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Influence of different toothpaste abrasives on the bristle end-rounding quality of toothbrushes

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Abstract: *Objectives:* To evaluate the influence of different toothpaste abrasives on the bristle wear and bristle tip morphology of toothbrushes with different degrees of hardness. *Material and methods:* Ninety samples of bovine incisor teeth were used in this study. The samples were randomly divided into three groups according to the bristle hardness of the toothbrush used: soft bristles (S); extra-soft bristles (ES); hard bristles (H). The toothbrushes of each group were randomly divided into six subgroups with five toothbrushes each, according to the abrasive of the toothpaste used in the simulation: Negative control (distilled water); toothpaste 1 (silica); toothpaste 2 (hydrated silica); toothpaste 3 (calcium carbonate, calcium bicarbonate and silica); toothpaste 4 (tetrapotassium pyrophosphate, silica and titanium dioxide); toothpaste 5 (calcium carbonate). The samples were placed in a toothbrushing simulating machine that simulating three months of brushing. The toothbrush bristles were evaluated by the bristle wear index, and the bristle tips morphology was evaluated by the bristle tip morphology index. *Results:* The ES brush presented the highest bristle wear among the toothbrushes. Additionally, the S brushes showed better morphology of the bristles followed by ES and H brushes. The type of abrasive only influenced the bristle tip morphology of the ES brushes. The toothpaste 3 induced the worse bristle tip morphology than all the other toothpastes. *Conclusions:* Different abrasives have influence only on the bristle tip morphology of the ES brushes.

Key words: *In vitro* studies; toothbrush; toothpastes

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Introduction

Dental caries and periodontal disease are the most common oral diseases worldwide (1). These two conditions share the same primary aetiologic factor, namely dental biofilms (2). Thus, prevention of these diseases should focus on the regular removal of dental biofilms (3).

The toothbrush is the primary instrument used to maintain oral hygiene. Currently, many products are available in the market, offering a wide variety of designs (4, 5). However, brush design must meet standards that enable highly efficient control of dental biofilms without damaging oral tissue (3). Among these standards, toothbrush bristle tips should have an appropriate morphology to protect the dental tissues and gums. The morphology of rounded bristle tips is the most highly recommended for preventing tissue damage (6, 7). Another important factor related to brushing efficiency is the general wear of the bristles during use. The assertion that the bristles of worn brushes demonstrate reduced ability to remove dental plaque compared with new brushes remains controversial because some studies indicated a higher level of plaque control in patients using new toothbrushes (8), while others have contradicted these findings (9–11). Nevertheless, bristle wear can serve as a parameter for determining brush replacement (8) as the bristle condition appears to be a more appropriate measure of brush replacement time than the commonly used toothbrush age (8).

The abrasive components in toothpaste are designed to remove microbial deposits via friction between the particles and the tooth surface (12, 13). The different types of abrasive particles in commercially available toothpastes range in size to provide greater friction during brushing (13), which does not necessarily indicate increased plaque removal (14). Therefore, different abrasives can influence the wear and morphology of toothbrush bristle tips during use. This study aimed to evaluate the influence of different toothpastes on the bristle wear and bristle tip morphology of toothbrushes with varying degrees of stiffness.

Material and methods

Ethical considerations

This project was approved by the Ethics Committee on Animal Experiments of the School of Dentistry of Araraquara – UNESP, within the regulations established by the Brazilian College of Animal Experimentation (COBEA) (03/2010).

Preparation of test bases and arrangement of groups

Ninety bovine incisor teeth were used in this study. The intact teeth were stored in sterile saline prior to testing. Enamel samples were prepared (10×4 mm^2 and 2 mm thick) using a low-speed diamond blade. The samples were stored individually in a solution containing 5 ml distilled water and maintained at 37°C. Ninety samples were then mounted in acrylic resin sample specimens (VIPI Cril, Pirassununga, Brazil) prepared with a metal matrix designed for this study.

The samples were randomly divided into three groups according to the bristle stiffness of the toothbrushes used: Group I: soft bristles (S) (30 toothbrushes – Oral-B Indicator 35, Oral-B Cincinnati, OH, USA); Group II: extra-soft bristles (ES) (30 toothbrushes – Colgate 360°, Colgate-Palmolive, New York, NY, USA); Group III: hard bristles (H) (30 toothbrushes – Tek, Johnson & Johnson, New Brunswick, NJ, USA) (Table 1 and Fig. 1).

