Effect of toothpaste tablets on gloss and surface roughness of resin-based composite materials

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ABSTRACT: Purpose: To evaluate the effects of toothpaste tablets on the gloss and surface roughness of resin-based composite materials and determine the relationship between gloss and roughness. **Methods:** Rectangular jigs were designed and printed. Wells (2 mm deep × 7 mm diameter) were filled with Filtek Supreme Ultra A2B, light-cured and polished. A small-area glossmeter was used for gloss (GU) measurements and a profilometer for roughness measurements (Ra) at baseline and after challenge with each toothpaste. An automated tooth-brushing machine was set at 120 strokes/minute for a total of 10,000 strokes to evaluate four test groups with 16 specimens in each group. NC: Brushing with distilled water; TABS: Colgate Anywhere Travel Tooth Tabs; CP: Colgate Cavity Protection Toothpaste and AW: Colgate Whitening Advanced Toothpaste. Kruskal-Wallis test was used to test the difference in gloss and surface roughness among the groups and Pearson correlation was used to compare the relationship between gloss and roughness. **Results:** There was no statistically significant difference in gloss and roughness among the four groups at baseline. At post-brushing, there was a statistically significant difference among the groups (P< 0.001) with increased roughness and decreased gloss for CP and AW when compared to TABS. There was a statistically significant correlation between post-brushing roughness and post-brushing gloss (P< 0.001, rho: -0.815). Thus, the higher the surface roughness the lower the gloss. (*Am J Dent* 2023;36:156-160).

CLINICAL SIGNIFICANCE: Toothpaste tablets retain better gloss and roughness of resin-based composite materials when compared to conventional toothpastes.

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Introduction

Toothbrushing is a well promoted daily practice to maintain oral health and the American Dental Association recommends brushing twice daily for 2 minutes.[1] As such the global toothpaste market size was USD 18 billion in 2019 and is projected to reach USD 22 billion by 2027. Key players that drive the market include GlaxoSmithKline PLC, Unilever PLC, and Colgate-Palmolive Company.[2] With the rising growth of the toothpaste market, concerns have been raised about the environmental burden caused by plastic toothpaste tubes that are non-biodegradable.[3] Thus, the environmental sustainability has been a key driving force in toothpaste tablets sales.[4] In a newly released report, Fairfield Market Research forecasted a healthy growth outlook for global toothpaste tablet market that is likely to reach the revenue of around USD 152 million by 2026 end, up from nearly USD 109 million recorded in the year 2021.[4]

The first toothpaste tablet was developed and sold in 2003 with the purpose of first, avoiding many toothpaste ingredients that were not necessary for dental care but potentially harmful to the body. Second, to dissolve rapidly in saliva and increase immediate fluoride bioavailability to promote remineralization. Third, to trend the growing consumer inclination for cruelty-free products and the prospects of eco-friendly brand imaging. Lastly, to meet stringent regulatory framework regarding plastics and plastic products.[5,6] The benefits of toothpaste tablets have been supported by several studies[7-9] showing that the bioavailability of fluoride and sustainability was superior to conventional toothpaste. Additionally, toothpaste tablets were less abrasive to human dentin when compared to other toothpastes.[10]

The effect of tablets on the human enamel and dentin has been investigated.[10] However, there is no information on how the use of toothpaste tablets may affect restorative materials within the oral cavity. Resin-based composite materials have become the primary choice for restorations in the anterior region due to their esthetic properties and minimal invasiveness.[11,12] Based on a systematic review,[13] fracture and secondary decay were the main causes of failure of resin-based composite restorations in the anterior region. It is important to note that the high expectation for esthetics within the anterior region suggests that restoration failure apart from fracture and caries will occur at a greater extent within the anterior region.[14] It is well known that tooth brushing with toothpastes causes overall roughness and reduction of gloss of resin-based composites over time which may be another cause for replacement of the restoration.[15,16]

Considering the lack of studies on the long-term effects of toothpaste tablets on resin-based composite materials, the purpose of this study was to evaluate the effects of toothpaste tablets on the gloss and surface roughness of resin-based composite materials and determine the relationship between gloss and roughness. The hypothesis was that there would be no difference in gloss and roughness when comparing toothpaste tablets to conventional toothpaste.

