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Investigation of wear in manual toothbrushes from different price categories

Key words: manual toothbrushes, purchase price, wear, surface area increase, SEM

Summary This clinical study examined differences in wear in manual toothbrushes from different price categories.

140 volunteers (14 groups of 10) brushed twice daily for 2–3 minutes over a period of three or six months using the modified Bass technique and seven different toothbrushes (TB) from three price categories.

A: 2 TB for under 1 €; **B:** 2 TB priced between 1 and 2 €; **C:** 3 TB priced at over 2 €. After a period of three or six months the increase in the bristle surface field was determined and the brush heads were rated macroscopically, by light microscopy and scanning electron microscopy (SEM) (grades 1–4: new, small, clear or very clear signs of use). The statistical analysis was performed with the Mann-Whitney U-test and Error Rates method ($p \leq 0.05$).

All bristle fields showed an increase in surface area over the period of use. When examined macroscopically and under light microscopy, very little difference was found between three and six months of use, or between brushes from the same price category. The clearest distinction was found between categories B and C, whereby C was rated worse. In SEM it was difficult to separate the findings according to price categories. Here, the scores most often awarded were 3 and 4.

The results of the three test methods differed markedly from one another. Thus no conclusions on the state of the bristles can be drawn from a marked increase in bristle field surface area. The category B TB tended to perform best.

Introduction

In addition to diet and fluoride application, dental hygiene is one of the most important aspects of dental caries prophylaxis and thus essential to the preservation of healthy teeth into old age. The most important and most frequently applied tool for everyday dental care is the toothbrush, and its benefit to oral hygiene and clinical efficacy for prevention of caries and periodontal disease is undisputed (RATEITSCHAK ET AL. 1989, RIETHE 1994).

Although a good toothbrush is indeed a prerequisite for good oral hygiene, it is only one aspect, and correct technique and

regular use are equally important. The American Dental Association (2002) recommends brushing twice daily with a soft to medium brush. Toothbrushes should not be used for longer than three months both for hygiene reasons, and for effective plaque removal, especially when used frequently (WOODALL & WILES 1993). An independent market analysis by Nielsen market research in 2003 found that Germans change their toothbrush on average only 1.3 times instead of 4–6 times a year (ZIEBOLZ ET AL. 2006). Similar results were found for a toothbrush consumption comparison in Germany and Switzerland in 2002; various market surveys have shown an average annual

consumption of two toothbrushes per person and thus a toothbrush change every six months (STAEHLE & KERSCHBAUM 2003).

The scientific evaluation of new or used toothbrushes takes several aspects into account: efficiency of plaque removal, the appearance of signs of wear, effects on dental hard tissue and surrounding soft tissues. Efficient plaque removal depends not only on the toothbrush but also on the cleaning technique and the patient's motivation (HAWKINS ET AL. 1986, SHORY ET AL. 1987). However SHARMA ET AL. (2005) have shown that significant plaque reduction can be achieved with some newly designed toothbrushes without any patient instruction at all. However, there are limitations when comparisons are made between clinical studies due to difficulties standardising parameters, such as differently shaped toothbrushes, test duration, group size, and subject instruction.

With increasing duration of use, there is an increase in the bristle field surface area (RAWLS ET AL. 1989, RAWLS ET AL. 1993). This is often used as an indicator of bristle bending. The bigger the area of the bristle field after use the further the bristles must have bent outwards. The assessment of the bristle field area increase is commonly used to determine the degree of wear of a brush (KREIFELDT ET AL. 1980, RAWLS ET AL. 1989). Although the appearance of the used brush is important for the decision to change a toothbrush, financial considerations often play a role too (ZIEBOLZ ET AL. 2006).

