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Research article

In vitro evaluation and comparison of the abrasive capacity of zirconia whitening toothpaste at different concentrations on the radicular dentin surface of human teeth

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ABSTRACT

Background: Marketed toothpastes vary in the extent to how much abrasive wear they cause to dentin. New abrasive particles in a dentifrice should be evaluated since there they can be at risk of abrasion to dentin and root surfaces.
Aim: The aim of this in vitro study was to evaluate abrasive dentin wear and surface roughness after brushing with whitening toothpaste containing zirconia at four different concentrations.
Material and method: This study tested 40 extracted human teeth. After crown removal, root dentin samples were randomly divided into four experimental groups based on zirconia toothpaste concentration: Group A (10 samples) brushed for 5 min with 0.5 % zirconia toothpaste, Group B (10 samples) with 1 %, Group C (10 samples) with 2 %, and the last 10 samples with 5 %. Before brushing, specimens were weighed three times using a precision analytical scale and measured with a Profile Projector. After completing the brushing cycles, surface roughness was measured to evaluate the differences after brushing.
Results: The Kruskal-Wallis test showed no significant difference in the weight of samples at 0.5 %, 1 %, and 2 % toothpaste concentrations. However, at the 5 % toothpaste concentration, there was a significant difference in sample weight measurements ($P < 0.05$). The mean roughness difference in the three lower concentrations indicated no significant statistical difference, but with the 5 % toothpaste, there was an increase in average dentin roughness ($P < 0.05$).
Conclusion: Results showed that percentage ≤2.0 % of zirconium powder added in a toothpaste, can lead to dentin minimal wear and better roughness by polishing effect. Toothpaste containing 5 % zirconia showed an abrasive effect on dentin and increased surface roughness.

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1. Introduction

Evaluating tooth wear, which is caused by multiple factors (acid attack, physical factors, and tooth disease), is very important for therapeutic strategies and investigation purposes [1]. The mechanism of tooth wear depends on the interplay of many factors, such as mechanical and chemical influences. Therefore, to choose the right restorative and dental materials, including toothpastes, it is important to investigate and understand their chemical and mechanical features to prevent tooth wear [2].

In today's cosmetic dentistry field, various teeth whitening techniques are available, both in professional dental settings and for at-home use by patients. People are increasingly seeking methods that are highly effective, quick, and safe, delivering whiter teeth without requiring a dental appointment. Consequently, the market offers a range of gels and toothpastes designed for this purpose [3].

Unlike bleaching gels, which primarily rely on high levels of hydrogen peroxide, whitening toothpastes offer a broader range of mechanisms for achieving whiter teeth [4]. Whitening toothpastes employ a multifaceted approach to enhance tooth whiteness. They utilize abrasive particles to scrub away extrinsic stains and dental plaque through frictional forces [5]. Chemical substances interact with tooth color molecules, breaking them down and altering their size, geometry, and polarity to change tooth color [6]. Additionally, optical brighteners like blue covarine coat tooth surfaces, enhancing the perception of whiteness [7].

As abrasive components are the primary active constituents in toothpaste formulations, they carry significant responsibility for teeth cleaning. However, it's crucial to regulate their abrasive potential, which can be affected from particle hardness, size, shape, and toothpaste pH [8]. Excessive abrasive content in toothpaste and its consistent use has the potential to harm both hard and soft oral tissues as well as dental restorations, resulting in issues like gum recession, cervical abrasion, and heightened dentinal sensitivity [9].

The remarkable mechanical characteristics of teeth, including their hardness and resistance to fracture, arise from the chemical and structural interplay between the inorganic hydroxyapatite and the organic protein matrix [10]. Research indicates that professional teeth whitening procedures in dental clinics can lead to structural harm to the enamel surface prisms and dentine