Materials and Methods

Specimen preparation - The experimental design from jig fabrication to final gloss and roughness assessment is illustrated in Fig. 1. Rectangular jigs of $11 \times 12 \times 18$ mm^3 including wells (2 mm depth and 7 mm diameter) were designed and printed with a 3D printer[a] using polylactic acid
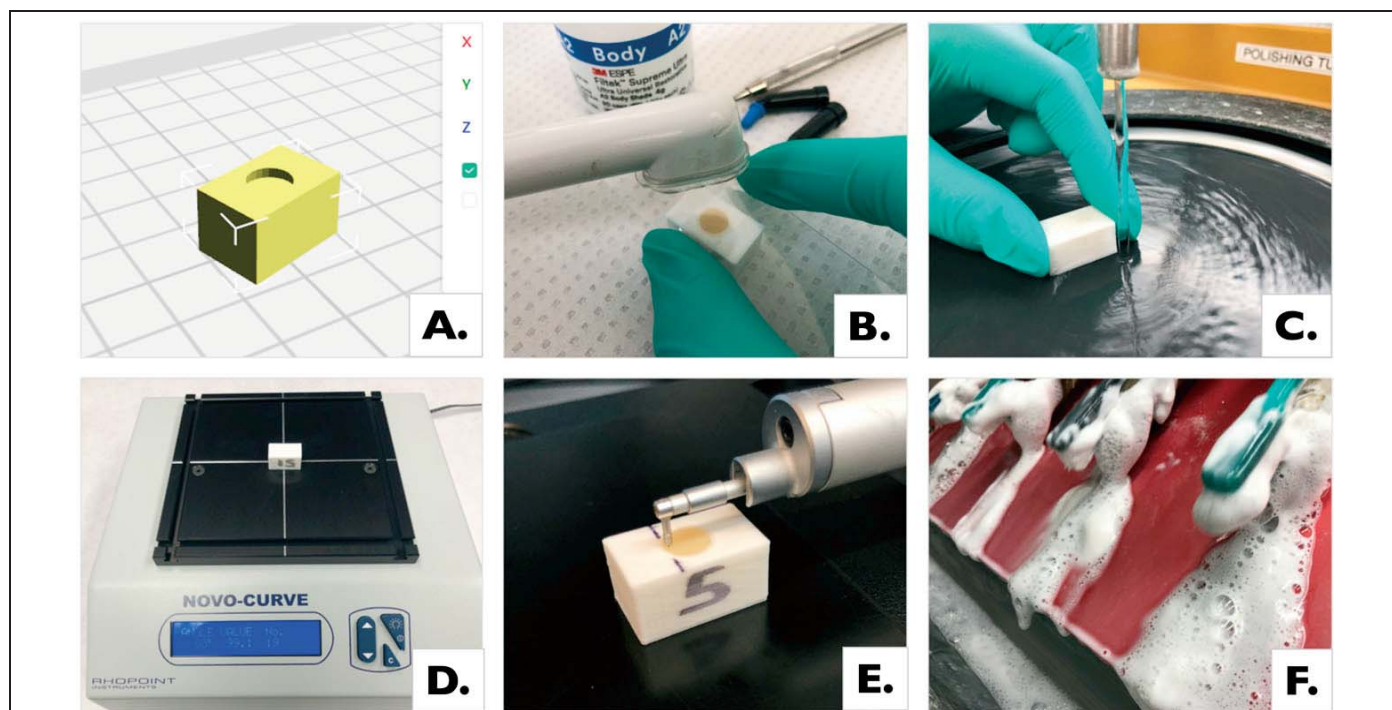
Fig. 1. Step-by-step experimental protocol. **A.** Rectangular jigs of 11x12x18 mm^3 including wells (2 mm depth and 7 mm diameter) were designed and printed. **B.** The wells were filled with nanohybrid composite and light-cured. **C.** Specimens were polished under a constant flow of water with a rotary polishing equipment. **D.** Gloss was measured using a small-area glossmeter. **E.** Surface roughness was measured using a contact-type profilometer. **F.** All specimens were challenged with respective toothpaste and an automated toothbrushing machine.

(PLA) 3D printer filaments (Fig. 1A). The wells were filled with nanohybrid composite (Filtek Supreme Ultra,[b] shade A2B) and a mylar strip and glass slide placed on top to extrude the excess material and flatten the surface of the specimens. The filled wells were then light cured for 40 seconds using a light-emitting diode curing light (Demi Plus[c]) with radiant emittance of 500 mW/cm^2 (Fig. 1B).