Looking at used toothbrushes, obvious signs of wear often correlate with poor brushing efficiency in relation to plaque removal (KREIFELDT ET AL. 1980, CONFORTI ET AL. 2003) or with gingival injuries due to split ends in the bristles. Bristles with rounded ends are favoured today because of the lower risk of soft tissue injury (SHARMA ET AL. 2005). The rounding of toothbrush bristles is seen as an important quality characteristic (REITER & WETZEL 1991, JUNG ET AL. 2005), even though newer brushes with micro-filaments have similar cleaning effectiveness (DÖRFER ET AL. 2003). Some studies have shown an increased risk of gingival injury for brushes with sharp-edged

bristles (ANNEROTH & POPPELMANN 1975, ALEXANDER ET AL. 1977, ADRIAENS ET AL. 1985, REITER & WETZEL 1991, MÜLLER ET AL. 1992). The prevalence of gingival injury seems to be increased mainly in people with good oral hygiene when using sharp-edged bristles (SANGES & GJERMO 1976). BREITENMOSER ET AL. (1978) also showed that sharp-edged bristles caused 30% more gingival injuries than rounded.

The present study aimed to address the question of whether manual toothbrushes from different price categories differed in their wear after various periods of use, i. e. after three months, as recommended, or after six months, as often practiced. In order to do this, the surface area increase in the bristle field was determined and the brush heads were evaluated macroscopically, using light microscopy and also using scanning electron microscopy (SEM). Furthermore, whether the three test methods produced similar results regarding wear should be investigated.

Method

Toothbrushes

Seven different adult toothbrushes from three price categories were selected for the investigation (Tab. I). Since most toothbrushes on the market in this price category had jagged brushing fields, this type of brush was used exclusively. Six toothbrushes had medium firm rounded bristles. The seventh toothbrush (*Meridol*; price category C) had finely tapered filaments and was therefore the only brush without round-ended bristles.

Volunteers

The study included a total of 140 volunteers (70 men and 70 women, mean age: 23.9 years). The participants were evenly distributed into 14 groups by drawing lots. Each group had

Tab. I List of the toothbrushes tested (commercial name) from three categories giving distributor, manufacturer and brush characteristics

	Price category A: under 1 Euro		Price category B: 1–2 Euro		Price category C: over 2 Euro		
Commercial name	Kurikur interaktiv	Perlodent Interdental	Dr. Best Flex interdental	Blend-a-dent professionell	Elmex Inter X	Oral B Cross Action	Meridol
Distributor	Aldi (Nord), Essen, Ger	Rossmann Burgwedel, Ger	Glaxo Smith Kline, Bühl, Ger	Procter & Gamble UK, Blend-a-med, Ger	GABA, Lörrach, Ger	Oral B Laboratories, Kronberg, Ger	GABA, Lörrach, Ger
Manufacturer	M&C Schiffer, Neustadt, Ger	M&C Schiffer, Neustadt, Ger	M&C Schiffer, Neustadt, Ger	M&C Schiffer, Neustadt, Ger	Frisetta, Schönau, Ger	Gillette Group, Ire	Frisetta, Schönau, Ger
Brush head	Length: 27 mm Width: 10 mm	Length: 28 mm Width: 12 mm	Length: 32 mm Width: 13.2 mm	Length: 31.5 mm Width: 14.7 mm	Length: 32 mm Width: 14 mm	Length: 31.5 mm Width: 15.5 mm	Length: 22 mm Width: 14 mm
Number of bristle tufts	38	40	44	44	26 straight, 10 X-cross	25	37
Bristle material	Nylon (not classified)	Nylon (not classified)	Nylon (PA 6.12-Polyamide)	Nylon (not classified)	Nylon (PA 6.12-Polyamide)	Polybutylene-terephthalate; (indicator bristles: Nylon)	Polyester
Bristle attachment	Metal anchor	Metal anchor	Metal anchor	Metal anchor	Metal anchor	Injection moulded	Metal anchor
Rounding of bristles?	Yes	Yes	Yes	Yes	Yes	Yes	No, tapered filaments
Price	0.38 €	0.39 €	1.79 €	1.79 €	2.89 €	3.15 €	3.79 €

5 men and 5 women, and at least one member of each group was left-handed. One particular toothbrush type was randomly assigned to two groups. Which of the two groups used the toothbrush for three or for six months was again determined by chance (drawing lots). All participants were instructed personally and in detail, and supplied with additional written instructional material, on the modified Bass technique. They were asked to brush with the assigned brush for two to three minutes (using a timer) twice daily (mornings and evenings). All participants used the same toothpaste (Colgate Total; RDA-value: 78; Colgate/Palmolive, Hamburg, Germany).

