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Quality of bristle end-rounding on replaceable heads of powered toothbrushes

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Abstract

Objectives: The aim of this study was to evaluate the geometry and the quality of bristle tip-rounding using 14 different heads from powered toothbrushes.

Material and Methods: Six powered toothbrushes for children and eight for juveniles and adults were included. Five replaceable heads of each product were randomly selected. Of each sample, 35 bristles were used for examination. This resulted in 175 bristles from each product being evaluated. The quality of end-rounding was assessed by scanning electron microscopy at an original magnification $\times$ 80 in two categories of acceptable and five categories of unacceptable rounding according to Silverstone & Featherstone (1988).

Results: The portion of acceptable end-rounding varied strongly between the products (18.9–94.3%). There were significant differences regarding the products for children ($p<0.001$) and for adults ($p<0.001$) with respect to end-rounding quality. Only one product achieved more than 90% and eight products had between 68% and 86% acceptable end-rounding. Two products for children and one for adults had less than 25% acceptable end-rounding.

Conclusion: A high standard of bristle tip-rounding is an important feature with respect to the safety of powered toothbrushes. Those products with a greater portion of unacceptably rounded bristles might cause more harm to oral soft tissues during use. The end-rounding quality of some of the products should be improved.

Key words: end-rounding of bristles; powered toothbrushes; safety of toothbrushes

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A great number of different models belonging to a new generation of powered toothbrushes have been developed during the past decade. In contrast to the first generation of powered toothbrushes in the 1960s and 1970s, the new products have become increasingly popular among the overall population and have gained wide acceptance concerning mechanical plaque control. There are a great number of experimental and clinical studies assessing the plaque-removing efficacy of powered toothbrushes. In 1998, a consensus report from the European Workshop on Mechanical Plaque Control concluded that powered toothbrushes are ''somewhat superior to manual brushes in plaque removal and gingival inflammation control'' (Egelberg & Claffey 1998). In a review of powered toothbrushes, Heasman & McCracken (1999) came to a similar conclusion. The authors criticized the great variability in design and inconsistencies regarding the results of the studies. Re-evaluation due to the development of new models of powered toothbrushes in the past few years showed that the majority of studies demonstrated a greater plaque-removing efficacy for powered toothbrushes compared with their manual counterparts (Barnes et al. 2003, Lazarescu et al. 2003, Nathoo et al. 2003, Niederman 2003, Williams et al. 2003). In contrast, a few studies reported manual toothbrushes to be more efficient (Dorfer et al. 2001a, b), while other investigators found no significant differences between powered and manual toothbrushes (Haffajee et al. 2001, Mantokoudis et al. 2001, McCracken et al. 2001, Deery et al. 2004).

Apart from their plaque-removing efficacy, the safety of manual or powered toothbrushes during use deserves special attention. One experimental (Yankell et al. 2002) and several clinical studies (Dorfer et al. 2001b, He et al. 2001, Mantokoudis et al. 2001, Dentino et al. 2002, Papas et al. 2002) demonstrated that powered toothbrushes were as safe as manual ones. After evaluating two powered toothbrushes, the authors concluded that both products were safe (Conforti et al. 2001).

Table 1. Attributes of the replaceable heads of powered toothbrushes evaluated in this study

