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Number, length and end-rounding quality of bristles in manual child and adult toothbrushes

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Background. The design of the bristles of a toothbrush can affect the overall efficacy of toothbrushing.

Aim. To evaluate and compare a number of selected features associated with the bristle (length, number and end-rounding quality) of manual child and adult toothbrushes.

Design. The bristle lengths of 11 child and 29 adult toothbrushes were measured on digital micrographs using open source image analysis software. Bristles of tufts from five regions were counted and classified as acceptable or non-acceptable on stereomicroscopic images according to the end-rounding morphology. The data was evaluated statistically.

Results. The number of bristles were similar in child and adult toothbrushes ($P > 0.05$). Despite significant differences in bristle end-rounding in some regions ($P < 0.05$), the overall quality of bristles were similar in child and adult toothbrushes ($P > 0.05$).

Conclusions. The variations observed in the number, length and end-rounding quality of the bristles indicate inherent shortcomings of a majority of the tested toothbrushes in plaque removal efficacy, along with the potential for irritation on the gums.

Introduction

Manual toothbrushes are widely used for mechanical removal of dental plaque, the primary cause of caries and periodontal disease[1,2]. When used efficiently, toothbrushing can prevent these dental diseases and improve the oral health of individuals[1].

Manual toothbrushes can be classified according to a number of features including the hardness, shape and type of bristles, as well as handle design[3]. Consumers may have difficulty in selecting a proper toothbrush, owing to a plethora of products that are being marketed with the claims of superiority in size, design, hardness and plaque removal efficacy[4]. In light of many studies that have been conducted to determine the ideal toothbrush, it seems evident that user-friendly products which remove plaque effectively and do not destruct the oral tissues are most acceptable[1].

The damage generated on gingiva during toothbrushing is mainly associated with the end-rounding quality of the bristles[5–7]. Accordingly, insufficient rounding of the bristle ends may increase the risk of gingiva laceration [5–7]. The stiffness of the toothbrushes increases the risk of toothbrush abrasion particularly in patients with dental erosion [8–10] which necessitates the use of soft toothbrushes [11]. Although information on the stiffness of bristles are generally provided by manufacturers, many products still do not contain information on their bristle end-rounding properties. The latter feature is of great concern to both the consumers and dentists, since it is one of the major factors that determine the effectiveness of a toothbrush in removing the plaque, as well as its potential deleterious effect on gingival tissues, cementum and dentin[12,13].

The number and length of bristles may also play an important role in the overall effectiveness of manual toothbrushes[14–16]. To date,

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only a few studies evaluated those features in adult and child toothbrushes[4,12,17–21], with only one study comparing the bristle end morphology of child and adult toothbrushes[17]. In light of these findings, this study was undertaken to evaluate and compare a number of selected features associated with the bristles (design, length, number and end-rounding quality) of proprietary manual child and adult toothbrushes.

Materials and methods

Eleven child and 29 adult manual toothbrushes from different manufacturers were included in this study. The list of toothbrushes and their level of stiffness are presented in Tables 1 and 2.

In the first part of the study, the length of bristles was measured by image analysis. A digital photograph of the lateral view of each toothbrush head was obtained at 4.5× under a stereomicroscope (Olympus; Tokyo, Japan). The images were, then, transferred to a Macintosh PowerPC workstation and recorded as TIFF files at 1280 × 1200 ppi resolution. The images were opened in ImageJ open-source image analysis software (V.1.34, National Institutes of Health, Bethesda, MD, USA), and the shortest and longest bristle lengths of the marginal (mesial and distal) and central thirds of each toothbrush were measured and recorded in a separate datasheet.

In the second set of measurements, the head of each toothbrush was divided into five equally-distributed areas representing three marginal (namely, regions 1, 3 and 5) and two central (regions 2 and 4) localizations[17] (Fig. 1). On each toothbrush, the bristles of one tuft from 5 regions were counted under a stereomicroscope at 4.5× standard magnification.