The toothbrushes were randomly divided into six groups according to the toothpaste abrasives used in the simulation with five toothbrushes in each group as follows: negative control (distilled water); toothpaste 1 (Oral-B pro-sensitive; Oral-B; main abrasive: silica); toothpaste 2 (Colgate Total 12; Colgate-Palmolive; main abrasives: hydrated silica and Gantrez); toothpaste 3 (Colgate Baking Soda & Peroxide with Tartar Control; Colgate-Palmolive; main abrasives: calcium carbonate, calcium bicarbonate and silica); toothpaste 4 (Colgate Sensitive Maximum Strength; Colgate-Palmolive; main abrasives: tetrapotassium pyrophosphate, silica and titanium dioxide); subgroup F: toothpaste 5 (Sorriso; Colgate-Palmolive, Osasco, Brazil; main abrasives: calcium carbonate) (Table 1). Despite the importance of relative dentin abrasion (RDA) information, the specific RDA values were not available for the commercial dentifrices used.

Brushing simulation

The samples were placed in a toothbrushing simulating machine and submerged in distilled water or 3:1 (mass ratio) distilled water/toothpaste solutions during the tests. After adjustments, the brushing simulation began with controlled-amplitude horizontal cyclic movements, allowing the brushes to move linearly 18 mm in each direction. This movement also allowed the continuous agitation of the brushing solutions, minimizing the possible deposition of the abrasive particles in the immersion medium. To simulate 3 months of brushing, 2700 cycles were performed at 10 rpm with a constant vertical force of 200 *g* (15).

Analysis of the toothbrush bristles

The 90 toothbrushes were evaluated for bristle wear and bristle tip morphology before and after the brushing cycles. To analyse brush wear, five measurements were recorded for each toothbrush using a digital caliper (Series 500-144B; Mitutoyo, Suzano, Brazil), according to the methodology used by Rawls *et al.* 1989 (16): free-long length (FLL) which corresponds to

Table 1. **List of toothbrushes and toothpastes used in this study**

Toothbrushes	Brand	Toothpastes	Brand
Soft bristle (S)	Oral-B Indicator 35, Oral-B Cincinnati, OH, USA	Negative control	Distilled water
		Toothpaste 1	Oral-B pro-sensitive Oral-B, Cincinnati, OH, USA
Extra-soft bristle (ES)	Colgate 360º, Colgate-Palmolive, New York, NY, USA	Toothpaste 2	Colgate total 12, Colgate-Palmolive, New York, NY, USA
		Toothpaste 3	Colgate Baking Soda & Peroxide with Tartar Control, Colgate-Palmolive, New York, NY, USA
Hard bristle (H)	Tek, Johnson & Johnson New Brunswick, NJ, USA	Toothpaste 4	Colgate Sensitive Maximum Strength Colgate-Palmolive, New York, NY, USA
		Toothpaste 5	Sorriso, Colgate-Palmolive, Osasco SP, Brazil

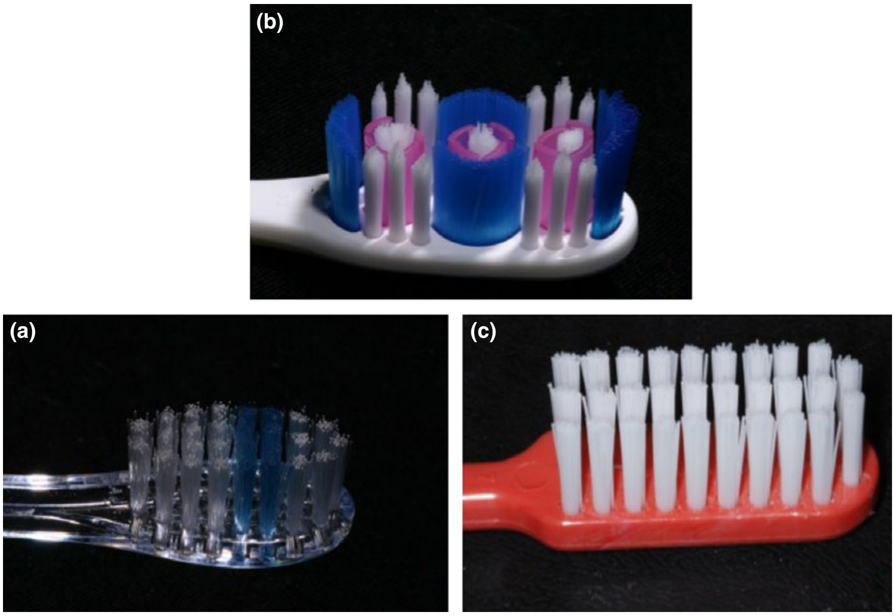

Fig. 1. Toothbrushes used in this study. (a) Soft bristle; (b) extra-soft bristle; (c) hard bristle.