No.	Product	Order no.	Manufacturer	Brushing principle	Dimensions of head in mm (diameter or length × width)	Number of tufts
1	EB 10-2 Kids	206521	Oral-B, Boston, MA, USA	Rotating–oscillating	12.3	21
2	Dentaclip Dentiphant	ZH 010	Rowenta, Offenbach, Germany	Vibrating–oscillating	13.5	14
3	Biocare Junior 634	0640-01	Krups-Moulinex, Solingen, Germany	Rotating–oscillating	13.6	28
4	Interplak Kids	50611	Interplak, Duesseldorf, Germany	Rotating–oscillating of individual tufts	16 × 14.6	6
5	Oral Control Plack Attack	4202 H2	WIK, Essen, Germany	Rotating–oscillating	13.7	23
6	Kaept'n Blaubaer	KB 007 B	Globalized, Koblenz, Germany	Rotating–oscillating	13.7	23
7	EB 15-2 Flexi Soft	4705164	Oral-B, Boston, MA, USA	Rotating–oscillating	13	26
8	Actibrush	RB 06	Colgate-Palmolive, New York, NY, USA	Oscillating	13.5	23
9	Biocare Family	0640-01	Krups-Moulinex, Solingen, Germany	Sonic technology	13.5	28
10	Sensiflex 2000	HX 2002-L	Philips Oral Healthcare, Snoqualmie, WA, USA	Rotating	19 × 14	35
11	Rotaclip medium	ZH 710	Rowenta, Offenbach, Germany	Vibrating–oscillating	15 × 13	28
12	Brushhead Severin	EB 9030	Severin, Sundern, Germany	Rotating–oscillating	13	24
13	Sonicare Compact Size	CH-2	Philips Optiva, Bellevue, WA, USA	Sonic technology	25 × 12	24
14	Brushhead Waterpik	SRB-2E	Intersante, Bensheim, Germany	Sonic technology	25 × 13	26

The fact that several investigations regarded powered toothbrushes to be safe during use does not imply that there were no adverse effects on oral soft tissues at all. Some 18% of the study group using two powered and one manual toothbrush were found to have soft-tissue symptoms (He et al. 2001). Only two out of 22 manual toothbrushes were classified as being ''not harmful to the gingiva'' (Imfeld et al. 2000). It has been stated that gingival abrasion may occur with both manual and powered toothbrushes (Egelberg & Claffey 1998). One important factor contributing to the traumatic potential of a toothbrush is the quality of bristle end-rounding (Imfeld et al. 2000). There are several studies investigating the geometry and quality of end-rounding with respect to manual toothbrushes (Rawls et al. 1993a, b, Dellerman & Burkett 1994, Imfeld et al. 2000, Checchi et al. 2001, Jung et al. 2003). Although the technical conditions for achieving a high standard in end-rounding are given, most of the studies demonstrated that there were considerable differences between the products and that several brands had poor quality of end-rounding. In contrast to manual brushes, studies evaluating the end-rounding quality of powered toothbrushes have not been conducted yet. For this reason, an evaluation of the quality of bristle-tip morphology of powered toothbrushes was deemed necessary.

The purpose of the present study was to assess the bristle end-rounding quality of replaceable toothbrush heads from a total of 14 different powered toothbrushes for children and adults.

Material and Methods

Fourteen different brands of replaceable toothbrush heads from powered toothbrushes were included in the study. Six products (nos. 1–6, Table 1) were designed for use by children and eight for use by juveniles and adults (nos. 7–14, Table 1).

Regarding the products for children, toothbrush head EB 10-2 (no. 1) has a circular shape with rounded contours (Fig. 1). One horizontal row of five tufts of reduced height is surrounded by 16 bristle bundles in a circular pattern. The brushing motion generated by the powered toothbrush can be described as rotating/oscillating. The Dentaclip head (no. 2) is circular. Fourteen tufts are arranged on the toothbrush head, which is used in a vibrating mode. Biocare Junior 634 (no. 3) also has a circular shape and is characterized by a rotating/oscillating brushing motion. As many as 28 tufts of two different lengths are aggregated on the head. Interplak Kids (no. 4) has a quadrangular design with

Fig. 1. Macroscopic characteristics of the toothbrush heads for children (product nos. 1–6) and adults (product nos. 7–14).

rounded contours. Each of the six tufts rotates around its own axis when in use. Product nos. 5 and 6 are very similar with respect to their macroscopic design. Both heads are circular and used with a rotating/oscillating brushing motion. A total of 23 tufts of two different lengths are arranged on the head.

Among the heads for juveniles and adults, product nos. 7, 8 and 9 are round and applied with a rotating/oscillating brushing motion. The tufts of each product are of two different lengths (Fig. 1). Sensiflex 2000 (no. 10) has a circular design; 28 tufts are arranged in a concave lateral bristle profile. Seven additional tufts that are intended for inter-dental use are located at the top of the head. Some 28 bristle bundles of two different lengths are aggregated on the oval-shaped head of the Rotaclip (no. 11). EB 9030 (no. 12) has a circular design with 24 tufts, forming a plain lateral bristle profile. CH-2 (no. 13) has a quadrangular shape with rounded contours; 24 tufts of consecutively varying lengths are arranged in a rippled lateral bristle profile. Water Pik (no. 14) is oval with rounded edges; 26 tufts of different lengths form a rippled lateral bristle profile.