The study was approved by the ethics commission of the University of Göttingen.

Evaluation of wear

After three and six months use there were 140 toothbrushes available for assessment. In order to have a format suitable for evaluation, the toothbrush heads were labelled and then separated from the handles.

A single examiner defined the evaluation criteria, prepared the brush heads for the various examinations, and took photographs and measurements of surface increases. A second examiner, who was blinded and had been calibrated previously (kappa-value: 0.8) carried out the macroscopic evaluation, and scored images created under light microscopy and scanning electron microscopy using the defined criteria (Tab. II, Fig. 1).

Surface area increase: Photographs were made to determine the surface area increase due to bristle bending. The brush heads were fixed in a stand so that the bristle plane was always the same distance (20 cm) from and in the same alignment with a digital camera (EOS 10D + Ring flash Macro Ring Lite MR-1HEX, Canon Germany). The analysis was performed using Image J (a free image analysis program developed by the National Institutes of Health [NIH] for use with Windows). Three brand new brushes (control group) per brush were also measured; they served as a starting reference. The area increase

for each used toothbrush was then determined on the basis of standardised images, compared to the starting reference.

Macroscopic examination: The same setup was used for the macroscopic study as for the surface area increase analysis. Each toothbrush was photographed from above. The images were classified according to the criteria given in Tab. II (Fig. 1).

Light microscopy: The brush heads were attached to a glass slide for light microscopy. They were examined using a stereomicroscope (NOVEX Zoom, Euromex Mikroskope BV, Arnhem, the Netherlands) under 5-times magnification and photographed using a black and white camera (type JAI 235, 1/2"-IT-CCD-Micro-Lens, Sony). The camera was integrated into the microscope unit. Three images per brush head were made (anterior, middle and posterior thirds), and also classified according to the criteria listed in Tab. II (Fig. 1).

Scanning electron microscopy (SEM): After evaporation of a uniform layer of gold onto the samples, they were inserted into a scanning electron microscope (S240, Cambridge Instruments, distributed by Zeiss, Oberkochen, Germany). The operating voltage was 5 kV for all samples. In preliminary tests higher operating voltages often resulted in the bristles becoming more highly charged, that is, at higher operating voltages the bristles were moved by electron bombardment, and the resulting flickering led to image blurring. All images were made at an angle of 70° and using focus 10 (MEYER-LUECKEL ET AL. 2004). The working distance was a uniform 15 mm, the magnification used was 100. Six images per brush head were made (two each of the front, middle and posterior thirds) and evaluated according to the criteria given in Tab. II (Fig. 1).

Statistical analysis: The statistical analyses were carried out using SPSS/PC software (version 15.0 for Windows, SPSS, Chicago, USA).

The median and 25th and 75th percentiles of each group of 10 brushes were calculated for each brush type and duration of use. In order to compare the other methods with each other, a score was given for each brush and method (Fig. 1, Tab. II). In the macroscopic examination only the score for the top view

Tab. II Evaluation criteria for scoring macroscopic, light microscopic and SEM images; sample images are given in Fig. 1 marked with the respective letters

Evaluation	Macroscopic evaluation criteria	Light microscopy evaluation criteria	Scanning electron microscopy (SEM) evaluation criteria
Score 1	New appearance, no bristle bending, no fraying of bristle tufts (Fig. 1a)	New appearance, no bristle bending, no fraying of bristle tufts, no split ends (Fig. 1b)	New appearance, acceptable round ended bristles, smooth bristle surface, no surplus acrylic, bristles standing straight and even, no split ends (Fig. 1c)
Score 2	Slight signs of wear, slight or few bristles bent, slight fraying of bristle tuft (Fig. 1d)	Slight signs of wear, slight or few bristles bent, slight fraying of bristle tuft, no split ends yet (Fig. 1e)	Slight signs of wear, bristles standing straight and even, irregular bristle end rounding to flattening, but recognisable end rounding (only few not rounded or badly rounded bristles), no surplus acrylic, little surface roughness, no split ends yet (Fig. 1f)
Score 3	Clear signs of wear, clearer bristle bending, clear fraying of bristle tuft (Fig. 1g)	Clear signs of wear, clearer bristle bending, clear fraying of bristle tuft and/or slight split end formation (Fig. 1h)	Clear signs of wear, bristles worn on one side (lance formed), tapered bristle ends, surplus acrylic, a lot of surface roughness, order of tufts no longer recognisable, slight end splitting (Fig. 1i)
Score 4	Very clear signs of wear, bristles very clearly bent, very clear fraying of bristle tuft (Fig. 1j)	Very clear signs of wear bristles very clearly bent, very clear fraying of bristle tuft and/or clear split end formation (Fig. 1k)	Clear signs of wear, bristles worn on one side (lance formed), tapered bristle ends, surplus acrylic, a lot of surface roughness, order of tufts no longer recognisable, slight end splitting (Fig. 1m)