Polishing protocol - Specimens were ground flat using a sequence starting at P600 and sequentially increasing to P1200 silicon carbide paper under a constant flow of water with a rotary polishing equipment (Ecomet II Polisher[d]). A slurry of aluminum oxide[d] (0.3 μm) was used for the final polishing (Fig. 1C).

Experimental groups - Specimens were randomized into four groups of 16 specimens each: Group NC: Brushing with distilled water; Group TABS: Colgate Anywhere Travel Toothpaste Tablets;[e] Group CP: Colgate Cavity Protection Toothpaste;[e] and Group AW: Colgate Whitening Advanced Toothpaste.[e]

Gloss measurements - To reduce variability that may be associated with any edge effects, we measured the gloss over a 6 mm diameter area in the center of each specimen. Gloss was measured in five different areas (top, bottom, left, right, and center of a cross shape) on each specimen using a small-area glossmeter (Novo-Curve[f]) with a measurement area of 2×2 mm and 60° geometry and calculated an average. Gloss was assessed at baseline and after the automated tooth-brushing (Fig. 1D).

Surface roughness measurements - A contact profilometer (Mitutoyo Surftest SV-2000[g]) was used to measure the roughness (Ra) at baseline (T1) and after simulated brushing (T2). Surface roughness was measured with a preset evaluation

length of 4 mm. Three scans of 4 mm were conducted and averaged (Fig. 1E).

Toothbrushing protocol - On completing the baseline surface roughness and gloss measurements, all specimens were mounted on an automated toothbrushing machine (V-8 Cross Brushing Machine[h]). 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. Thus, the samples were brushed for a total of 83 minutes (Fig. 1F). Considering that brushing is recommended twice daily, the amount of dentin brushing equates to approximately 415 days of brushing. The dentifrice slurries were prepared according to ISO 11609 by adding 40 ml of water to 25 g of each dentifrice. All slurries were used shortly after preparation and after vigorous mechanical stirring to prevent particles from settling.

Scanning electron microscopy (SEM) - Selected resin-based composite specimens from each group were removed from the printed jig and sputter coated with gold in a vacuum evaporator for observation with the scanning electron microscope (Quanta FEG 250[i]). Photomicrographs of representative areas for qualitative analysis were taken at 5,000× magnifications.

Data analysis: G*Power[j] 3.1.9.4 was used to determine the sample size based on a previous unpublished study using the following parameters: 80% power and 20% difference and four experimental groups. A minimum sample size of 15 specimens per group was assessed to be appropriate. Means and standard deviations of gloss and surface roughness between the baseline and post-brushing measurements were calculated. Measurements of interest for surface roughness

Table. Summary of gloss and surface roughness by group at baseline and post-brushing (Mean ± SD).

	NC	TABS	CP	AW	P-value*
Baseline gloss (GU)	91.0 ± 1.8A	91.1 ± 2.4A	91.0 ± 3.3A	90.7 ± 2.2A	0.956
Post-brushing gloss (GU)	85.1 ± 6.6aA	72.3 ± 8.6bB	45.8 ± 7.6cB	44.2 ± 5.3cB	<0.001
Baseline roughness (Ra)	0.030 ± 0.004A	0.029 ± 0.004A	0.030 ± 0.003A	0.029 ± 0.003A	0.72
Post-brushing roughness (Ra)	0.032 ± 0.009aA	0.041 ± 0.009bB	0.054 ± 0.008cB	0.053 ± 0.008cB	<0.001