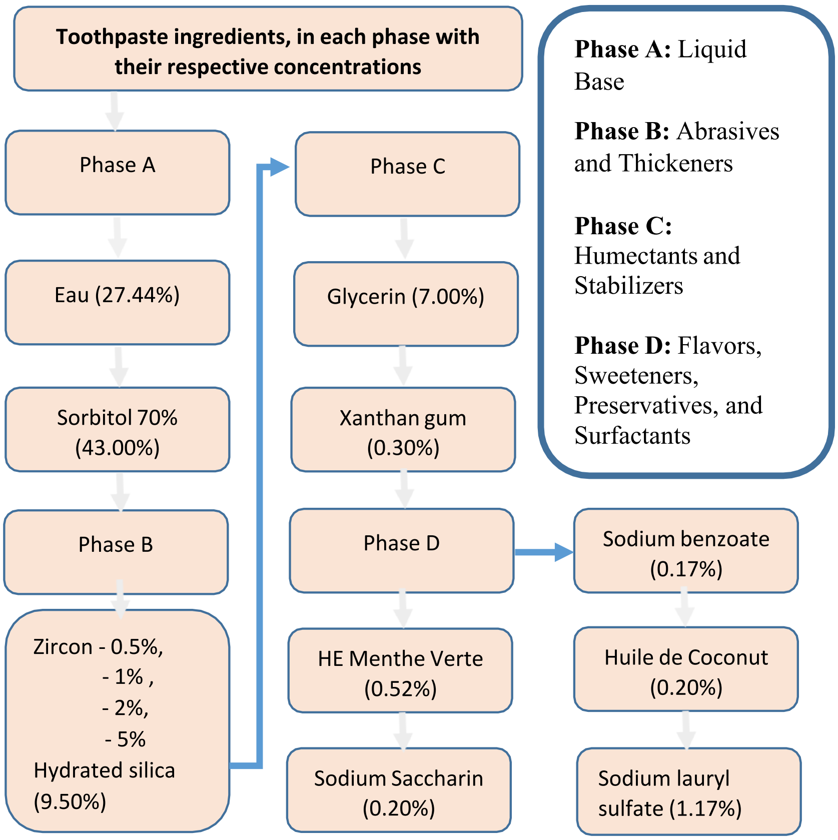

Fig. 1. Visually represented the flow of ingredients through different phases of the toothpaste production process, including their respective concentrations.

surface, and heightened tooth sensitivity [11].

Tooth structure can be lost in the crown, root, or both, leading to the formation of distinct cavities known as non-carious cervical lesions. A comprehensive review of these lesions identified that the primary risk factors for abrasion include age, oral hygiene practices, and the type of toothpaste used [12]. Abrasion is characterized by the abnormal loss of tooth surface, typically on the front side, caused by improper and aggressive brushing techniques, especially when using highly abrasive toothpastes. This condition can affect the health of the pulp and the appearance of the teeth. The extent of dentin loss appears to be linked to the abrasiveness of the tooth paste used [13].

Abrasive toothpastes, while effective in removing dental plaque and stains, can have detrimental effects on radicular dentin, the part of the tooth root that becomes exposed due to gum recession. [14]. The repeated use of such toothpastes, combined with improper brushing techniques, can lead to radicular dentin abrasion [15]. This condition not only compromises the structural integrity of the tooth but also increases sensitivity and the risk of further dental issues [16]. Understanding the impacts of abrasive toothpastes on radicular dentin is crucial for both dental professionals and patients to make informed choices that balance oral hygiene and dental health. [17].

Some of the most common abrasives in the toothpastes include silica based particles, calcium-carbonate and phosphate [18]. The new whitening toothpaste containing zirconia particles represents a significant innovation in dental care. The inclusion of zirconia particles potentially enhances the toothpaste's ability to effectively remove stains, providing a brighter, whiter smile. As shown in the diagram in Fig. 1, the toothpaste formulation was developed by researchers at Dermaflore, a Canadian laboratory located in St-Denis-sur-Richelieu, Quebec. The formulation combines zirconia with other active compounds to maximize whitening efficacy while ensuring gentle care for enamel and dentine. This advanced formulation, which has been tested for the first time, is not yet commercially available. The zirconia concentrations used in the study—0.5 %, 1.0 %, 2.0 %, and 5.0%—are part of a pilot phase and were specifically chosen by the research team based on preliminary studies to evaluate optimal whitening performance without compromising safety.

The aim of this in vitro study was to assess the magnitude of abrasive dentin wear and surface roughness caused by a new formulation whitening toothpaste containing zirconia at four different concentrations. Additionally, the study sought to determine which concentration is most adequate in minimizing dentin wear. Specifically, the hypothesis of the study is as follows:

1.1. *Primary hypothesis (H_1)*

There is a significant difference in the magnitude of dentine wear (weight loss) and surface roughness between the toothpaste formulations containing different concentrations of zirconia (0.5 %, 1.0 %, 2.0 %, and 5.0 %), with the higher concentrations (2.0 % and 5.0 %) causing more dentine wear and roughness compared to the lower concentrations (0.5 % and 1.0 %).