Ten toothbrush heads of each product were provided by the manufacturers. Five of the heads were randomly selected for evaluation by scanning electron microscopy (SEM). Each head was divided in five equally distributed areas with marginal (regions 1, 3 and 5) and central localization (regions 2 and 4) of the bristles (Fig. 2). Seven bristles from each of the five areas on the toothbrush head were used for the evaluation of bristle-tip geometry. As a result, 35 bristles were taken per sample, with 21 bristles from marginal and 14 bristles from central regions. This meant that a total of 175 bristles were examined per product.

The bristles taken from one sample were fixed on to adhesive tape, which was subsequently rolled and mounted on an SEM tray with the help of Leit-C (Neubauer Chemicals; Münster, Germany). After drying for 24 h, the samples were gold-coated with the sputtering device SCD-040 (Bal-tec, Balzers, Liechtenstein). Sputtering was performed for 3 min. at 30 mA in a water-cooled chamber at a temperature $<25°C$. In order to ensure a thorough coating of the bristles, the trays were mounted on a battery-operated device, rotating at 4.5 r.p.m. during the sputtering process.

SEM evaluation was performed using the PSEM 500 (Philips; Eindhoven, the Netherlands) at a working tension of 12 kV. For the evaluation of bristle-tip geometry, photomicrographs were taken at an original magnification $\times 80$; the viewing angle was 45°. The evaluation of bristle-tip morphology was carried out according to the classification of Silverstone & Featherstone (1988), as modified by Reiter & Wetzel (1991). As proposed by Jung et al. (2003), the number of acceptable rounding geometries was limited to two categories (A1 and A2) and the number of unacceptable rounding geometries to five categories (N1–N5, Fig. 3). During the SEM investigation and during evaluation of bristle-tip geometry, the brands of the samples were unknown to the examiner.

Statistical analysis was performed separately for toothbrush heads for children and for adults. Significant differences between the products with regard to the quality of end-rounding were analysed with one-way ANOVA and Scheffé post hoc tests. The effects of bristle localization on the quality of end-rounding were calculated with the Wilcoxon Matched-Pairs Signed-Rank Test (SPSS for Windows, version 10.07, SPSS Inc., Chicago, IL, USA).

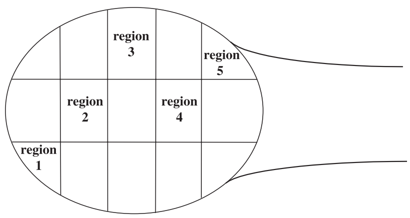

Fig. 2. Schematic drawing of the distribution of the examined areas on the head of the toothbrush.

Results

Among the toothbrush heads for children, product nos. 2, 3, 5 and 6 mainly showed acceptable end-rounding (Table 2). Bristle-tip geometries with a central plateau and rounded lateral contours (A1) were characteristic for product no. 2 (Fig. 4), whereas semi-spherical rounding was predominant for product nos. 3 and 5 (Fig. 5). Both types of acceptable rounding were found for product no. 6. With regard to product no. 1, the tips of the shorter, centrally localized bristles showed acceptable rounding. In contrast, the longer white filaments showed an irregular splitting of the bristle ends and were assessed as not acceptable (category N5, Fig. 6). Bristle tips with laterally protruding bits of plastic material (category N4) were frequently found with product no. 4 (Fig. 7). Sharp-edged, oblique bristle tips (category N2) were present only in

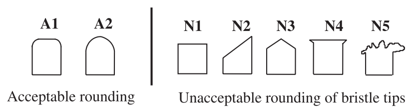

Fig. 3. The classification of bristle-tip geometry into two groups of acceptable rounding and five groups of unacceptable rounding.