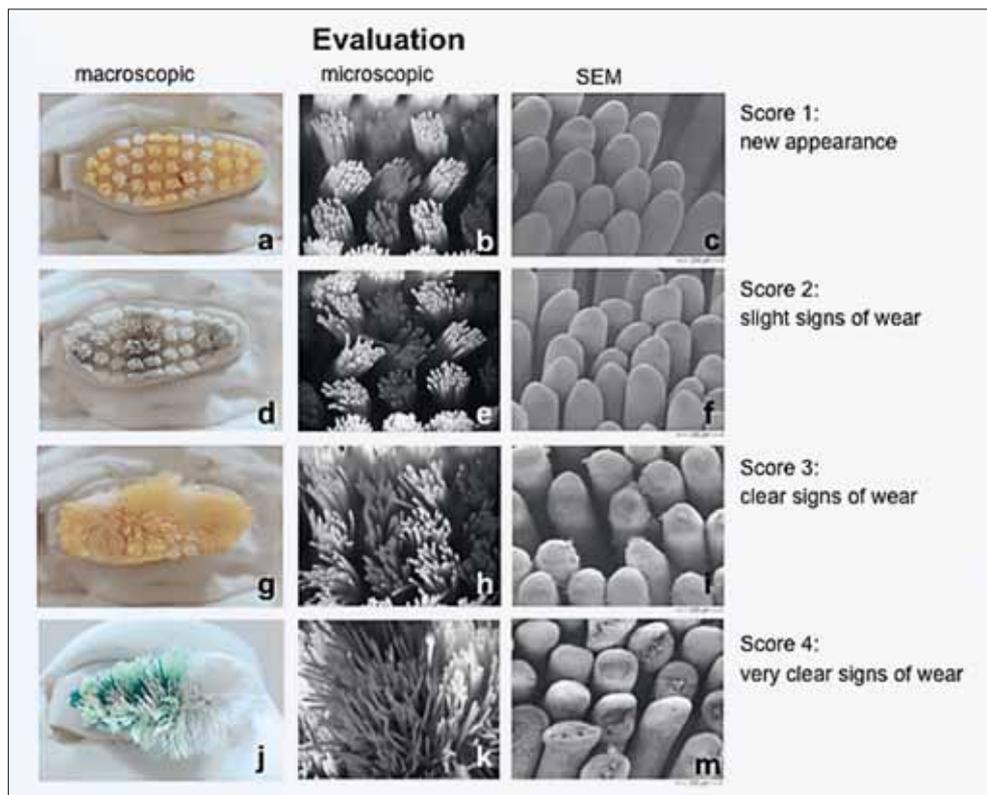


Fig. 1 Example of the macroscopic, light microscopic and SEM evaluation of the brush and the scores awarded according to Tab. II criteria.

was used. For microscopy, the overall score for a brush head was the median of the three individual scores given for a particular brush. In SEM the overall score for a brush head was the higher median value of the six individual scores (see above: SEM evaluation). This was followed by a pairwise comparison of the sample groups for each test method using the Mann-Whitney U-Test. To statistically assess the impact of each particular parameter, the level of significance α was adjusted according to the Error Rates method as follows: $\alpha^*(k) = 1 - (1-\alpha)^{1/k}$, whereby k = the number of pairwise tests to be considered. The level of significance α was set at 0.05, therefore, there was a significant difference when the error probability was $p \leq 0.05$.