1.2. *Secondary hypothesis (H_2)*

The 5.0 % zirconia concentration will cause the most significant increase in dentine surface roughness, potentially due to higher abrasivity, while the 0.5 % and 1.0 % concentrations will cause less significant changes in dentine roughness, resulting in a smoother surface after brushing.

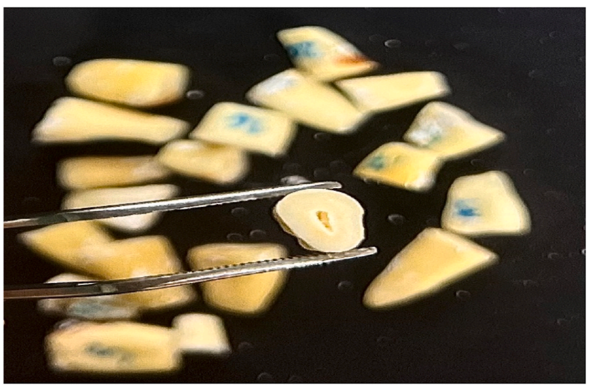

Fig. 2. Initial condition of Dentine samples after crown removal.

1.3. Exploratory hypothesis (H_3)

No significant differences will be observed in dentine wear or surface roughness between the 0.5 %, 1 %, and 2 % zirconia concentrations, as these are expected to have comparable abrasive effects.

2. Materials and methods

Approval to conduct this research was obtained from the Ethical Committee (nr.296/2, dt. 1.03.2024) of the University Dentistry Clinical Center of Kosova.

2.1. Preparation of samples

For this study, forty sections of root dentine from extracted, caries free, human incisors were utilized. After the teeth were extracted, the residual soft tissues were meticulously removed, and the tooth surfaces were cleaned using water. Subsequently, the crowns and root apices were removed, with a water-cooled diamond disc (Smart Cut 4002, UKAM, Valencia, USA) resulting in specimens approximately 1.5 cm in length (Fig. 2). Both surfaces of each specimen were flattened. The separated parts were then stored in a formalin solution (Sigma-Aldrich, St. Louis, MO, USA).

2.2. Experimental procedure

The root specimens were randomly divided into four groups (n = 10). Each group was subjected to tooth brushing with a paste containing Zirconia particles (Dermaflore, St-Denis-sur-Richeliue, Quebec, Canada) at different concentrations: 0.5 %, 1.0 %, 2.0 %, and 5.0 %.

The specimens were weighed three times before brushing using a precision analytical scale (A&D Company, Limited, Japan). Following this, the specimens were measured with a Profile Projector (Mitutoyo P1300), which has an accuracy of 0.001 mm and values were recorded. Three measurements were taken at perpendicular angles, before the toothpaste was applied, and then the samples were fixated into silicone cubes (Zhermack Zetaplus C Silicone kit, Zhermack SpA, Italy).

The samples were subjected to brushing cycles using a handpiece brush attached to a stationary micromotor, which was mounted on an improvised machine, which served for fixation purposes in the brushing phase. This setup ensured simultaneous, uniform brushing applied perpendicularly to the dentin surface (Fig. 3). A toothpaste slurry was evenly applied to each sample. Each group underwent 5000 brushing cycles, equivalent to 5 min of timed brushing, using medium bristle brushes to simulate consistent manual brushing pressure. The brushes were replaced after every five samples.

After all groups completed the brushing cycles, the specimens were rinsed with running water and air-dried to prevent inaccurate results in subsequent surface roughness measurements with the profilometer (Fig. 4), and then were once again subjected to triple weighing and triple measurement using the Profile Projector.

We also evaluated surface morphology alterations before and after cleaning with the paste at the four concentrations, using confocal microscopy (3D Optical Surface Metrology System Leica DCM8, Leica Microsystems CMS GmbH, Mannheim, Germany) at 20x magnification.

2.3. Statistics

The data were analyzed using the free version of InStat. The statistical parameters calculated included the arithmetic mean, standard deviation, median, minimum value, and maximum value. Data comparisons before and after tooth brushing with toothpaste were performed using either the paired *t*-test or the Wilcoxon matched-pairs signed-rank test, depending on the data distribution.

Fig. 3. Brushing condition of Dentine samples.