*Kruskal-Wallis test.
Different lower-case letters within the same row indicate significance after pairwise comparisons.
Different upper-case letters within the same column indicate significance on Repeated ANOVA measures.
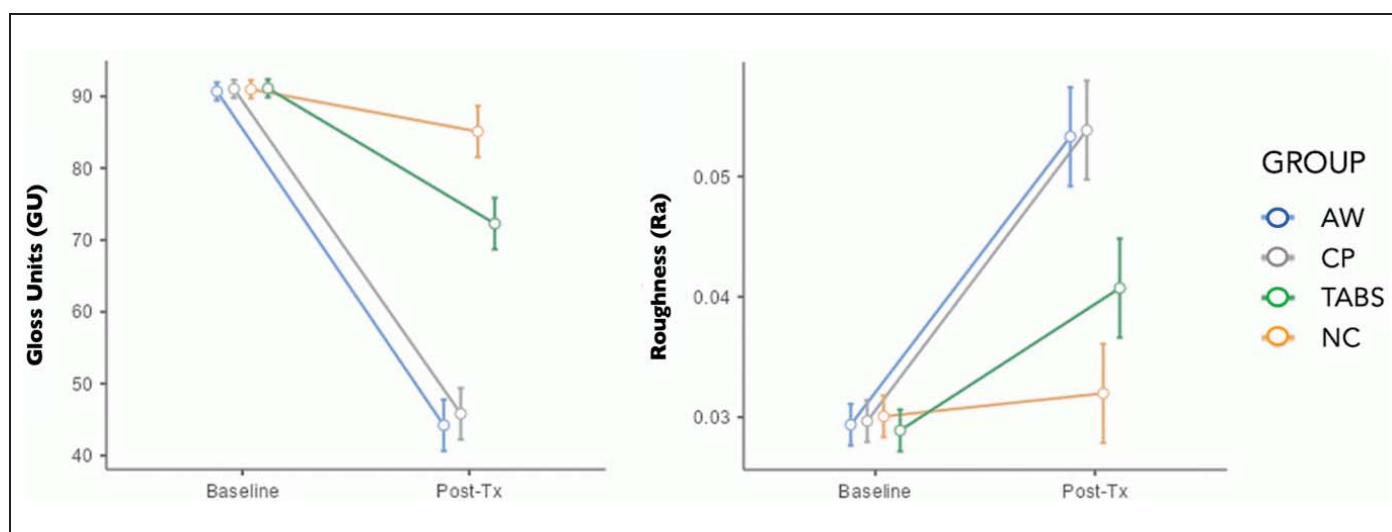

Fig. 2. Change of gloss and surface roughness from baseline to post-brushing within each group. Groups TABS, CP, and AW showed decreased gloss and increased surface roughness (P< 0.05, in all instances). There was no statistically significant difference in baseline and post-brushing for gloss and surface roughness within group NC (P> 0.05, for both instances).

evaluations included gloss and Ra at T1 and T2. The Kruskal-Wallis procedure was performed to compare the difference by groups. Post hoc comparisons were conducted with Bonferroni corrections where appropriate. Pearson Correlation was used to compare the relationship between gloss and roughness. All tests of significance were two-sided and conducted at an alpha level of 0.05 with SPSS[k] v25.

Results

The mean gloss and surface roughness by groups is summarized in the Table. There was no statistically significant difference in gloss and surface roughness among the groups at baseline (P= 0.956 and P= 0.720). On completion of 10,000 brushing strokes, there was a statistically significant difference in gloss and surface roughness among the four groups (P< 0.001 in both instances). After multiple pairwise comparisons, group NC had the highest gloss with a mean of 85.1 followed by group TABS with a mean of 72.3. Groups CP and AW had the lowest gloss which were not statistically significantly different from each other (45.8 vs 44.2). Group NC showed the lowest surface roughness with a mean of 0.032 μm followed by group TABS with a mean of 0.041 μm. Groups CP and AW had the highest roughness which were not statistically significantly different from each other (0.054 μm vs 0.053 μm).

The change of gloss and surface roughness from baseline to post-brushing within each group is illustrated as line plots in Fig. 2. The automated brushing decreased gloss and increased surface roughness for groups TABS, CP, and AW (P< 0.05, in all instances). There was no statistically significant difference in baseline and post-brushing for gloss and surface roughness within group NC using Repeated Measures of ANOVA (P> 0.05, in both instances).

There was a statistically significant correlation between post-brushing roughness and post-brushing gloss (P< 0.001, rho: -0.815). Thus, the higher the surface roughness the lower the gloss. Filtek Supreme Ultra is a nanocomposite formulated using both engineered nanoparticle and zirconia/silica nanocluster fillers. The nanocluster filler particles consist of loosely bound aggregates of engineered nanofiller particles. The qualitative SEM photomicrographs are illustrated in Fig. 3. In each group, the shape of the primary nanoparticles was evident in the big clusters. The potential dislodging of fillers in group AW has been labeled with white arrows (Fig. 3).