Table 2. Categories of bristle-tip geometry and number of bristle tips with acceptable and unacceptable rounding ($n = 175$ for each product); pointed bristle tips (category N3) were not found

Product no.	Acceptable end-rounding		Not acceptable end-rounding			
	A1	A2	N1	N2	N4	N5
1	10	25	–	–	–	140
2	117	25	–	10	15	8
3	1	164	–	1	7	2
4	–	33	–	1	128	13
5	27	123	–	13	9	3
6	47	95	–	17	11	5
7	53	74	–	35	11	2
8	37	82	–	44	12	–
9	21	123	–	29	2	–
10	12	85	–	61	12	5
11	120	4	2	29	19	1
12	73	59	1	30	11	1
13	41	31	7	44	20	32
14	3	35	–	89	17	31

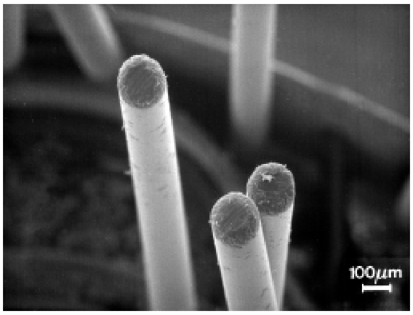

Fig. 4. Acceptably rounding of bristle ends with a central plateau and rounded contours (category A1, product no. 2).

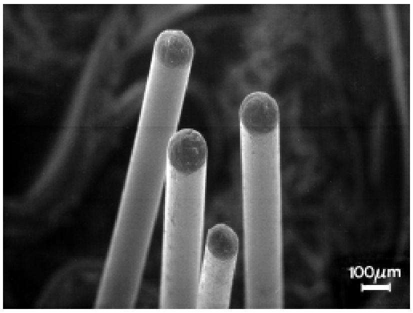

Fig. 5. Acceptable rounding with semi-spherical bristle tips (category A2, product no. 3).

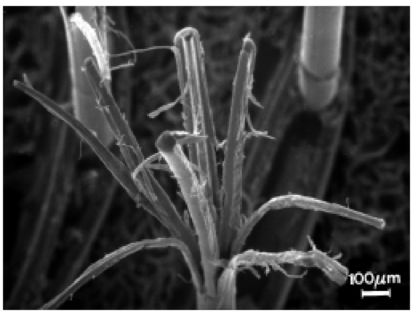

Fig. 6. Splitting of bristle tips of product no. 1 (category N5).

small numbers in the case of product nos. 2, 5 and 6 (Fig. 8).

Several of the toothbrush heads for juveniles and adults had a large portion of acceptably rounded bristle tips. Both categories of acceptable geometries (A1 and A2) were characteristic for product nos. 7, 8 and 12, whereas category A1 was mainly found for product no. 11 and category A2 for product no. 9.

Product no. 10 had nearly equal numbers of acceptably and unacceptably rounded tips; edged oblique bristle tips (category N2) prevailed as far as the unacceptable geometries for this product were concerned. Oblique-edged bristle

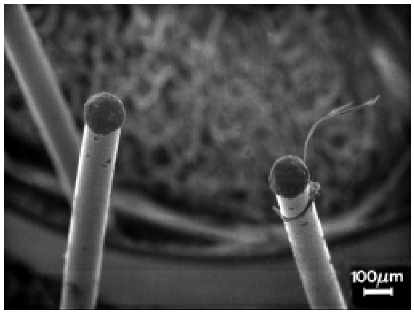

Fig. 7. Laterally protruding edged bristle tips of product no. 4 (category N4).

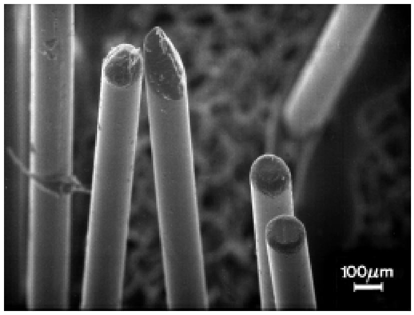

Fig. 8. Three acceptably rounded and one sharp and oblique bristle end (category N2) of product no. 5.