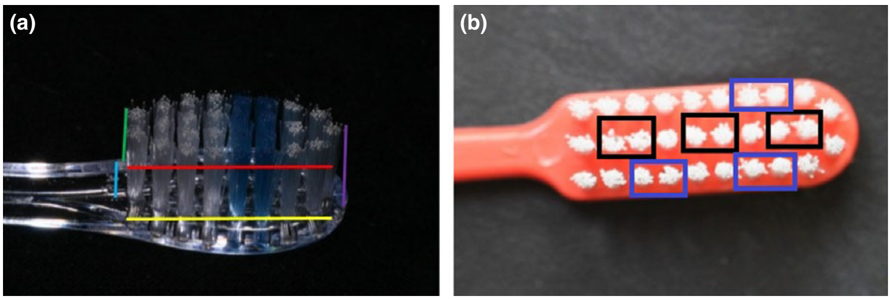

Fig. 2. Analysis of the toothbrush bristles. (a) Toothbrush wear analysis: FLL (red straight); BLL (yellow straight); FFL (green straight); BFL (blue straight); BRL (purple straight). (b) Analysis of the bristle tip deterioration: the black squares represents the fields of the central bristle analysis, while the blue squares represents the fields of the lateral bristle analysis.

the length of the toothbrush head at the top of the larger side; base-long length (BLL) which corresponds to the length of the toothbrush head at the bottom (base) of the longer side; front-free length (FFL) which corresponds to the length of toothbrush head measured at the top of the shorter side (base); base-free length (BFL) which corresponds to the length of the toothbrush head measured at the bottom (base) of the shorter side; and bristle length (BRL) measured at the height of the bristles. The wear rate was calculated using the following formula: WI = FLL−BLL+FFL−BFL/BRL (16) (Fig. 2a).

To analyse bristle tip deterioration, six images were produced for each toothbrush using an optical microscope at 20× magnification (Leica Reichert & Jung Products, Wetzlar, Hessen, Germany). Three of these images captured the top view to evaluate the central bristles, and three images captured the lateral view to evaluate the lateral bristles in randomly selected areas (Fig. 2b). A blind examiner, trained and calibrated, conducted two measurements of the toothbrush bristle tips (Kappa Index = 0.83), using the index proposed by Silverstone and Featherstone 1988 (17) to rate the bristle tip morphology as acceptable or unacceptable depending on the rounding of the bristle tips (Fig. 3).

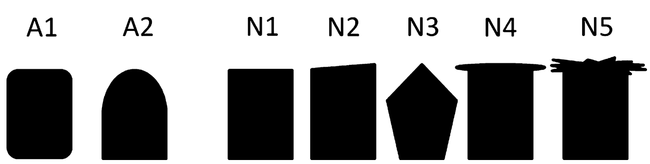

Fig. 3. Classification of bristle tip geometry in two groups. The group (A) represents the acceptable rounding, and the group N represents the non-acceptable rounding.

Prior to the brushing cycle, the toothbrushes were evaluated for bristle tip morphology, and group S exhibited a more rounded morphology than group ES or H ($P < 0.05$). Group ES exhibited a more rounded bristle tip morphology than group H (Fig. 4a–c) ($P < 0.05$). Comparing the bristle groups, the central bristles of the toothbrushes in groups S and ES were more rounded than those in group H. In addition, the lateral bristles of group S exhibited a more rounded bristle tip standard morphology than those in groups ES and H (Fig. 4d–f) ($P < 0.05$). The toothbrushes in group ES showed a more rounded pattern in their lateral bristle tip morphology than those in group H (Table 2) ($P < 0.05$). No differences were noted in the bristle tip morphology and bristle wear within the subgroups of each toothbrush analysed.