Discussion

The study prompted a paradigm shift in the awareness for environmentally friendly oral hygiene products and thorough assessment on their potential benefits and harm to the oral cavity. Specifically, the study aimed to investigate the impact of toothpaste tablets on the gloss and surface roughness of resin-based composite materials. Gloss which is recorded as gloss units (GU) is a relatively under-examined visual property of dental materials' surfaces. It is used to quantitate
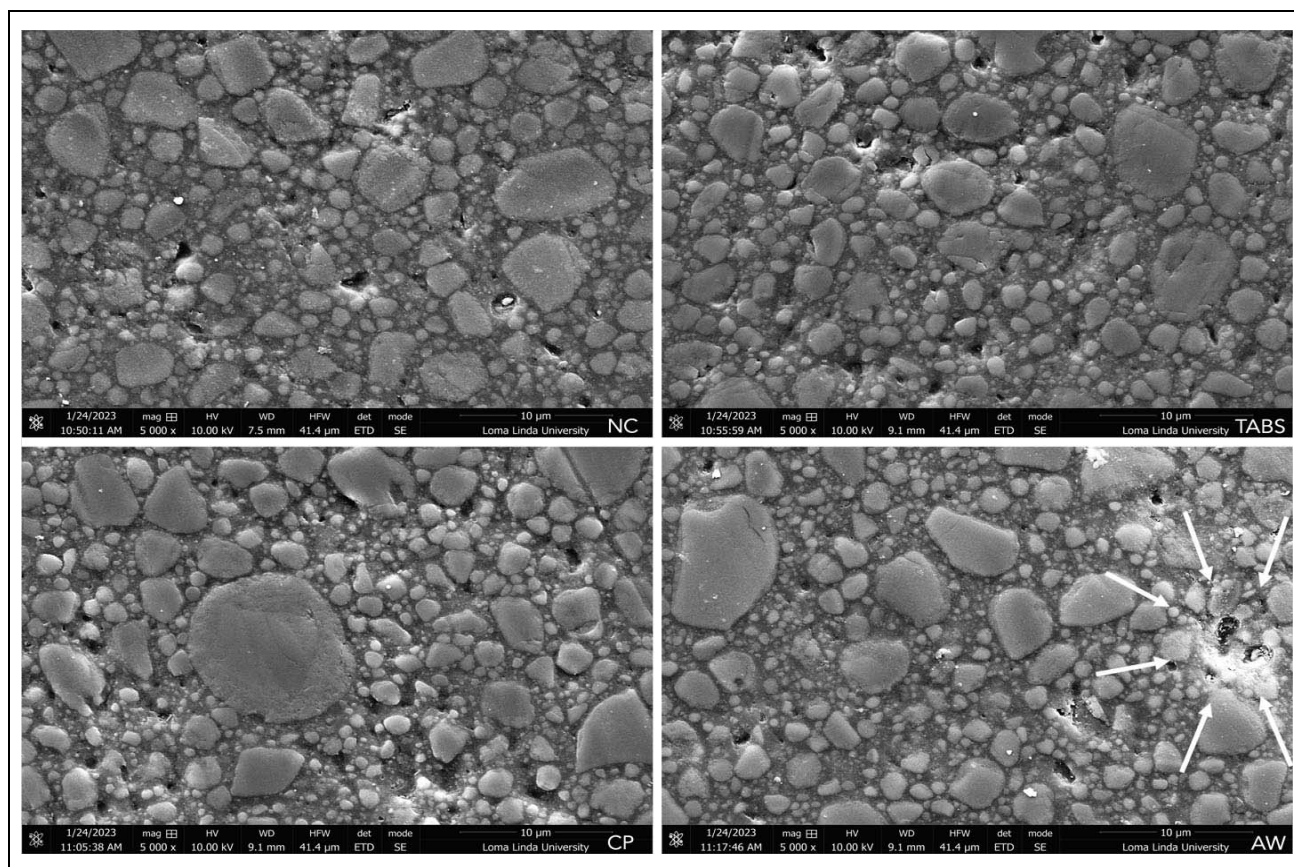
Fig. 3. SEM Photomicrographs by group. AW: White arrows indicate possible dislodging of fillers from the resin matrix.