Fig. 4. Evaluation of dentin roughness with Profilometer.

Group differences were assessed with the Kruskal-Wallis test and Dunn's multiple comparison test. The significance level was set at $P < 0.05$.

3. Results

3.1. Dentine weight changes

The dentine weight before and after tooth brushing with toothpaste at four different concentrations was analyzed using both parametric and non-parametric methods, depending on the data distribution. Normality was assessed using the Shapiro-Wilk test, and the results indicated that the data for the 0.5 %, 1 %, and 2 % concentrations were not normally distributed ($P < 0.05$ for all groups), justifying the use of the Wilcoxon signed-rank test for these groups. In contrast, the 5 % concentration showed normal distribution ($P = 0.39$), allowing for the use of the paired *t*-test.

At the three lower toothpaste concentrations (0.5 %, 1 %, and 2 %), there was no significant difference in dentine weight before and after brushing ($P = 1.00$ for all groups). However, at the 5 % toothpaste concentration, there was a significant decrease in sample weight measurements ($P = 0.031$) (Table 1, Fig. 5).

The mean weight difference for each toothpaste concentration was calculated, and the results showed a significant reduction only at the 5 % concentration, with an 18.75 % decrease in dentine wear (Table 2, Fig. 6). For all other concentrations, no significant change was observed.

Table 1
Measurement of dentine wear values in grams measured before and after brushing with each concentration of the toothpaste.

Groups	Parameters	Dentine wear before (g)	Dentine wear after (g)	P-value
A. TP 0.5 % (n = 10)	Mean ± SD	0.0026 ± 0.0008	0.0026 ± 0.0008	P = 1.00
	Median (Rank)	0.002 (0.002–0.004)	0.002 (0.002–0.004)	
B. TP 1 % (n = 10)	Mean ± SD	0.0022 ± 0.0012	0.0022 ± 0.0012	P = 1.00
	Median (Rank)	0.002 (0.001–0.004)	0.002 (0.001–0.004)	
C. TP 2 % (n = 10)	Mean ± SD	0.0026 ± 0.0011	0.0026 ± 0.0011	P = 1.00
	Median (Rank)	0.003 (0.001–0.004)	0.003 (0.001–0.004)	
D. TP 5 % (n = 10)	Mean ± SD	0.0032 ± 0.0008	0.0026 ± 0.0005	P = 0.031
	Median (Rank)	0.003 (0.002–0.004)	0.003 (0.002–0.003)	

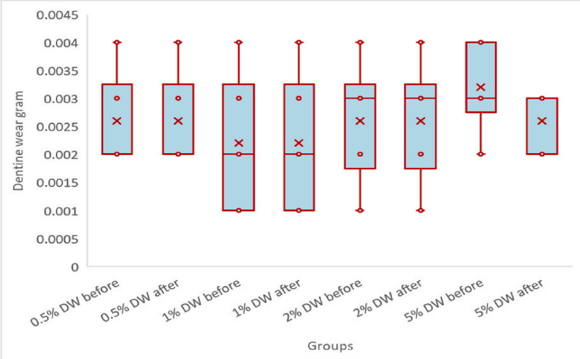

Fig. 5. Graphical distribution dentine wear changes (grams) before and after brushing with toothpaste concentration.

Table 2
Dentine wear differences (gram) before and after brushing with each concentration of the toothpaste.

Groups	Difference Mean ± SD Median (Rank)	% Differences
A. TP 0.5 %	0.0000 0.0000	0.00 %
B. TP 1 %	0.0000 0.0000	0.00 %
C. TP 2 %	0.0000 0.0000	0.00 %
D. TP 5 %	0.0006 ± 0.0005 0.001 (0.000–0.001)	18.75 %

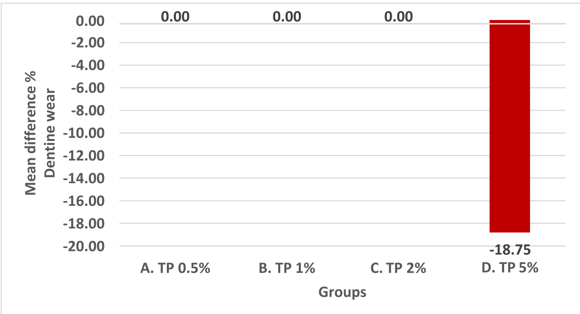

Fig. 6. Mean dentine wear differences (%) before and after brushing with each concentration of the toothpaste.