To evaluate the stiffness of the toothbrush bristles, three randomly selected images from 10 toothbrushes in each group

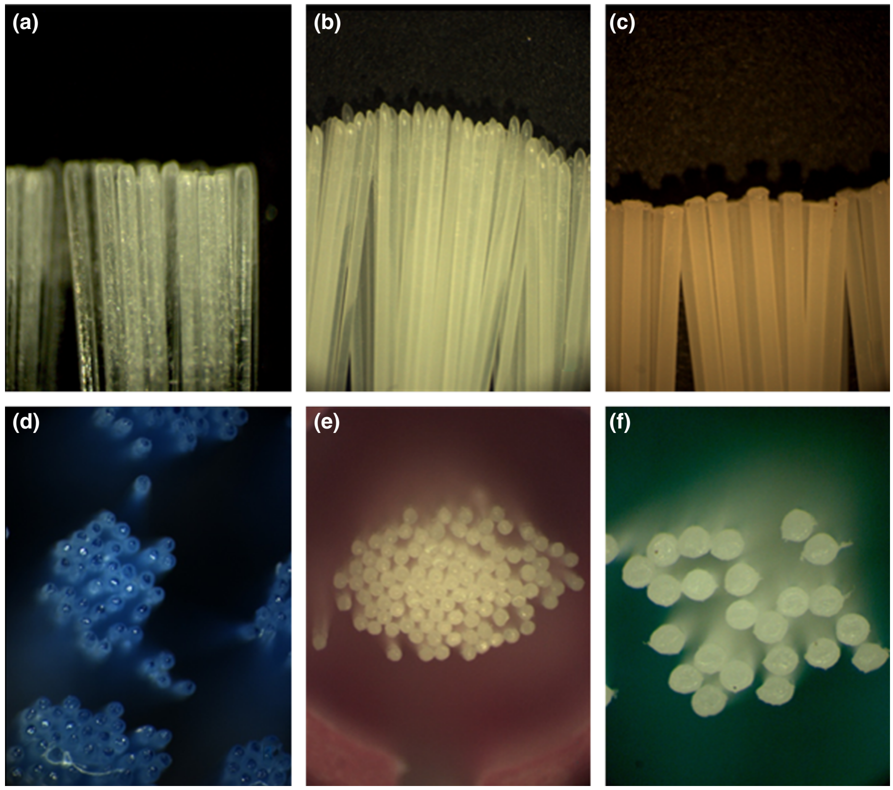

Fig. 4. Images of the toothbrushes before the brushing cycles. (a) Side view of the toothbrush 1 demonstrating score A1; (b) side view of the toothbrush 2 demonstrating score N3; (c) side view of the toothbrush 3 demonstrating score N4; (d) upper view of the toothbrush 1 demonstrating score A1; (e) upper view of the toothbrush 2 demonstrating score A1; (f) upper view of the toothbrush 3 demonstrating score N4.

Table 2. **Distribution of the scores of the bristle tip morphology before the brushing simulation and the level of the pattern of each toothbrush, the letter A represents the best pattern, while the subsequent letters represents the worsening of the pattern of the bristle tip morphology (Mann–Whiney test). It was performed three evaluations in the central bristles and more three evaluations in the lateral bristles giving six evaluations per toothbrush**

	Toothbrush	A1	A2	N1	N2	N3	N4	N5	Level
Central bristles	Soft bristle	18	–	72	–	–	–	–	A
	Extra-soft bristle	5	10	61	–	–	9	1	A
	Hard bristle	–	–	4	–	–	47	39	B
Lateral bristles	Soft bristle	41	30	19	–	–	–	–	A
	Extra-soft bristle	–	52	–	13	25	–	–	B
	Hard bristle	7	–	9	–	16	30	28	C
General	Soft bristle	59	30	91	–	–	–	–	A
	Extra-soft bristle	5	62	74	–	25	9	1	B
	Hard bristle	7	–	13	–	16	77	67	C

were analysed with respect to their bristle diameter. The toothbrushes in group ES had a bristle diameter of 0.28 ± 0.03 mm, those in group S had a diameter of 0.34 ± 0.03 mm, and the toothbrushes in group H had a diameter of 0.70 ± 0.06 mm. The toothbrushes in group ES presented a lower bristle diameter than those in the other two groups ($P < 0.01$), while the toothbrushes in group S presented a lower bristle diameter than those in group H ($P < 0.01$).