To evaluate the end-rounding morphology, the bristles counted on regions 1 to 5 were cut off with a surgical blade from the bottom of the tuft. The bristles were mounted on a glass slab with clear adhesive tape. Digital micrographs were obtained (at 20×) and transferred to the PC as with previous measurements. The end-rounding morphology was evaluated parallel to the long axis of the bristles in accordance with the Silverstone and Featherstone scale[12] modified by Reiter and Wetzel[22]. To discard operator variability, the scale was scanned at high (300 pixels/inch) resolution, and converted into a fully-scalable, rotatable, semi-transparent digital template that could be superimposed on the bristle ends (Fig. 2). Using this method, the bristle ends were rated as acceptable and non-acceptable according to that scale[22] (Fig. 2). A total of 685 bristles in child toothbrushes and 1413 bristles in adult toothbrushes were examined by one calibrated operator, who was familiar with the end-rounding evaluation and image analysis; and blinded to the brands of the toothbrushes.

Statistical analysis

T-test was used to compare the number of bristles between child and adult toothbrushes ($P = 0.05$). The end-rounding morphology (acceptable *versus* non-acceptable) among and between the latter two groups were compared statistically using the chi-square test ($P = 0.05$).

Table 1. Child toothbrushes evaluated in this study. Stiffness of the bristles has been provided by the manufacturers.

Toothbrush	Manufacturer	Stiffness of bristles
Colgate Smiles ages 2–5	Colgate-Palmolive Co., Yangzhou, China	Soft
Colgate Smiles ages 0–2	Colgate-Palmolive Co., Yangzhou, China	Baby soft
Colgate Kids 2+	Colgate-Palmolive Co., Yangzhou, China	Extra soft
Colgate Smiles ages 2–6	Colgate-Palmolive Co., Yangzhou, China	Extra soft
Dr. Difas Cocuk	Difas Co., Istanbul, Turkey	Medium
Signal 7–13	Unilever, Switzerland	Soft
Signal Kids World	Lever Faberge, Switzerland	Medium
Shine	Ideal Standart A.S., Istanbul, Turkey	Soft
Oral B Stages 3	Oral-B Laboratories, Newbridge, Co., Kildare, Ireland	Soft
Oral B Stages 1	Oral-B Laboratories, Newbridge, Co., Kildare, Ireland	Baby soft
Vepa Yombi Timba	Vepa Co., Istanbul, Turkey	Soft

Table 2. Adult toothbrushes evaluated in this study. Stiffness of the bristles has been provided by the manufacturers.

Toothbrush	Manufacturer	Stiffness of bristles
Aquafresh Clean & Flex	Interbros GmbH, Germany	Medium
Banat Tri-action TooFresh	Banat Co., Istanbul, Turkey	Medium
Banat Gercek Taraftar 1 + 1	Banat Co., Istanbul, Turkey	Soft-medium
Banat Economic 2 Duo	Banat Co., Istanbul, Turkey	Medium
Banat Optima	Banat Co., Istanbul, Turkey	Medium
Colgate Twister Fresh	Colgate-Palmolive, China	Medium
Colgate 360° Whole Mouth Clean	Colgate-Palmolive, China	Medium
Colgate 360° microSonic Power	Colgate-Palmolive, China	Medium
Colgate 360° Deep Clean	Colgate-Palmolive, Switzerland	Soft
Colgate 360° Sensitive	Colgate-Palmolive, Switzerland	Ultra soft
Dr. Difas Family	Difas Co., Istanbul, Turkey	Medium
Dr. Difas Smoker	Difas Co., Istanbul, Turkey	Extra hard
Dr. Difas Double Power	Difas Co., Istanbul, Turkey	Medium
Ipana Aktif Kontrol	Shummi, ShenZhen, China	Soft
Ipana Aktif Kontrol	Shummi, ShenZhen, China	Medium
Oral B Advantage Breath Refresh	Oral B Laboratories, Iowa City, USA	Soft
Oral B Advantage 3D White	Braun Oral B Newbridge, Co Kildare, Ireland	Soft
Oral B Indicator 40	Braun Oral B, Newbridge Co Kildare, Ireland	Medium
Oral B Cross Action	Oral-B Laboratories, Newbridge, Co., Kildare, Ireland	Medium
Oral B Cross Action Vitalizer	Oral-B Laboratories, Newbridge, Co., Kildare, Ireland	Soft
Pronamel	M + C Schiffer GmbH, Germany	Soft
Sensodye Total Care	M + C Schiffer GmbH, Germany	-
Signal Air Precision	Unilever, Switzerland	Medium
Shine	Ideal Standart Co., İstanbul, Turkey	Medium-hard
Tepe Gentle Care	Tepe Munhygienprodukter AB, Sweden	XX-soft
Tepe Select	Tepe Munhygienprodukter AB, Sweden	X-soft
Tepe Implant/Orthodontic	Tepe Munhygienprodukter AB, Sweden	-
Tepe Soft	Tepe Munhygienprodukter AB, Sweden	Soft
Vepa 4 system	Vepa Co., Istanbul, Turkey	Medium