3.2. Dentine roughness

Dentine surface roughness before and after brushing with toothpaste at different concentrations was also assessed. The normality of the data was tested using the Shapiro-Wilk test. For groups with non-normal distributions (0.5 %, 1 %, and 2 % concentrations), the

Table 3
Profilometric measurements of Dentine Surface roughness(micrometers) before and after brushing with different toothpaste concentrations.

Groups	Parameters	Dentine Surface roughness before (μm)	Dentine Surface roughness after (μm)	P-value
A. TP 0.5 % (n = 10)	Mean ± SD	1.62 ± 0.71	1.00 ± 0.42	P = 0.0020
	Median (Rank)	1.71 (0.55–2.37)	1.06 (0.27–1.42)	
B. TP 1 % (n = 10)	Mean ± SD	1.14 ± 0.46	0.77 ± 0.32	P = 0.037
	Median (Rank)	0.94 (0.87–2.02)	0.78 (0.23–1.09)	
C. TP 2 % (n = 10)	Mean ± SD	1.57 ± 0.36	1.06 ± 0.29	P = 0.0098
	Median (Rank)	1.56 (0.98–1.96)	0.93 (0.78–1.56)	
D. TP 5 % (n = 10)	Mean ± SD	1.48 ± 0.70	1.87 ± 1.12	P = 0.420
	Median (Rank)	1.50 (0.57–2.29)	2.24 (0.22–3.38)	

Wilcoxon signed-rank test was applied, while the 5 % concentration data approximated a normal distribution and were analyzed using the paired *t*-test.

There were significant differences in dentine roughness for the 0.5 % (P = 0.002), 1 % (P = 0.037), and 2 % (P = 0.0098) concentrations, but no significant difference for the 5 % concentration (P = 0.420) (Table 3, Fig. 7).

The mean difference in dentine roughness was calculated for each toothpaste concentration and analyzed using the Kruskal-Wallis test. While no overall significant difference was observed across the groups (P = 0.069), Dunn's multiple comparison test was conducted to perform pairwise comparisons between the concentrations. The results showed a significant difference in dentine roughness between the 5 % concentration and the other three concentrations (0.5 %, 1 %, and 2 %), with the 5 % concentration leading to an increase in roughness in 26.96 % of the cases, while the three lower concentrations (0.5 %, 1 %, and 2 %) generally resulted in a decrease in roughness (Table 4, Fig. 8). No significant differences were found between the 0.5 %, 1 %, and 2 % concentrations. The following table and figure provide a summary of the results:

3.2.1. Effects of tooth brushing on surface morphology alterations

Representative images of the sample subjected to four different concentrations of toothpaste, captured using confocal microscopy at 20x magnification, are shown in Fig. 9A–F.

The changes in surface morphology were consistent with the results obtained from other evaluation methods. Defects such as iregularities and scratches were observed in the areas where the toothbrush was applied. The area treated with the highest zirconia-containing toothpaste concentration showed the most severe and deepest irregularities and imperfections. Conversely, using the toothpaste with the lowest concentration produced minimal surface features and irregularities, resulting in a surface that was significantly smoother and more polished than the unbrushed sample.

4. Discussion

Over the years, teeth brushing can cause enamel and dentin damage due to surface loss [19]. Additionally, tooth surface roughness not only has a negative aesthetic effect but also provides an ideal place for extrinsic stain deposition [20]. Nowadays, newer toothpastes are formulated with advanced abrasives to enhance extrinsic stain removal [21].

In the current study, we analyzed surface loss and roughness after brushing with new abrasive toothpaste containing zirconia particles at four different concentrations to evaluate the effect of toothpaste abrasiveness on dentin. This dual approach offers valuable insights into the degree of tooth material worn away and the resulting surface texture.

According to our findings, at lower toothpaste concentrations (0.5 %, 1 %, and 2 %), there was no significant change in the weight of the dentin samples after brushing, suggesting minimal abrasive impact at these levels. However, at the highest concentration (5 %), a significant weight decrease of 18.75 % was observed, indicating a substantial abrasive effect on the dentin at this concentration.

Although statistical analyses showed no significant difference in roughness across the groups, there was a noticeable trend: at lower concentrations (0.5 %, 1 %, and 2 %), there was a decrease in dentin roughness. At the highest concentration (5 %), an increase in roughness was observed in 26.96 % of cases, which corresponds with the significant weight loss and suggests increased abrasive activity.