Statistical analysis

Biostat 5.0 (Instituto Mamirauá, Belém, Brazil) was used for the statistical analysis. The Shapiro–Wilk normality test indicated that the bristle wear data complied with the central distribution theorem; therefore, parametric tests were used to analyse these data. To compare the wear of the toothbrush bristles before and after brushing, a paired *t*-test was performed. For comparison between the groups, an ANOVA test was supplemented with a Tukey test. To evaluate the bristle tip morphology, a Kruskal–Wallis test was supplemented with a Mann–Whitney test to compare the effects of the different abrasives on the toothbrush bristle tips, and a Wilcoxon test assessed the bristle tips within each toothbrush group before and after brushing. All tests were applied with a 95% significance level ($P < 0.05$).

Results

Analysis of the bristle tip deterioration

After the brushing cycles, the Kruskal–Wallis tests revealed significant differences between the groups ($P < 0.05$). The Mann–Whitney test indicated that the toothbrushes in group S presented a more rounded bristle tip morphology when compared with those in groups ES and H ($P < 0.05$). Furthermore, the toothbrushes in group ES exhibited a more rounded bristle tip morphology than those in group H ($P < 0.05$). These results were replicated when the different bristle regions were considered separately (Fig. 5a–f) (Table 3). All toothbrushes showed less rounded bristle tips after the brushing cycles ($P < 0.05$).

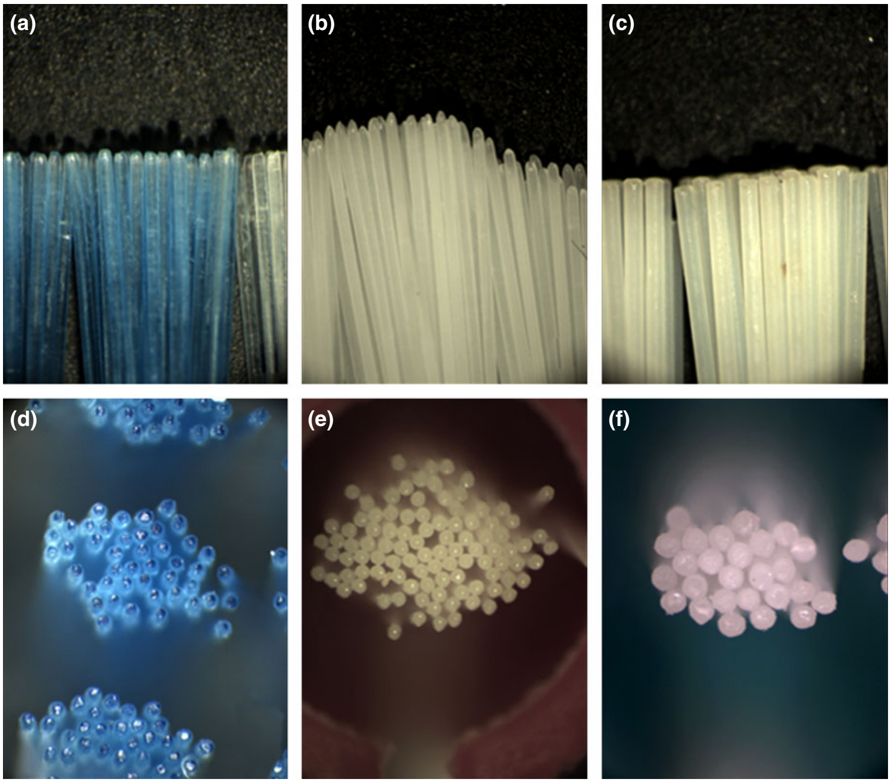

Fig. 5. Images of the toothbrushes after the brushing cycles. (a) Side view of the toothbrush 1 demonstrating score A2; (b) side view of the toothbrush 2 demonstrating score N3; (c) side view of the toothbrush 3 demonstrating score N4; (d) upper view of the toothbrush 1 demonstrating score N1; (e) upper view of the toothbrush 2 demonstrating score N1; (f) upper view of the toothbrush 3 demonstrating score N4.

