8/4.4, 66.8/3.0, and 230.3/15.5 for DT, BT, CP, and AW respectively. Dentin and enamel abrasion depth of AW was the highest and was different from all other groups after multiple comparisons ($P < 0.05$). (*Am J Dent* 2021;34:235-239).

CLINICAL SIGNIFICANCE: Dentin abrasivity of toothpaste tabs is negligible as determined with microCT.

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Introduction

Toothpaste was first put into collapsible plastic tubes in 1892.¹ Since the tubes' multi-material is impossible to separate economically and leaves harsh chemical residues, every toothpaste tube must be thrown away, leading to 1.5 billion tubes to be sent to the landfill every year.¹⁻³ Additionally, the plastics in the tubes can take up to 500 years before even beginning to decompose.⁴ As a result, the toothpaste tube has become an environmentally hazardous product. In response to these concerns, toothpaste brands such as Colgate and Tom's of Maine have developed a recyclable toothpaste tube.⁵ Others have turned in a very different direction with the development of toothpaste tablets that nullifies the need for both toothpaste and tubes completely.⁵⁻⁸ These tablets usually include fluoride alternatives, charcoal, and natural ingredients. Although these products are gaining popularity with eco-friendly marketing, there is scarce information in the literature on the efficacy on toothpaste tablets on plaque removal, caries prevention, user-friendliness, and potential adverse effects on the enamel and dentin such as abrasivity.

The International Organization for Standardization (ISO) provides documents that detail requirements and guidelines to ensure that materials and products are fit for their purpose.⁹ The ISO 11609 standard outlines two test methods for laboratory assessment of toothpaste abrasivity.¹⁰ Measuring dentin changes after brushing with a toothpaste using a scintillation counter and radioactive dentin is most frequently used and regarded as the gold standard.¹¹ Laboratories that do not have access to a research reactor and regulatory clearance for isotope can also use the alternative surface profilometry method on artificially created flat dentin. While surface profilometry has an advantage of directly measuring the surface loss, its limita-

tion includes a higher variation as compared to the radiotracer method.^{11,12} With the advancement of technology, micro computed tomography (microCT) has been extensively utilized as 3D analysis techniques for dental research, including qualitative and quantitative information on material density and structural loss.^{13,14} Thus, the use of microCT for abrasivity testing could be another alternative method to the radiotracer and profilometry method.

With the need for more information on the usage of toothpaste tablets and the use of microCT for abrasivity testing, this study used microCT to evaluate dentin and enamel abrasion depth caused by toothpaste tablets when compared to conventional toothpastes. The null hypotheses were that there would be no difference in dentin and enamel abrasion depths among the tested products.

Materials and Methods

Sample selection and preparation - Extracted sound human third molars without identifiers (N= 64) were collected and stored in 0.2% sodium azide solution at 4°C. Loma Linda University Institutional Review Board approved the use of the extracted human teeth with no identifiers as a non-human subject study. The experimental set-up is illustrated in Fig. 1. Teeth were cleaned of gross debris and placed in artificial saliva at room temperature. Artificial saliva containing CaCl₂ 0.078 g/L, MgCl₂·6H₂O 0.041 g/L, KH₂PO₄ 0.544 g/L, KCl 2.24 g/L, HEPES buffer acid 4.77 g/L, pH 7.1, was prepared according to Shellis' protocol.¹⁵ Enamel blocks (N=64) were prepared by sectioning the crown portion to a rectangular shape of 4 × 4 × 6 mm³ (Fig. 1a). Root portions were used to prepare dentin blocks (N= 64) the same way as for enamel specimens. All blocks were then embedded in self curing acrylic resin with the enamel and dentin surface facing up. The surface was ground

Table. Summary of toothpastes used.