Zirconia toothpaste exhibits varying effects on radicular dentin wear depending on its concentration. While concentrations of 0.5 %, 1 %, and 2 % show minimal impact on both weight and roughness, the 5 % concentration significantly reduces dentin weight and increases roughness, indicating a higher abrasive potential at this level. Our findings revealed a clear dose-dependent relationship, with the highest concentration of 5 % zirconia leading to the most significant dentin wear. This observation warrants a closer examination of zirconia as an abrasive agent in comparison to other commonly used abrasives in whitening toothpastes.

Previous research has highlighted the abrasive potential of various whitening agents. For instance, perlite, another abrasive agent, was shown to cause significant dentin wear [22], similar to our findings with high-concentration zirconia. Conversely, less abrasive alternatives, such as papain, an enzyme-based whitening agent, caused minimal dentin wear [23]. This suggests that enzyme-based agents can be gentler on dentin while still providing whitening benefits. Additionally, it was found that enzyme-containing toothpastes produced less dentin wear compared to those containing calcium pyrophosphate [24]. Another gentle alternative is hydroxyapatite, which Amaechi et al. [25] found to cause negligible dentin abrasion, highlighting its potential as a safe abrasive agent.

Charcoal, although popular in some whitening toothpastes, has been reported to be highly abrasive, posing risks of excessive dentin wear [26]. Dionysopoulos et al. [27] found that charcoal-containing toothpaste resulted in the highest surface roughness and exhibited the greatest surface loss in their study on abrasive wear of dentin, following tooth brushing simulation. This finding is similar to the results observed by Pertiwi et al. [28], where brushing with a charcoal-containing whitening toothpaste for three months led to an increase in surface roughness.

Toothpastes containing hydrated silica induced less abrasive wear on dentin [29] compared to charcoal whitening toothpastes, which caused more extensive and deep craters in the tooth surface [30]. After comparing silica toothpastes with those containing calcium carbonate, Priyam et al. [31] showed moderate abrasive dentin wear after brushing with toothpastes that contain silica. Similarly, it was reported that whitening toothpastes containing sodium hexametaphosphate demonstrated higher dentin abrasion than silica toothpastes [32].

This aligns with our findings at high zirconia concentrations, suggesting that while these agents can be effective in removing stains, they must be used with caution to avoid damaging the tooth structure. These findings indicate that while lower concentrations may be safer for dental health, higher concentrations should be used with caution due to their potential to cause significant dentin wear.

As individuals choose the right toothpaste to maintain oral health without compromising tooth structure, and given the limited

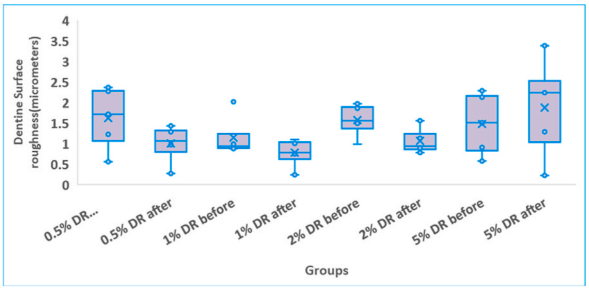

Fig. 7. Graphical Representation of Dentine Surface roughness(micrometers) before and after brushing with different toothpaste concentrations.

Table 4
Mean differences in dentine surface roughness (micrometers) before and after brushing with different toothpaste concentrations, as measured by profilometry.

Groups	Difference Mean ± SD Median (Rank)	% Differences	Dunn's test results (p-values)
A. TP 0.5 %	0.62 ± 0.51 0.29 (0.16–1.40)	−38.35 %	0.87 (ns)
B. TP 1 %	0.37 ± 0.44 0.20 (−0.15–1.02)	−32.75 %	0.74 (ns)
C. TP 2 %	0.51 ± 0.60 0.71 (−0.58–1.08)	−32.74 %	0.62 (ns)
D. TP 5 %	−0.51 ± 1.49 −0.39 (−1.88–2.07)	+26.96 %	0.03*
P- value KW test P = 0.069			

Significance: *$p < 0.05$ indicates significant difference between the 5 % concentration and the other groups after adjusting for multiple comparisons.