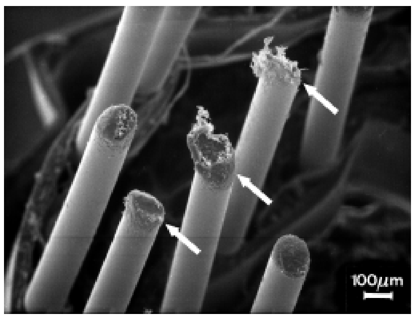

Fig. 9. Irregularly shaped bristle tips (arrows) with abundant plastic material (category N5; product no. 13).

tips and abundant plastic material jutting out laterally (category N5) were frequently found in the case of product no. 13 (Fig. 9). A great number of oblique-edged geometries were characteristic for product no. 14 (Fig. 10). Smaller numbers of bristle tips with laterally protruding plastic material were observed for all the toothbrush heads for adults. Rectangular-edged geometries (category N1) and pointed bristle tips (category N3) were seldom found.

With respect to toothbrush heads for children, the extent of not acceptable rounding varied widely from 5.7% (product no. 3) to 81.1% (product no. 4).

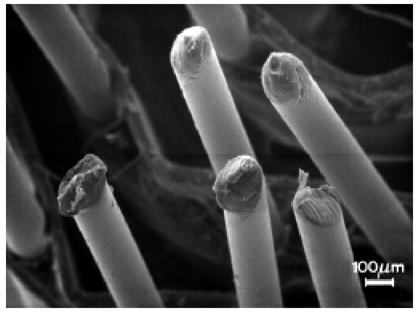

Fig. 10. Three edged oblique bristle tips in the lower row, partly with lateral overhang (category N2 and N4, product no. 14).

Statistical analysis of the proportion of acceptable and not acceptable rounding revealed that there were significant differences with regard to the products for children ($p < 0.001$). The extent of unacceptable rounding was significantly greater in product nos. 1 and 4 compared with rest of the toothbrush heads for children (Table 3).

The quantitative results for the toothbrush heads for adults varied considerably. Just one product had $< 20\%$ unacceptable rounding geometries (product no. 9). Three products had between 20% and 30% unacceptable bristle ends (product nos. 7, 11 and 12). Some 58.9% and 78.3% unacceptable rounding were observed for product nos. 13 and 14, respectively. The differences between the products for adults were significant ($p < 0.001$); Scheffé post-hoc tests showed that product no. 14 and, with one exception, product no. 13 had a significantly higher proportion of poorly end-rounded bristles than was the case with the rest of the products (Table 4).

Whether the bristle tips were located at the margin or in the centre of the toothbrush head had no significant effect on the quality of end-rounding ($p = 0.180$ for product nos. 1–6 and $p = 0.124$ for product nos. 7–14).

Discussion

Studies evaluating bristle-tip morphology are usually carried out using a stereomicroscope or SEM. One problem that might be associated with SEM-based studies concerns conditions during the sputtering procedure. Franchi & Checchi (1995) described an artificial rounding of those bristle tips that were close to the sputtering cathode and attributed this to the higher temperatures found there (Franchi & Checchi 1995). The extremely fine ramifications of split

Table 3. Portion of unacceptable end-rounding and significant differences (×) among the heads for powered toothbrushes for children (one-way ANOVA and Scheffé post hoc tests; $p<0.05$)

Product (no.)	Portion of unacceptable end-rounding	Product no.				
		3	5	2	6	1
Biocare Junior 634 (3)	5.7					
Oral Plack Attack (5)	14.3					
Dentaclip Dentiphant (2)	18.9					
Kaept'n Blaubaer (6)	18.9					
EB 10-2 Kids (1)	80.0	×	×	×	×	
Interplak Kids (4)	81.1	×	×	×	×	

Table 4. Portion of unacceptable end-rounding and significant differences (×) among the heads for powered toothbrushes for juveniles and adults (one-way ANOVA and Scheffé post hoc tests; $p<0.05$)

Product (no.)	Portion of unacceptable end-rounding	Product no.						
		9	12	7	11	8	10	13
Biocare Family (9)	17.7							
Severin (12)	24.6							
EB 15-2 Flexi Soft (7)	27.4							
Rotaclip Medium (11)	29.1							
Actibrush (8)	32.0							
Sensiflex 2000 (10)	44.6	×						
Sonicaire Compact Size (13)	58.9	×	×	×	×	×		
Brushhead Waterpik (14)	78.3	×	×	×	×	×	×	

bristle tips shown in Fig. 6 demonstrated that in the present study the sputtering chamber was sufficiently cooled to prevent artificial rounding. By using a rotary sample holder, it was possible to achieve equal distribution of the gold coating along the complete length of the bristles.