Results

Only the six round bristled toothbrushes (two in each price category) are considered in the results, because, in hindsight, comparing them with the tapered filament bristles of the *Meridol* brush (price category C) did not seem admissible. Nevertheless, for the sake of completeness, the results for the *Meridol* toothbrush are illustrated in Fig. 2 and in Tab. I and II (see comment at the end of the discussion).

Surface area increase

The biggest surface area increase, after three months use, was recorded for the cheaper brushes (price category A). *Kurikur* performed worst with a surface area increase of over 50% (Fig. 2). The surface area increase was smallest overall in price category B (Fig. 2). While no significant ($p > 0.05$) surface area increase was seen after six months use in category A, it increased markedly in categories B and C (Fig. 2). Length of use only effected surface area increase significantly for one toothbrush (*Elmex*) from category C ($p = 0.043$). No significant difference between three and six months use was found for any other toothbrush ($p > 0.05$).

The price category A and C toothbrushes showed clear differences in surface area increase compared to the category B brushes (Fig. 2). After three months, the price category A brushes were found to be significantly worse than the other brushes ($p \leq 0.05$), with the exception of *Oral B* in category C ($p > 0.05$). After six months, no significant differences could be found between the category A and the category C brushes ($p > 0.05$).

Macroscopic examination and light microscopy

The macroscopic and light microscopic assessment of the brushes showed similar results and therefore they are presented together.

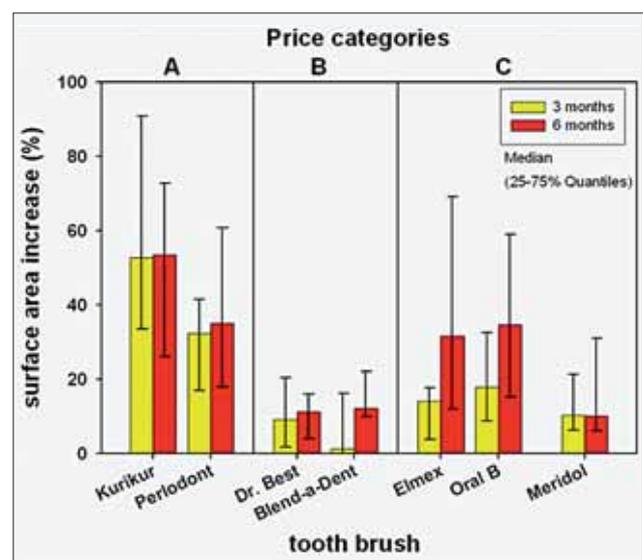


Fig. 2 Surface area increase of brushes in each of the three price categories after three and six months clinical use

Tab. III gives an overview of the frequency of individual scores awarded to each brush after three or six months use.

Overall, no significant differences were found for the brushes within a price category ($p > 0.05$). There were also no significant differences between three and six months use for any brush ($p > 0.05$). Macroscopically, both category A brushes only differed significantly from one category B brush (*Dr. Best*) ($p = 0.029$) and one category C brush (*Oral B*) ($p = 0.02$) after six months use; whereby they scored worse than *Dr. Best* and better than *Oral B*. In the microscopic assessment only *Kurikur* (category A) scored significantly higher than *Blend-a-dent* (category B) ($p = 0.033$) after three months; there was no significant difference between the other brushes after three or after six months ($p > 0.05$). Comparing categories A and C only one brush (*Oral B*) was scored significantly higher: after three months ($p = 0.031$) and after six months ($p = 0.017$).

SEM assessment

In the SEM assessment the scores 3 and 4 were awarded more often than in the macroscopic or light microscopic assessments (Tab. III).

In category B *Blend-a-dent* scored significantly higher after three and also after six months compared to *Dr. Best* ($p \leq 0.001$).

No significant differences were found between three and six months with one exception: *Perlodent* (category A) was scored significantly higher after six months than after three months ($p = 0.042$).

The comparison of the category A brushes with those from category B showed, that after three months, both *Kurikur* and *Perlodent* scored significantly better than *Blend-a-dent* ($p \leq 0.001$). Furthermore, after six months *Kurikur* also scored significantly better ($p \leq 0.001$); *Perlodent* however scored significantly higher than *Blend-a-dent* ($p \leq 0.003$). *Dr. Best* did not differ significantly from other brushes after three or after six months ($p > 0.05$).