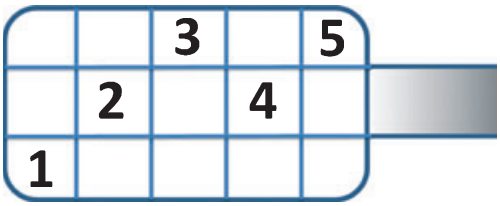

Fig. 1. Schematic representation of the areas selected for evaluation of bristle number (Modified from Jung *et al.*[17]).

Results

In child toothbrushes, the mean length of bristles ranged between 6.63 mm and 9.26 mm (Table 3). In adult toothbrushes, the length of bristles ranged between 8.50 mm and 11.42 mm (Table 4). Representative micrographs of acceptable and non-acceptable bristle ends are presented in Fig. 3. The number and percentage of acceptable *versus* non-acceptable end-rounding of bristles are presented in Tables 5 and 6. Significant differences were found among child toothbrushes with respect to acceptable *versus* non-acceptable bristles in the 3rd, 4th and 5th regions (chi-square test, $P < 0.05$). Colgate Kids 2 + had the least acceptable bristle end morphology

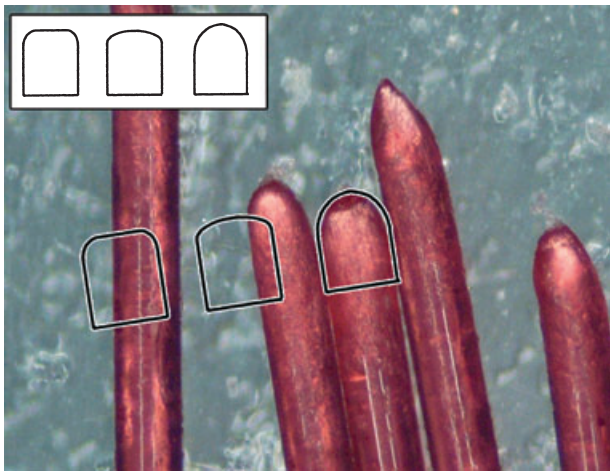

Fig. 2. Inset: The semi transparent template used for determination of acceptable bristle end morphology. The template scaled, rotated and superimposed on a bristle end to evaluate conformity to one of three bristle end patterns. Note that some of the neighbouring bristle ends are 'unacceptable'.

Table 3. The mean bristle length of child toothbrushes (in mm).

Toothbrush	Bristle length
Colgate Smiles ages 2–5	7.79
Colgate Smiles ages 0–2	7.27
Colgate Kids 2+	7.53
Colgate Smiles ages 2–6	7.42
Dr. Difas Cocuk	8.93
Shine	8.86
Signal Kids World	7.90
Signal 7–13	9.16
Oral B Stages 1	6.63
Oral B Stages 3	7.66
Vepa Yombi Timba	9.26

Table 4. The mean bristle length of adult toothbrushes (in mm).