Table 3. **Distribution of the scores of the bristle tip morphology after the brushing simulation and the level of the pattern of each toothbrush, the letter A represents the best pattern, while the subsequent letters represents the worsening of the pattern of the bristle tip morphology (Mann–Whiney test). It was performed three evaluations in the central bristles and more three evaluations in the lateral bristles giving six evaluations per toothbrush**

	Toothbrush	A1	A2	N1	N2	N3	N4	N5	Level
Central bristles	Soft bristle	4	1	45	–	–	39	1	A
	Extra-soft bristle	–	–	26	5	7	38	14	B
	Hard bristle	–	–	–	–	–	8	82	C
Lateral bristles	Soft bristle	42	16	27	–	–	5	–	A
	Extra-soft bristle	2	31	–	27	30	–	–	B
	Hard bristle	–	–	3	–	18	18	51	C
General	Soft bristle	46	17	72	–	–	44	1	A
	Extra-soft bristle	2	31	26	32	37	38	14	B
	Hard bristle	–	–	3	–	18	26	133	C

Given the different abrasives, the Kruskal–Wallis test showed no differences between the bristle tip morphologies of the groups prior to the brushing cycles, indicating that randomization provided equal distribution of the different bristle tip morphological designs throughout the groups.

The Kruskal–Wallis test demonstrated that the type of abrasive did not influence the bristle tip morphology of the toothbrushes in groups S and H. The Wilcoxon test showed a reduced rounding of the bristles after the brushing cycle in all toothbrushes ($P < 0.05$) except for the toothbrushes in group H, which were brushed with abrasive toothpaste 2 (hydrated silica).

Table 4. **Distribution of the scores of the bristle tip morphology of the extra-soft bristle toothbrushes after the brushing simulation according the type of toothpaste used during the experiment (Mann–Whiney test)**

Abrasive	A1	A2	N1	N2	N3	N4	N5	Level
(–) Control	–	6	12	4	5	3	–	A
Toothpaste 1	–	7	2	3	5	13	–	B
Toothpaste 2	–	5	7	7	8	3	–	A
Toothpaste 3	–	6	–	4	5	1	14	C
Toothpaste 4	1	3	5	9	9	3	–	A
Toothpaste 5	1	4	–	5	5	15	–	B

The Kruskal–Wallis test demonstrated that the bristle tip morphology of the toothbrushes in group ES was influenced by the type of abrasive ($P < 0.05$). The Mann–Whitney test indicated that toothpaste 3 (calcium carbonate, calcium bicarbonate and silica) caused the greatest reduction in bristle tip rounding, followed by toothpastes 1 (silica) and 5 (calcium carbonate) ($P < 0.05$). Toothpaste 2 (hydrated silica) and 4 (tetrapotassium pyrophosphate, silica and titanium dioxide) induced a reduction in the bristle tip rounding similar to the control group (Table 4). All groups exhibited reduced rounding of the bristle tips after the brushing cycles ($P < 0.05$).

Toothbrush wear analysis

The ANOVA test showed that before the brushing cycles, the bristle wear analysis showed no significant differences among the toothbrushes ($P < 0.05$). After the brushing cycles, the paired *t*-test showed that all the toothbrushes were more worn ($P < 0.05$). Additionally, the ANOVA test revealed differences between the toothbrushes after the brushing cycle ($P < 0.05$), and the Tukey test demonstrated that groups S and H present reduced bristle wear when compared with group ES ($P < 0.05$). The ANOVA test confirmed that the various toothpastes did not interfere in the wear of any toothbrush bristles analysed ($P < 0.05$).

Discussion

This study used a 3-month brushing simulation to evaluate the influences of several commercially available toothpastes on the bristle wear and bristle tip morphology of three different toothbrushes with varying degrees of bristle hardness.

Prior to brushing, this evaluation found that the soft bristle brush presented the best bristle tip morphology, demonstrating better quality control, when compared with the other toothbrushes. In contrast, the hard bristle toothbrush presented the worst bristle tip morphology and may injure the hard and soft tissues (7, 18). After the brushing cycles, the bristle tip morphologies of all toothbrushes declined, except the hard toothbrush when brushed with toothpaste 2 (hydrated silica). The inadequate initial conditions are the likely explanation for the lack of deterioration in these brushes' bristle tip morphologies because deterioration was observed in the control group. The decline in bristle tip morphology in the toothbrushes after the brushing cycles was previously demonstrated in another study (15).

The various abrasive toothpastes influenced the bristle tip deterioration in the ES toothbrush, but did not influence the bristle tip deterioration of the S and H toothbrushes. The degree of bristle stiffness provides a likely explanation for this influence because the extra-soft bristles were less stiff than the soft and hard bristles. Factors such as material composition, bristle length and diameter influence the stiffness (3), and because the bristle lengths and toothbrush materials used in the study are identical, the bristle diameters must exert more influence over the different bristle tip morphologies affected by the abrasives. The extra-soft bristles have smaller diameters than the soft and hard bristles (19), a fact that was confirmed by our study given that the diameter of the extra-soft bristles was smaller than that of the other toothbrushes.