Nor were differences found after three months between categories A and C ($p > 0.05$). However, after six months *Perlodent* did score significantly higher than *Elmex*. When comparing the category B and C toothbrushes, *Blend-a-dent* scored significantly higher after three and after six months than *Elmex* and *Oral B*; there was no significant difference between *Dr. Best* and *Elmex* or *Oral B* after three or after six months ($p > 0.05$).

Discussion

The planning and execution of in vivo studies on toothbrush wear is difficult because of the different brushing habits of volunteers. Despite the difficulties in standardising various parameters, for example brushing technique, duration and the use of the prescribed toothpaste, an in vivo study still provides valuable insights. Although an investigation into the enlargement of the bristle field after use showed no significant difference between clinical and laboratory studies (RAWLS ET AL. 1993), another study found that the “human factor” was one of the decisive criteria in toothbrush wear (WOLTMANN 1980, STEWART & WOLFE 1989, RAWLS ET AL. 1989). An in vitro study showed, that very clear signs of use could be shown even after 30 minutes of use, depending on the pressure and the quantity of toothpaste used (MCLEY ET AL. 1997). To minimise errors due to individual differences in use the volunteers in this study all received detailed instruction in a uniform brushing technique (modified Bass technique).

The division of volunteers into groups was strictly symmetrical for gender and always included one left-handed volunteer peer group. In previous studies evaluating bristle end-rounding, information on whether the examiners were blinded to each other was not included (DRISKO ET AL. 1995). In order to completely avoid bias and to ensure standardisation of the material investigated, all samples and images (macroscopic, microscopic and SEM images) were prepared by one individual. In this way, differences in the preparation of samples and imaging technique could be avoided. The randomly coded images were then assessed by a second blinded and previously calibrated person according to defined criteria, so that any differences due to multiple “experts” or their influencing each other could be excluded. However, when looking at the samples in this study, it must be considered that the images used are 2-dimensional images of 3-dimensional objects; therefore any assessment of the invisible areas was not possible. This could lead to false positive results (DRISKO ET AL. 1995).

The assessment of bristle field area increase is a commonly used method to determine brush wear. While in the present study the relative surface increase was determined, other authors have used a scale of 0 to 3 for this parameter (RAWLS ET AL. 1989). The surface area increase is significantly influenced by the quality of the bristles (RAWLS ET AL. 1993); it is described by some authors as a simple criterion for the decision to change

Tab. III Number of individual brushes in a price category with a particular score, listed according to test method and length of clinical use

Price-category toothbrushes	Test method	Time	Score	Macroscopic								Light microscopic								SEM							
				3 months				6 months				3 months				6 months				3 months				6 months			
				1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A	Kurikur			4	4	2		5	5			4	2	4	2	3	4	1	1	6	3			3	7		
A	Perlodent	1	4	5			5	5		3	2	3	2	1	6	1	2		5	5			1	8	1		
B	Dr. Best	1	6	3			2	7	1	2	4	2	2	4	3	3			4	6			3	7			
B	Blend-a-dent	1	6	3			1	7	2	4	2	4		1	6	1	2		2	8			2	8			
C	Elmex		3	7			3	3	4		4	2	4		5	1	4			4	6			1	4	5	
C	Oral B		3	5	2		1	6	3		1	2	7		1	5	4			6	4			6	4		
C	Meridol		5	5			4	6		1	5	3	1		4	6				5	5				2	8	

a brush (KREIFELDT ET AL. 1980). An Australian study found that more than 70% of all Australian dentists use this procedure and recommend that their patients change their toothbrush when the bristles are bent and spread out (DALY ET AL. 2000).

In the present study the evaluation of each brush head on a macroscopic, microscopic and SEM level was based on defined parameters. The classification of bristle end-rounding in SEM according to SILVERSTONE & FEATHERSTONE (1988) is commonly used.