Group	Brand name	Listed ingredients	RDA
CP	Cavity Protection	Active ingredient: Sodium monofluorophosphate 0.76% (0.15% W/V Fluoride Ion). Inactive Ingredients: Dicalcium phosphate dihydrate, water, glycerin, Sodium Lauryl Sulfate, Cellulose gum, flavor, tetrasodium pyrophosphate, sodium saccharin.	68
DT	Denttabs	Microcrystalline cellulose, sodium bicarbonate, silica, sodium lauroyl glutamate, magnesium stearate, aroma, menthol, xanthan-gum, stevioside, citric acid, sodium fluoride, eugenol.	<30
BT	Bite	Xylitol, erythritol, calcium carbonate, sodium cocoyl glutamate, sodium bicarbonate, guar gum, natural mint flavor, nano-hydroxyapatite	43
AW	Total Advanced Whitening	Active ingredient: Stannous fluoride 0.454% (0.15% w/v fluoride ion). Inactive ingredients: glycerin, hydrated silica, water, propylene glycol, PEG-12, pentasodium triphosphate, sodium citrate, sodium lauryl sulfate, flavor, PVP, microcrystalline cellulose, trisodium phosphate, zinc oxide, citric acid, zinc citrate, phosphoric acid, sodium saccharin, cocamidopropyl betaine, carrageenan, xanthan gum, PVM/MA copolymer, sucralose, titanium dioxide	160

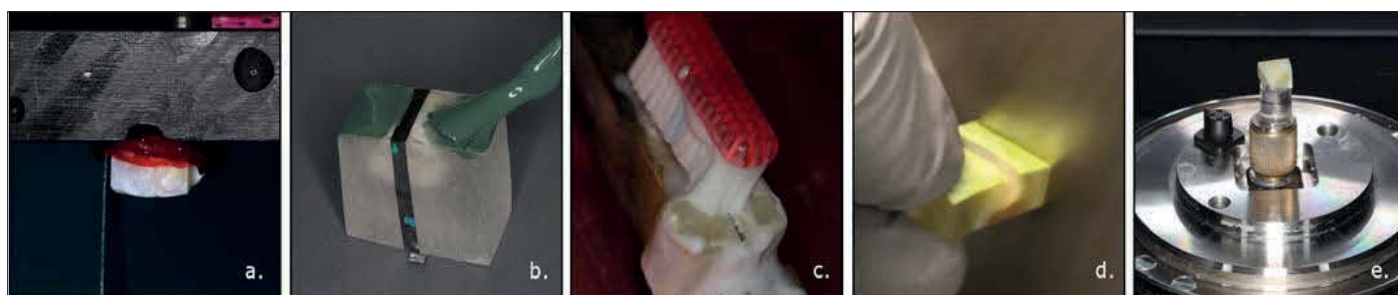


Fig. 1. Step-by-Step experimental procedure. **a.** Enamel blocks are prepared by sectioning the crown portion to a rectangular shape of $4 \times 4 \times 6 \text{ mm}^3$. **b.** Enamel and dentin blocks are embedded in acrylic and painted with nail-varnish to expose a flat $2 \times 4 \text{ mm}^2$ window. **c.** The toothbrush is positioned to pass reciprocally at a small angle over the mounted specimens while immersed in a dentifrice slurry. **d.** Specimen is trimmed to fit the microCT scanning dimensions. **e.** Specimen is scanned using the SkyScan 1272 desktop microCT system.

using a sequence starting at P400 and sequentially increasing to P1,200 silicon carbide paper under a constant flow of water. A slurry of aluminum oxide with a mean particle size of $0.3 \mu\text{m}$ was used for the final polishing. The enamel and dentin blocks were painted with nail varnish^a and additionally taped with Scotch High Strength Filament Tape 890RCT^b to expose a flat $2 \times 4 \text{ mm}^2$ window (Fig. 1b).

Experimental groups – The Table summarizes the brand name, composition, and RDA of the toothpastes used for the study. Specimens were randomized into four experimental groups of 16 specimens each for enamel and dentin. CP: Colgate Cavity Protection^c served as the low abrasive toothpaste with a known RDA of 68;^{16,17} AW: Total Advanced Whitening^c was used to represent a highly abrasive toothpaste group regarded within harmful limits with a known RDA of 160.^{16,17} Two different types of toothpaste tablets were used. DT: Denttabs^d was used as a fluoride containing toothpaste tablet group; BT: Bite tabs^c was used as a fluoride-free toothpaste tablet group.

Tooth brushing protocol - An automated cross-brushing machine (V8^f cross brushing machine) with eight specimen holders was used. The toothbrush (Fuchs Adult Record Multituft Nylon Toothbrush^g) was positioned to pass reciprocally at a small angle ($\approx 5^\circ$) over the mounted specimens while immersed in a dentifrice slurry. New toothbrushes were used for each group and substrate type (dentin and enamel). Slabs were mounted and the toothbrushing speed controlled at 120 strokes/minute (Fig. 1c). For enamel 40,000 strokes were performed while 10,000 strokes were used for dentin per ISO 11609 guidelines.¹⁰ To prepare the slurries, 40 mL of water were added to 25 g of each toothpaste and 4.4 g of each toothpaste tab. Calculation on the ratio of tabs to water was

based on a calculation of one time use weight of toothpaste (2 g) to one tab (0.35 g).