Toothbrush	Bristle length
Aquafresh Clean & Flex	10.48
Banat Tri-action TooFresh	10.01
Banat Gercek Taraftar 1 + 1	10.38
Banat Economic 2 Duo	10.28
Banat Optima	11.42
Colgate 360° Whole Mouth Clean	8.59
Colgate 360° Deep Clean	9.72
Colgate Twister Fresh	9.09
Colgate 360° Sensitive	9.05
Colgate 360° microSonic Power	8.50
Dr. Difas Family Set	9.60
Dr. Difas Smoker	9.18
Dr. Difas Double Power	9.46
Ipana Aktif Kontrol (soft)	9.69
Ipana Aktif Kontrol (medium)	10.36
Oral B Advantage Breath Refresh	9.50
Oral B Advantage 3D White	8.74
Oral B Indicator	9.58
Oral B Cross Action	9.35
Oral B Cross Action Vitalizer	9.45
Sensodyne Total Care	9.76
Pronamel	9.91
Shine	9.93
Signal Air Precision	10.03
Tepe Gentle Care	10.09
Tepe Select	10.03
Tepe Implant/Orthodontic	10.68
Tepe Soft	10.14
Vepa 4 system	8.50

in the 3rd, 4th and 5th regions ($P < 0.05$). The toothbrushes with greatest amount of acceptable bristle ends in the same regions were Oral B Stages 3, Dr. Difas Cocuk and Colgate Smiles ages 2–6, respectively (chi-square test, $P < 0.05$). As for the adult toothbrushes, significant differences were found with respect to acceptable *versus* non-acceptable bristles in 2nd, 3rd, 4th and 5th regions (chi-square test, $P < 0.05$). Oral B Advantage 3D White had the most acceptable bristle end morphology in 1st and 3rd regions. Adult toothbrushes demonstrating the most acceptable bristle ends in the 1st, 2nd, 4th and 5th regions were Colgate 360° microSonic Power, Oral B Cross Action Vitalizer, Ipana Aktif Kontrol (Soft) and Tepe Select, respectively. Toothbrushes with the least acceptable bristle end morphology were Pronamel (all regions), Colgate Twister Fresh and Tepe Implant/Orthodontic (2nd, 3rd, 4th and 5th regions), Oral B Indicator (2nd region) and Banat Tri-action TooFresh (4th region) (chi-square test, $P < 0.05$).

Overall, there were no significant differences between child and adult toothbrushes with respect to the number of bristles in the regions of interest (*t*-test, $P > 0.05$) (Table 7). Significant differences were however found between both groups with respect to acceptable *versus* non-acceptable bristles in the 1st, 3rd and 5th regions (chi-square test, $P < 0.05$) (Table 7).

Discussion

The bristle length plays an important role in accessing interproximal areas, and toothbrushes with different bristle lengths (so-called multileveled brushes) are more effective in this regard[14,15,23,24]. Among the child toothbrushes evaluated, the shortest bristle length was found in Oral-B Stages 1, which may be related with its intended use by small children. The longest bristles were found in Vepa Yombi Timba, which would be more suitable for use by relatively older children, but the manufacturer did not provide such information. Colgate 360° microSonic Power was one of the adult toothbrushes with the shortest bristles, which may be related with its rotational function. This powered toothbrush was included in this study, since it can also be used as a manual one. The second longest bristles were found in Tepe Implant/Orthodontic. As the brand name implies, this product is designed to be used during orthodontic therapy or in patients with dental implants. Thus, the presence of long bristles was considered to be compatible with the aim of the brush.