The surface area increase assessment showed clear differences between brushes in different price categories after three months, particularly between category A brushes (less than 1 €) and the other two categories. Although the brushes examined all had round ended nylon bristles, the nylon material may have differed in its chemical composition (e.g. 6.6.- or 6.10.- or 6.12.-Polyamide); The influence of the bristle material on bending has already been shown (RAWLS ET AL. 1993). Since the surface increase of the bristle field has not been calculated from bristle bending up until now, the results of the present are only partially comparable with previous studies. Nevertheless, the method used is to be recommended for future studies because it allows better comparability than the division of results into a 0–3 scale as RAWLS ET AL. (1989) recommended, since this can be dependent on the investigator.

Both the macroscopic and microscopic analysis in the present study indicated that there was no difference between three and six months use for any brush. There were also no differences between toothbrushes in a single price category. Although the results of the different test methods may seem identical at first glance, a closer look at the results shows that the number of brushes with “clear signs of wear” (score 4) is much greater than for the macroscopic examination.

Likewise, the SEM evaluation in the present study showed no differences between three or six months use for any brush apart from *Perlodent* (price category A). It was more difficult to order the results for the SEM investigation according to price category than with the other test methods. Overall, scores 3 and 4 were awarded more often in SEM. This observation might be explained by the fact that with increasing magnification the signs of wear are more easily identified, because the SEM provides more plastic images of the bristle surface than macroscopic or microscopic images.

The results for evaluation of bristles after clinical use varies widely in the literature: They range from an increased rounding of bristles with use after 40 days (HENSCHKE ET AL. 1978) or for two months (RIETHE & MUNZ 1979), possibly due to removal of processing residues, up to club formation after more than three months use, after initial bristle rounding (MASSASSATI & FRANK 1982). This may also explain the higher number of studies, which only deal with the evaluation of bristles in relatively

new brushes (SILVERSTONE & FEATHERSTONE 1988, KOCKAPAN & WETZEL 1987, MULRY ET AL. 2002, JUNG ET AL. 2005).

An unequivocal assessment of the wear of toothbrushes in different price categories is not possible with the present study design. In particular, no conclusions on the state of bristles can be drawn from a large increase in bristle field surface area.

A note on the *Meridol* toothbrush with filament bristles: While the surface area increase was small after three or six months compared to the control (Fig. 2), the assessment of macroscopic, microscopic and SEM images according to the criteria used in this study proved to be extremely difficult.

Conclusion

Overall, when assessing manual toothbrush wear, the method of investigation chosen seems to play an important role. Without considering the individual brushes, all the test methods used produced very different results. The computer assisted surface area calculation for the bristle field, presented here for the first time, should be pursued further.

Résumé

Cette étude clinique a eu pour but d'analyser une éventuelle différence dans l'usure de brosses à dents de prix différents. 140 personnes (14 groupes à 10 personnes) se sont lavées les dents avec la technique de Bass modifiée pendant 3 resp. 6 mois 2 fois par jour, 2 à 3 minutes avec sept brosses à dents (BD) de catégories de prix différents. A: 2 BD de moins de 1 €; B: 2 BD de 1 à 2 €; C: 3 BD de plus de 2 €. Après 3 resp. 6 mois d'utilisation, l'accroissement de la surface des champs de soie a été déterminé. Additionnellement, les têtes des brosses ont été évaluées de façon macroscopique avec un microscope optique et un MEB à 4 niveaux (notes de 1 à 4: état neuf, insignifiant, fort, très fortement usé). L'évaluation statistique s'est effectuée à l'aide du Mann Whitney-U-Test et de la méthode Error Rates ($p \leq 0,05$).

Tous les champs de soie ont montrés un accroissement de la surface pendant la durée d'utilisation. Entre 3 resp. 6 mois d'utilisation, une différence marginale a été constatée d'un point de vue macroscopique et microscopique, ainsi que pour les BD de même prix. Les différences entre les BD de catégorie B et C étaient évidentes, bien que la catégorie C était la moins bonne. Dans le MEB, l'attribution des résultats d'après les catégories de prix était difficile. Les notes 3 et 4 ont été attribuées le plus fréquemment. Les résultats des 4 méthodes d'examen se distinguaient nettement les uns des autres. C'est pourquoi il n'était pas possible d'attribuer les résultats d'une forte croissance de la surface des champs de soie par rapport à l'état des soies. Les BD de la catégorie B ont reçu tendanciellement les meilleurs résultats.

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