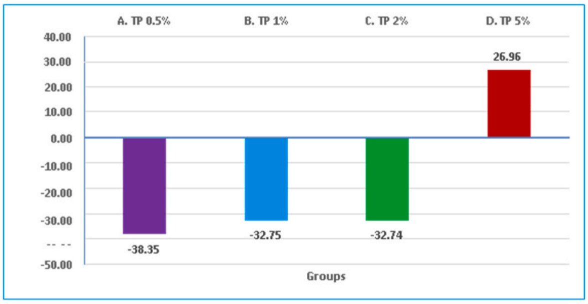

Fig. 8. Distribution of Mean differences on dentine roughness (%) before and after brushing with different toothpaste concentrations.

studies on zirconia-containing toothpastes, further research is needed to evaluate their abrasive effects on dentin.

5. Conclusion

Based on the results of this study, the following conclusions can be drawn:

1) Zirconia toothpaste demonstrated minimal abrasive impact at concentrations of 0.5 %, 1 %, and 2 %.
2) At a concentration of 5 %, zirconia toothpaste exhibited a substantial abrasive effect on dentin.
3) Toothpaste with zirconia at concentrations of 0.5 %, 1 %, and 2 % resulted in a decrease in dentin roughness.
4) At the highest concentration (5 %), an increase in dentin roughness was observed.

CRediT authorship contribution statement

Miranda Stavileci: Writing – original draft, Methodology, Formal analysis, Data curation. **Teuta Pustina:** Writing – review & editing, Formal analysis. **Besir Salihu:** Writing – review & editing, Visualization, Validation, Methodology. **Jacques Veronneau:** Project administration, Data curation, Conceptualization. **Xhevahir Bajrami:** Validation, Formal analysis, Data curation. **Afrim**

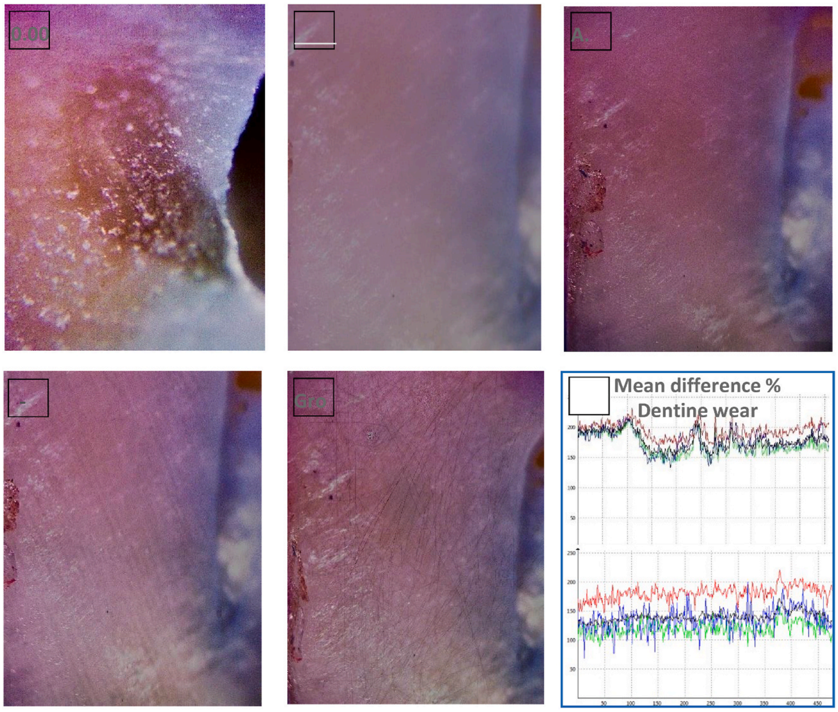

Fig. 9. Representative images from a single dentin sample in the study reveal the morphological differences between unbrushed dentin surfaces and those brushed with four varying concentrations of toothpaste. These images, captured using confocal microscopy at 20x magnification, illustrate the impact of tooth brushing on dentin morphology. (A): unbrushed surface; (B): brushed with 0.5 % concentration; (C): brushed with 1 % concentration; (D): brushed with 2 % concentration; (E): brushed with 5 % concentration; (F): the surface profile changes evaluated on microscopy between the unbrushed sample and the sample brushed with the highest concentration of Zirconia (5 %).

Gjelaj: Formal analysis, Data curation.

Data availability statement

The data supporting this study's findings are available from the corresponding authors upon request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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