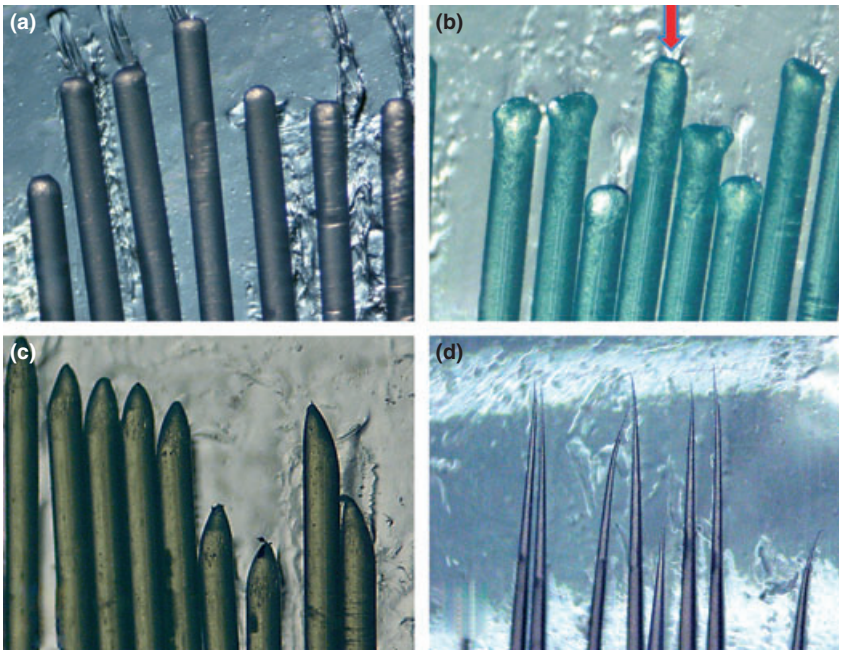

Fig. 3. (a) Acceptable bristle ends; (b) Slightly enlarged, bulbous bristle ends. Arrow shows an acceptable bristle end; (c) Arrow-shaped, unacceptable bristle ends; (d) Spiky, unacceptable bristle ends.

Table 5. The number and percentage of acceptable *versus* non-acceptable bristles in child toothbrushes.

Toothbrush	Bristles examined (*n*)	Acceptable bristles (%)	Non-acceptable bristles (%)
Colgate Smiles ages 2–5	69	24 (34.8%)	45 (65.2%)
Colgate Smiles ages 0–2	64	18 (28.1%)	46 (71.9%)
Colgate Kids 2 +	69	14 (20.3%)	55 (79.7%)
Colgate Smiles ages 2–6	63	36 (57.1%)	27 (42.9%)
Dr. Difas Cocuk*	64	34 (53.1%)	30 (46.9%)
Shine*	49	26 (53.1%)	23 (46.9%)
Signal Kids World	53	29 (54.7%)	24 (45.3%)
Signal 7–13	53	10 (18.9%)	43 (81.1%)
Oral B Stages 1	76	43 (56.6%)	33 (43.4%)
Oral B Stages 3	78	47 (60.3%)	31 (39.7%)
Vepa Yombi Timba*	47	16 (34.0%)	31 (66.0%)
Total	685	297 (43.4%)	388 (56.6%)

*Brushes with round-ended tufts as claimed by manufacturers.

Almost all of the present toothbrush packages contained information regarding the stiffness of the bristles. Information about the end-rounding quality was, however present in only a few products (3 child and 11 adult toothbrushes) which may imply that the latter feature does not appear to be adequately accentuated. In some studies, only a few number of bristles have been evaluated for the end-rounding quality, probably owing to the labour-intensive nature of analysis[19,25,26]. Here, only one sample per product was examined for end-rounding, due to the great number of samples analysed herein (i.e., 2000 +). Because of differences in rounding quality which are known to occur between the samples of a single batch as well as differences between various batches, a greater number of samples of each product need to be included to draw more meaningful conclusions on the general quality of a product. In an attempt to provide standardization, Jung *et al.*[17,18] have recommended evaluating bristles from five different regions, which are equally distributed in the head. This study utilized the same methodology[17,18].