MicroCT analysis - On completion of the brushing cycles, all specimens were trimmed to fit the scanning dimensions (Fig. 1d) and scanned using the SkyScan 1272^h desktop microCT system, with an accelerating source voltage of 100 keV, a source current of 100 mA and an exposure time of 2,600 ms (Fig. 1e). All specimens were positioned consistently in the center of rotation of the mounting device. During the scanning process, the samples were rotated at 180 degrees, with an imaging voxel size of $4.5 \mu\text{m}$ and rotation step of 0.4. The images were saved as 16-bit Tagged Image File Format (TIFF) and consequently exported to a reconstruction program (NRecon^h software, version 1.7.4.6) for the reconstruction of the 3D object. The tomographic reconstruction (Fig. 2a) produced a dataset of slice views in 16-bit TIFF format, which were assessed in the analysis program (CTAn^h software, version 1.18.8.0). Lesion depths were assessed in the middle slice of each sample (Fig. 2b). Three measurements were recorded by drawing a line connecting the two untreated tooth structure edges of the lesion (Fig. 2c). The line was divided in half and a measurement was recorded in the middle. The area to the right and left of the middle measurement were divided in half and a measurement was recorded on each side. The measurements were recorded from the line connecting the untreated surface to the base of the lesion. The three vertical measurements were then recorded and averaged.¹⁴ One operator, who was blinded to the treatment groups, performed the reconstruction and measurements.

Data analysis - G*Powerⁱ 3.1.9.4 was used to determine the sample size based on the following parameters: 80% power, 30%

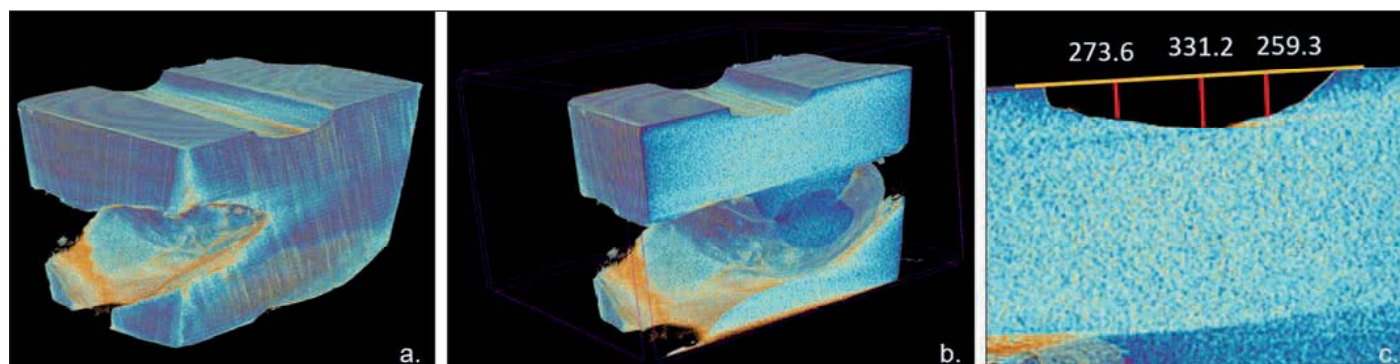


Fig. 2. MicroCT analysis of dentin sample. **a.** Tomographic 3D reconstruction of dentin sample. **b.** Lesion depths are assessed in the middle slice of each sample. **c.** Three measurements are recorded by drawing a line connecting the two untreated tooth structure edges of the lesion.