Of the various abrasive toothpastes, toothpaste 3 (calcium bicarbonate, calcium carbonate and hydrated silica) resulted in the greatest deterioration in the bristle tip morphology of toothbrush ES, followed by toothpaste 5 (calcium carbonate) and 1 (silica). The groups brushed with toothpaste 2 (hydrated silica and Gantrez), 4 (tetrapotassium pyrophosphate, silica and titanium dioxide) and the control presented identical results. The vast range of abrasives in toothpaste 3 (calcium bicarbonate, calcium carbonate and hydrated silica) may explain the increased deterioration in the bristle tip morphology of toothbrush B (extra-soft bristles) because the interaction of different abrasives can improve the RDA value of this toothpaste (20).

Factors related to the abrasive toothpaste such as type, size and shape of the abrasive particles greatly influence the friction force generated by the toothbrush (16). These factors influenced the RDA values of the toothpaste and may explain why toothpastes with the same abrasives cause the variety of changes to the bristle tip morphologies observed in this study. Toothpastes 1, 2 and 4 contain hydrated silica as their primary abrasive, but the group brushed with toothpaste 1 exhibited the worse bristle deterioration when compared to the groups brushed with the other two toothpastes. Although these factors were not assessed in our study, toothpaste 1 likely contains larger, irregularly and unevenly distributed hydrated silica particles (13, 21).

Another important result of this study was the deterioration of the bristle tips caused by the abrasive toothpaste 5 (calcium carbonate) because this substance was found to be less abrasive than silica and pyrophosphate in another study (12). However, in the same study, the authors also consider physical factors that affect the degree of abrasiveness such as the load, frequency and environmental temperature during brushing. When these authors increased the ambient temperature, calcium carbonate produced greater wear in the enamel, while the wear created by pyrophosphate was reduced (12). Given that our study was conducted in a tropical region with high temperatures, the temperature likely caused the greatest deterioration in the bristle tip morphology in the subgroup containing the brushes with extra-soft bristles brushed with toothpaste 5 (calcium carbonate) and the least deterioration in those brushed with toothpaste 4 (pyrophosphate and silica).

The toothbrush bristles of all brushes were more worn after brushing with the extra-soft bristle toothbrushes showing the greatest wear. The degree of bristle hardness provides a likely explanation for this observation (22). The various abrasives did not promote different rates of bristle wear; instead, mechanical factors proved more important to bristle wear than the type of toothpaste used during this three-month brushing simulation (23).

The previous discussion reveals that the present study has some limitations. One limitation arises because the toothbrushes had differences in the quality of their bristle tips at the baseline, making it impossible to directly compare the effect of brushing on the bristle tip morphologies of the different brushes. Another limitation is the lack of information regarding the RDA values of toothpastes used in this study because the manufacturers did not provide this information. The RDA value could provide an explanation for the differences in the bristle tip morphology of the extra-soft toothbrushes induced by the various toothpastes.

Based on our results, the main findings of this research were as follows: (i) different abrasive toothpastes influence the deterioration of the bristle tip morphology in toothbrushes with extra-soft bristles. (ii) The toothpaste containing calcium carbonate, calcium bicarbonate and silica produced the lowest bristle tip standards in the extra-soft toothbrushes when compared with the other toothpastes. (iii) The ES toothbrushes exhibited the highest bristle wear among the brushes evaluated.

Clinical relevance

The clinical significance of this research was to offer clinicians a better understanding regarding the replacement of toothbrushes according to the toothbrush type and the toothpaste used. Of the toothbrushes evaluated in this study, the hard bristle toothbrushes were proven unsuitable for use by patients due to their low standard of bristle tip morphology prior to the brushing cycles. In addition, their great stiffness can induce soft and hard tissue lesions. After the 3-month brushing simulation, the soft bristle toothbrushes presented a better pattern of bristles wear than the extra-soft bristle toothbrushes. Thus, patients that use extra-soft bristle toothbrushes should replace their brushes more often than those who use soft bristle toothbrushes, especially when toothpaste containing the abrasives calcium carbonate, calcium bicarbonate and silica is use for brushing.

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Conflict of interest

The authors declare to have no conflict of interest.

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