Meyer-Lueckel *et al.*[27] suggested that localization of the bristles from either the edge of

Table 6. The number and percentage of acceptable *versus* non-acceptable bristles in adult toothbrushes.

Toothbrush	Bristles examined (*n*)	Acceptable bristles (%)	Non-acceptable bristles (%)
Aquafresh Clean & Flex*	49	26 (53.1%)	23 (46.9%)
Banat Tri-action TooFresh*	46	14 (30.4%)	32 (69.6%)
Banat Gercek Taraftar 1 + 1*	44	19 (43.2%)	25 (56.8%)
Banat Economic 2 Duo*	41	16 (39%)	25 (61%)
Banat Optima*	44	19 (43.2%)	25 (56.8%)
Colgate 360° Whole Mouth Clean	34	22 (64.7%)	12 (35.3%)
Colgate 360° Deep Clean	39	23 (59%)	16 (41%)
Colgate Twister Fresh	53	1 (1.9%)	52 (98.1%)
Colgate 360° Sensitive	43	17 (39.5%)	26 (60.5%)
Colgate 360° microSonic Power	40	24 (60%)	16 (40%)
Dr. Difas Family Set*	56	19 (33.9%)	37 (66.1%)
Dr. Difas Smoker*	45	12 (26.7%)	33 (73.3%)
Dr. Difas Double Power*	58	30 (51.7%)	28 (48.3%)
Ipana Aktif Kontrol (soft)	64	36 (56.3%)	28 (43.8%)
Ipana Aktif Kontrol (medium)	45	17 (37.8%)	28 (62.2%)
Oral B Advantage Breath Refresh	55	28 (50.9%)	27 (49.1%)
Oral B Advantage 3D White	71	43 (60.6%)	28 (39.4%)
Oral B Indicator	53	11 (20.8%)	42 (79.2%)
Oral B Cross Action	47	19 (40.4%)	28(59.6%)
Oral B Cross Action Vitalizer	41	19 (46.3%)	22 (53.7%)
Pronamel	37	0 (0%)	37 (100%)
Sensodyne Total Care*	74	24 (32.4%)	50 (67.6%)
Shine*	48	19 (39.6%)	29 (60.4%)
Signal Air Precision	45	25 (51%)	24 (49%)
Tepe Gentle Care	54	11 (20.4%)	43 (79.6%)
Tepe Select	49	27 (55.1%)	22 (44.9%)
Tepe Implant/Orthodontic	44	1 (2.3%)	43 (97.7%)
Tepe Soft	49	24 (49%)	25 (51%)
Vepa 4 system*	41	10 (24.4%)	31 (75.6%)
Total	**1413**	**556 (39.3%)**	**857 (60.7%)**

*Brushes with round-ended tufts as claimed by manufacturers.

Table 7. Number of bristles in all regions and the percentage of bristles in child and adult toothbrushes.

	Number of bristles		Acceptable bristles	
Region	Child toothbrushes	Adult toothbrushes	Child toothbrushes	Adult toothbrushes
1	56.09 ± 8.75	64.38 ± 45.77	29.1%*	40.9%*
2	56.18 ± 10.86	56.00 ± 29.12	41%	41.8%
3	54.82 ± 9.59	69.38 ± 70.92	47.6%*	36.1%*
4	54.64 ± 8.94	56.31 ± 29.93	48.5%	40.6%
5	54.00 ± 8.72	62.00 ± 44.68	50.4%*	37.7%*
Total	55.14 ± 9.04	61.61 ± 40.18	43.4%	39.3%

*Significant difference with respect to acceptable *versus* non-acceptable bristles in child and adult toothbrushes ($P < 0.05$).

a tuft or those located in the inner part had no effect on the assessment of the bristle ends. They also compared viewing angles of 45° and 90°. The authors concluded that although viewing angle of 45° allows more filaments within a tuft to be judged it showed comparable end-rounding results as from 90°. In this study, no distinction among the localization of the bristles within a tuft was made. The bristles were cut off with a surgical blade from the bottom of the tuft and the ones that could be mounted on a glass slab were analysed. Since the filaments were fixed with an adhesive tape, the filaments were viewed parallel to their long axis. This method facilitated one to one comparison of the bristle ends with the two-dimensional Silverstone and Featherstone scale since the scale was converted into a fully-scalable, rotatable, semi-transparent

digital template that could be superimposed on the bristle ends (Fig. 2).