The classification of Silverstone & Featherstone (1988) is widely accepted in the assessment of bristle-tip morphology (Mulry et al. 1992, Dellerman & Burkett 1994, Franchi & Checchi 1995, Checchi et al. 2001). Reiter & Wetzel (1991) proposed using three categories of acceptable and six categories of unacceptable rounding geometries; this led to an intra- and inter-individual reproducibility of more than 90% when this classification was used (Jung et al. 2003). The authors encountered difficulties in trying to differentiate between two similar types of end-rounding geometries; therefore, the number of acceptable categories was reduced to two and the number of unacceptable categories to five in the present study.

With regard to safety during application, brushing alone seems to have no effect on enamel and very little on dentine (Addy & Hunter 2003). On the other hand, it is well documented that vigorous brushing can cause soft-tissue lesions such as gingival erosion and recession (Sandholm et al. 1982, Smukler & Landsberg 1984). Poor end-rounding of the bristles can contribute among other factors to gingival abrasion and recession. In studies using gingiva of animals, soft-tissue abrasion was caused by sharp-edged bristle tips (Alexander et al. 1977); soft-tissue lesions extending into the submucosa were reported after the use of toothbrushes with a rippled bristle profile and poor end-rounding quality (Plagmann et al. 1978). Imfeld et al. (2000) demonstrated superficial and transepithelial gingival injury after toothbrushing; sharp and edged bristle tips were determined to be one of the factors contributing to this. In a clinical study, the quality of filament end-rounding was identified as a factor influencing gingival abrasion (Danser et al. 1998). In the case of manual brushing, the sharpness of bristle ends has been associated with gingival abrasion (Egelberg & Claffey 1998).

During brushing, more force is applied with manual toothbrushes than with their powered counterparts (Van der Weijden et al. 1996). Nevertheless, special attention should be given to the end-rounding quality of powered toothbrushes, because the brushing force is not correlated with the incidence of gingival abrasion (Danser et al. 1998).

Several studies have demonstrated that it is technically possible to achieve >90% acceptable end-rounding (Mulry et al. 1992, Dellerman & Burkett 1994, Jung et al. 2003). The present study disclosed that only nine of the 14 products under investigation had more than 70% acceptable end-rounding; three products had less than 30% rounded bristle tips. This shows that some of the manufacturers of heads for powered toothbrushes do not take sufficient care in trying to achieve a high standard of end-rounding.

A new type of bristle-tip morphology was observed for product no. 1; the ends of the longer, white-coloured bristles were split into various numbers of small ramifications. According to the morphologically based classification used in this study, these bristles had to be graded as unacceptable. Based on the present results, it remains unclear whether or not these ramifications can cause soft-tissue injury due to their small diameter and low stiffness. On the other hand, it cannot be excluded that several of the fine plastic ramifications may disrupt during use of the brush and may subsequently be swallowed by children. If this plastic material may affect children's digestive system and health cannot be answered yet.

Recent studies evaluating the end-rounding of manual toothbrushes disclosed great differences between the products under investigation; at the same time an increasing number of products with >90% acceptable bristle-tip geometries were found (Imfeld et al. 2000, Jung et al. 2003). The present study revealed similar differences in end-rounding among the various powered toothbrushes; however, there was only one product with more than 90% acceptable rounding. Compared with manual toothbrushes, this indicates only a moderate quality standard.

It is recommended that some of the products should be improved with respect to the quality of bristle-tip rounding.

Achieving effective plaque control in children can be particularly difficult because of problems with motivation. Powered toothbrushes may help to overcome these problems because of their "gadget appeal", which could motivate children to brush more often. Bristle end-rounding deserves special attention with respect to products designed for children. Depending on the individual age, limited manual dexterity in children may result in an uncontrolled brushing technique. For this reason, the poor end-rounding quality of two of the powered toothbrushes for children (product nos. 1 and 4) should be emphasized.

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