the shininess of a surface and understood to be a complex interaction of variables including illumination, surface properties and observer.[17] Based on the study results the hypothesis that there were differences in gloss among the groups with the new toothpaste tablets showing less gloss reduction as compared to conventional toothpastes was rejected. This is a significant finding as it may indicate that toothpaste tablets could be a viable and environmentally friendly alternative to traditional toothpaste for individuals with dental restorations. The effect of conventional tooth-pastes on the gloss of nano-filled resin-based composite materials had been investigated and the amount of gloss reduction was comparable to a previous study.[15] Noteworthy was the fact that even with the reduction in gloss, all tested toothpastes maintained the visually acceptable gloss threshold of 40 through 50 GU.[18]

The surface roughness of resin-based composite materials has been shown to have a significant impact on the formation of biofilms by oral bacteria. When composite materials used for dental restorations have a rough or uneven surface, they can provide more favorable conditions for bacterial colonization and biofilm formation, which can increase the risk of secondary caries developing around the restoration.[19,20] The effect of toothpaste tablets on surface roughness was identical to its finding on gloss. Based on the results, the hypothesis that there would be no difference in roughness among the groups was rejected. Brushing with toothpaste tablets increased surface roughness compared to brushing with distilled water (negative control) but produced less roughness compared to conventional toothpastes. The

findings are comparable to other studies[15,21-25] that reported an increase in surface roughness of resin-based composite materials after simulated toothbrushing with various toothpastes. It is important to point out that Colgate Cavity Protection with a known RDA of 65 had similar increase in surface roughness as compared to Advanced Tooth Whitening toothpaste with RDA of 142. This is contrary to other studies[15] that reported that the more abrasive the toothpaste the rougher the resulting surface.

A unique feature that was visible to the naked eye in specimens brushed with Advanced Tooth Whitening toothpaste was localized pitting of the resin-based composite surface. This has also been identified on the qualitative SEM images that were taken on selective specimens. It is possible that the "citric acid" included in the Advanced Whitening toothpaste may have caused localized dissolution of the resin matrix and caused dislodgement of the filler particles. Despite the increase in surface roughness in all test groups, none of the toothpastes evaluated showed surface roughness value equal or above the 0.2 μm threshold value for bacterial retention. The average surface roughness values were much lower than the threshold that is 0.041 μm, 0.054 μm, and 0.053 μm for Colgate toothpaste tablets, Colgate Cavity Protection, and Colgate Advanced Whitening, respectively. Not surprisingly, the current study also found that there was an inverse relationship between roughness and gloss, indicating that the higher the surface roughness the lower the gloss.

To the best of the authors' knowledge, this is the first study that evaluated the effect of toothpaste tablets on the gloss and surface roughness of resin-based composite materi-

als. A major strength included the use of a negative control of brushing with distilled water to rule out possible abrasive effects of the toothbrush used. The present results reflected that the negative control indeed did not affect gloss nor surface roughness. In vitro studies have inherent limitations of not fully representing the dynamic in vivo process with the presence of saliva and complex interactions within the oral cavity. Furthermore, the study did not evaluate the wide variety of different toothpaste tablets that are available on the market and the effect of specific toothpaste ingredients on gloss and surface roughness on other resin composites.

Overall, the study's findings suggest that toothpaste tablets may be a promising option for environmentally friendly oral hygiene while also minimizing any potential harm to dental restorations made from resin-based composite materials. Further research is needed to confirm these findings and evaluate the long-term effects of using toothpaste tablets on oral health to provide valuable information for dental professionals and patients who may be considering using this new oral hygiene product. Moreover, the study's focus on gloss as a visual property of dental materials' surfaces highlights the importance of considering a range of factors when evaluating the impact of oral hygiene products on dental restorations.

a. Anycubic, Shenzhen, China.
b. 3M Oral Care, Irvine, CA, USA.
c. Kerr Corp., Brea CA, USA.
d. Buehler Ltd, Lake Bluff, IL, USA.
e. Colgate-Palmolive, New York, NY, USA.
f. Rhopoint Instruments, Troy, MI, USA.
g. Mitutoyo, Tokyo, Japan.
h. Sabri Dental, Downers Grove, IL, USA.
i. Thermo Fisher, Waltham, MA, USA.
j. Heinrich-Heine Dusseldorf University, Germany.
k. SPSS, Armonk, NY, USA.

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