Evaluation of bristle ends has generally been performed under the scanning electron microscope, as a virtue of its considerably high magnification[12,17,18,27,28]. The temperature rise during sputter-coating procedures can however alter the filament morphology[29]. For this reason, Checchi *et al.*[19] and Franchi and Checchi[29] and have recommended stereomicroscopic evaluation, which was also utilized herein.

Studies have documented variety great variation in bristle end morphology, ranging from rounded to sharp-edged[12,25,28]. It has also been shown that the percentage of acceptable bristle ends vary considerably among different brands[30–32]. Among eight different brands, Silverstone and Featherstone[12] reported the range of acceptable filaments as 22–88%. Thus, evaluation of the bristle ends of recent toothbrushes appears to be both logical and essential[17]. In line with previous studies, the present results showed that the percentage of acceptable *versus* non-acceptable bristle ends differ in each brand. Among the child toothbrushes investigated, the percentage acceptable bristles were greater than 50% in Colgate Smiles ages 2–6, Signal Kids World, Shine, Dr Difas Cocuk, Oral B Stages 3 and Oral B Stages 1. It is noteworthy to mention that the packages of Shine and Dr. Difas Cocuk provide information that the toothbrushes contain rounded bristles. While the same information was present on the package of Vepa Yombi Timba, only 34% of its bristles were found to be acceptable. As for adult toothbrushes, Pronamel did not contain acceptable bristles and showed spiky bristle ends as demonstrated in Fig. 3d. Although those spiky ends would be related to the microfine bristles as the toothbrush is specifically designed for individuals with sensitive teeth, they were also classified as unacceptable since they were not compatible with the scale used. The other toothbrushes with less acceptable bristle ends were Colgate Twister Fresh (1.9%), and Tepe Implant/Orthodontic (2.3%). Aquafresh Clean&Flex and Dr. Difas Double Power were found to have more than 50% acceptable bristles, along with package information indicating the inclusion of rounded bristles. Oral B Advantage Breath Refresh, Oral B Advantage 3D White, Colgate 360° Whole Mouth Clean, Colgate 360° Deep Clean, Colgate 360° microSonic Power, Ipana Aktif Kontrol (soft), Signal Air Precision and Tepe Select had more than 50% acceptable bristles, but lacked the information on their packages.

Unrounded bristle ends do not necessarily affect the cleaning efficacy of a toothbrush, but can cause soft tissue injuries[5,6,33]. Although bristle ends become more rounded by clinical use, there are controversial reports regarding the time needed for such wear to occur[25,34]. Jung *et al.*[17] pointed out that the risk of soft tissue trauma caused by unacceptable bristle end morphology can increase in handicapped individuals owing to uncontrolled brushing movements. The same concern should apply for healthy children, since individuals under 8 years lack sufficient manual dexterity[35]. According to the present results, this inherent shortcoming applies to both the child and adult toothbrushes. On the other hand, soft toothbrushes with unacceptable bristle end morphology may not necessarily cause soft-tissue injuries.

What this paper adds

- The variations obtained with respect to the number, length and end-rounding quality of the bristles among the toothbrushes examined indicates inherent shortcomings in plaque removal efficacy and possible irritations on the gums.

Why this paper is important to paediatric dentists

- A majority of consumers select their toothbrushes based on non-scientific criteria including brand, cost, and even colour or shape. The quality of bristle end-rounding is seldom known by patients, who usually consider the softness of bristles to be the decisive factor. Some patients may, however prefer to seek professional advice. Thus, the paediatric dentist to be familiar with the technical features of proprietary toothbrushes.

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