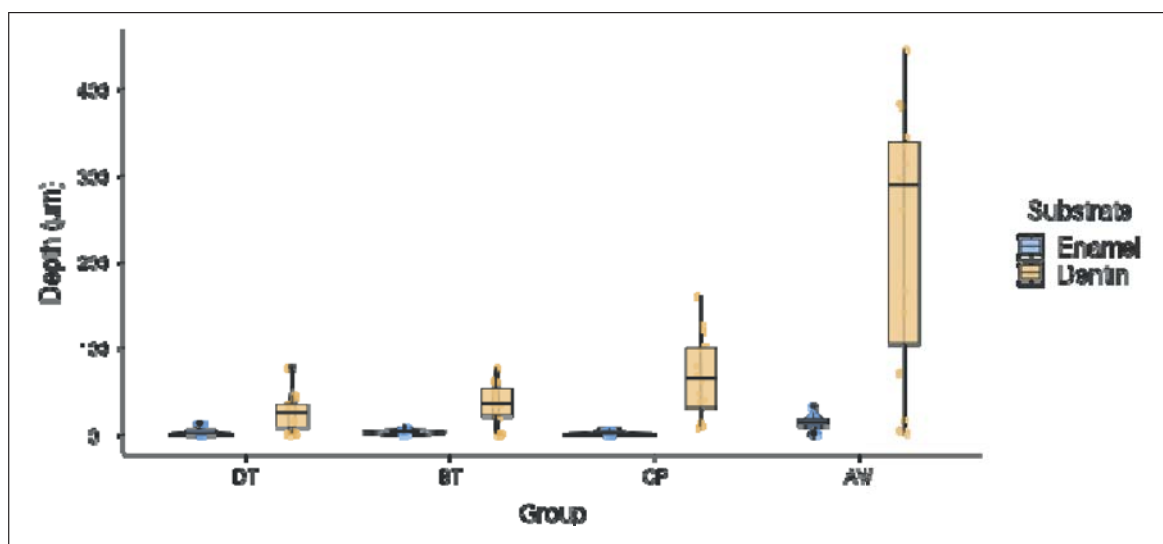


Fig. 3. Boxplots of dentin and enamel abrasion depths by group.

difference and four experimental groups. A minimum sample size of 15 specimens per group was assessed to be appropriate. Kruskal-Wallis procedure was performed to compare abrasion depth among the different groups. All post hoc comparisons were conducted with Bonferroni corrections. Spearman's rho was used for correlation testing. All tests were two-sided and conducted at an alpha level of 0.05 with R version 4.3 and Jamovi¹ v.1.1.9.0.

Results

The mean abrasion depth by tooth substrate and group is illustrated as boxplots in Fig. 3. On completion of 10,000 brushing strokes on the dentin specimens, there was a statistically significant difference in dentin abrasion depth among the four groups ($P < 0.001$). The dentin abrasion depth of AW was the highest with a mean of 230.3 μm and was different from all other groups after multiple comparisons ($P < 0.05$) while DT showed the lowest depth with a mean of 25.3 μm . The abrasion depth of CP was statistically significantly different from DT ($P = 0.036$) but did not differ from BT ($P = 0.162$). Figure 2 illustrates a representative 3D reconstruction of a dentin sample and the measuring at the middle slice of the sample with three vertical measurements. There was a statistically significant correlation between dentin abrasion depth and RDA values ($P < 0.001$, $\rho = 0.567$). Thus, the higher the RDA value the higher the dentin abrasion depth.

On completion of 40,000 brushing strokes on the enamel specimens, there was a statistically significant difference in enamel abrasion depth among the four groups ($P < 0.001$). The enamel abrasion depth of AW was the highest with a mean of 15.5 μm and was different from all other groups after multiple comparisons ($P < 0.05$) while CP, DT, and BT did not differ from each other ($P \geq 0.252$, in all instances). Thus, enamel abrasion depth was greater only for the toothpaste with the highest RDA. There was a statistically significant correlation between enamel abrasion depth and RDA values ($P < 0.001$, $\rho = 0.431$).

Discussion

Tooth abrasion can be attributed to multiple factors including the physicochemical properties of toothpaste, the stiffness of the toothbrush, and patient-related factors such as toothbrushing force and frequency.^{16,18} Along with these factors, it is vital to consider the relative dentin abrasivity of toothpaste, which can be measured in a laboratory by measuring the amount of dentin worn away using a standardized tooth brushing protocol. The RDA scale attributes toothpastes an abrasivity value relative to a standard reference abrasive that is arbitrarily given an RDA value of 100.^{11,19} Although toothpastes with an RDA value below 250 are considered safe and effective,²⁰ a commonly used RDA chart categorizes toothpastes as low abrasive (0-70), medium abrasive (71-100),

highly abrasive (101-150), and harmful (151-250).¹⁷ These groups can help consumers and oral healthcare professionals in selecting a toothpaste that best fits its intended purpose and the consumer's oral characteristics. Toothpaste tablets, a recently introduced tooth cleaning product, come in powder compressed into tablet form, which has raised misconceptions on their abrasivity since early tooth cleaning powders were highly abrasive.²¹

This study evaluated the dentin and enamel abrasion depths caused by automated toothbrushing as specified in ISO 11069 in conjunction with toothpaste tablets and conventional toothpastes. Adequate plaque removal generally requires toothbrushing for around 2 minutes, with each tooth surface needing approximately 6 seconds of toothbrushing. The automated brushing machine was set at 120 strokes/minute for a total of 10,000 strokes for dentin. Thus, the samples were brushed for a total of 83 minutes. Considering that brushing is recommended twice daily, the amount of dentin brushing equates to approximately 415 days of brushing. Enamel samples were brushed for a total of 40,000 strokes which represents approximately 5 years of brushing. Based on the present results, the first null hypothesis was rejected. There was a significant difference in dentin abrasion depth among groups with varying RDA values. Not surprisingly, the AW with the highest known RDA value of 180 showed the greatest abrasion depth that was about 0.23 mm into the dentin. This was followed by CP that has a RDA value of 68 and resulted in abrasion depth of 0.06 mm. As for the toothpaste tablets, which had RDA values of 30 and 43 respectively,^{6,8} they both produced a negligible loss of 0.02 and 0.03 mm, respectively. The microCT depth measurements in dentin had a strong positive correlation to reported RDA values. This is in accordance with a study that evaluated the effect of toothpaste abrasion level on the progression of non-caries cervical lesions and reported that slurry abrasivity level was strongly correlated with dentin volume loss.²² Few studies showed that the laboratory RDA values are not predictive of the abrasive wear in vivo or in situ,^{23,24} and that toothpastes should be considered safe when they do not exceed the RDA threshold of 250.²¹ However, since there are multiple factors that contribute to the degree of abrasive wear, oral healthcare professionals should cater to patient's specific needs and oral characteristics and caution them to not use a more abrasive toothpaste than is needed.²⁵ The second null hypothesis was rejected. There was a significant difference in enamel abrasion depth among the four groups with different RDA values. Even though enamel loss of 0.01 mm in AW was negligible, it was still higher compared to the other three groups.

To the best knowledge of the authors, this is the first study that compared the abrasivity of toothpaste tablets to conventional toothpastes using microCT. These results are significant because they shed light on the misconception that toothpaste tabs which are made of compressed powder may damage tooth structure, restricting the benefits toothpaste tablets bring both to consumers and the environment.²¹ This study prompts a paradigm shift in the awareness and need for environmentally friendly oral hygiene products. Plastic toothpaste tubes are among the most hazardous waste problems because their materials take several centuries to decompose. To address this issue, many manufacturers are reducing the amount

of packaging for their products or making the packaging reusable or recyclable.⁸ It is exciting that through promoting the use of toothpaste tablets, oral healthcare professionals have the potential to stir up a movement that encourages care for our planet and sets an example for future generations. It is noteworthy to point out several limitations of this study. First, the study did not assess the suitability of microCT in measuring the surface loss compared to other more commonly used equipment such as a surface profilometer. Second, it did not evaluate the efficacy of toothpaste tablets in removing plaque and other desired effects that most consumers desire. Third, while there are standards that detail specifics on slurry composition and appropriate ratio for conventional toothpastes, there are no guidelines on the slurry composition of tabs. Therefore, the calculation on the ratio of tabs to water used in this study may have to be modified as more information and studies on this topic become available. Lastly, since toothpaste as a paste is the conventional form, there has yet to be a study that evaluates how consumers perceive the user-friendliness of toothpaste tablets. All these unanswered questions warrant further study on this topic in the future.

Considering the limitations of this study, it is concluded that the dentin abrasivity of toothpaste tablets is negligible as substantiated with microCT. The loss of dentin tooth structure in microns correlates well to respective toothpastes' RDA values.

- a. Sally Hansen, New York, NY, USA.
- b. 3M, St. Paul, MN, USA.
- c. Colgate-Palmolive, New York, NY, USA.
- d. Denttabs GmbH, Berlin, Germany.
- e. The Kind Lab, Marina del Rey, CA, USA.
- f. Sabri Dental Enterprises Inc, Downers Grove, IL, USA.
- g. Fuchs, Twin Lakes, WI, USA.
- h. Bruker microCT N.V., Kontich, Belgium.
- i. Heinrich-Heine Dusseldorf University, Dusseldorf, Germany.
- j. The Jamovi project, Sidney, Australia.

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