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Tapered toothbrush filaments in relation to gingival abrasion, removal of plaque and treatment of gingivitis

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Versteeg PA, Piscaer M, Rosema NAM, Timmerman MF, Van der Velden U, Van der Weijden GA. Tapered toothbrush filaments in relation to gingival abrasion, removal of plaque and treatment of gingivitis.

Abstract: *Objectives:* To compare a tapered filament toothbrush (TFTB) to a control toothbrush (ADA) in their potential to cause gingival abrasion and improve the gingival condition following a period of experimental gingivitis. *Methods:* Thirty-two subjects refrained from brushing mandibular teeth for 21 days. During a subsequent 4-week treatment phase, the left or right side of the mouth was brushed with either the TFTB or ADA as randomly allocated. Gingival abrasion, plaque and gingival bleeding were assessed. *Results:* During the treatment phase gingival abrasion showed a trend to be lower with the TFTB than the ADA, which was significant at the 2-week assessment. The mean plaque scores changed from 2.98 (day 21) to 1.59 for the TFTB and from 3.00 (day 21) to 1.31 for the ADA. The mean bleeding scores changed from 1.86 (day 21) to 1.35 for the TFTB and from 1.85 (day 21) to 1.20 for the ADA. Plaque and bleeding scores were significantly lower with the ADA. *Conclusions:* Both toothbrushes improved gingival health and effectively removed plaque. Although there was a tendency towards fewer sites with gingival abrasion with the TFTB brush, it was less effective than the ADA in the removal of plaque biofilm and reduction of bleeding. Subjects considered the TFTB to be more pleasant to use.

Key words: clinical trial; experimental gingivitis; gingival abrasion; plaque; tapered filaments; toothbrush

Clinical Relevance

Scientific rationale: Toothbrushing may introduce gingival abrasion. Softer toothbrush filaments tend to be safer.

Principal findings: With a tendency towards fewer sites with gingival abrasion, the tapered filament toothbrush was less effective than the ADA-reference brush.

Practical implication: Soft toothbrushes may not be as effective as a medium brush.

Introduction

The main factor that induces inflammation of gingival tissue is the presence of bacterial biofilm (dental plaque) on the teeth/gingival interfaces (1). The products of biofilm bacteria are known to initiate a chain of reactions in the tissue leading to inflammation as well as a destructive process (2). The current therapeutic strategy to control periodontal diseases involves mechanical removal of deposits.

The development of the first toothbrushes can be traced to the Chinese as early as AD 1000 (3). Because of the price of the natural bristles the toothbrush did not become widely used until the end of the 19th century. In the late 1930s DuPont Chemical Co. developed the less expensive nylon filaments which made toothbrushes inexpensive enough for virtually everybody to own one.

The degree of hardness and stiffness of a toothbrush is influenced by filament characteristics such as material, diameter and length. Toothbrushes with bigger filament diameters are harder and less flexible. This increased stiffness will prevent the filament ends to from bending back during brushing but do create the potential of damaging the gums (4). However, the filament must be sufficiently stiff so that during brushing enough pressure is exerted to remove the plaque. Consider a rod, which is to represent a filament of a toothbrush. Whilst brushing, a vertical upward load is exerted, which in turn can exert an effect on the oral surfaces. The force of the brush acting on the individual filament is proportional to the load exercised by the filament tip (5). Consequently, if the load is increased the danger of damage increases that the filament's tip can penetrate into the mucosa. However, elastic rods demonstrate a peculiarity in their behaviour. They suddenly fold back laterally when a certain limit load is reached. When folding back, the rod suddenly gives way elastically (without breaking) and the load diminishes abruptly (5). A load higher than this fold-back limit load can thus not be transferred onto the mucosa by the rod, via its tip. But there is no point if a brush with very thin filaments merely strokes across the tooth and as a result of the lack of load no longer cleans (4). In this context the diameter of the filament has a lower limit in order to provide good cleaning performance and long durability.

As late as 1967, most people were buying hard brushes (6). The shift in preference to soft brushes paralleled the change that occurred in oral health care when calculus used to be considered the prime etiologic factor in periodontal disease (7). The focus on plaque, especially in the cervicular area and the attention to intra-sulcular brushing strongly influenced the change from hard to soft filaments, primarily because of the concern with trauma to the gingival tissues (8). In order to improve patient comfort, brush head shape, filament shape, and placement of filaments into the handles also have also been subject to changes over time. Cross placed filaments, crimped, and tapered filaments are the most recent changes. Those tapered filaments have endings with the shape of an ellipsoid instead of a hemisphere (see Fig. 1). This is suggested to give the filaments very soft endings combined with a good stability of the filament corpus.

As new brushes develop it is important to evaluate their safety and relative ability to remove plaque and improve gingival health so dental professionals are informed about the most effective toothbrushes available. The primary objective of the present study was to test the relative potential of a tapered filament toothbrush (TFTB) as compared to a control toothbrush

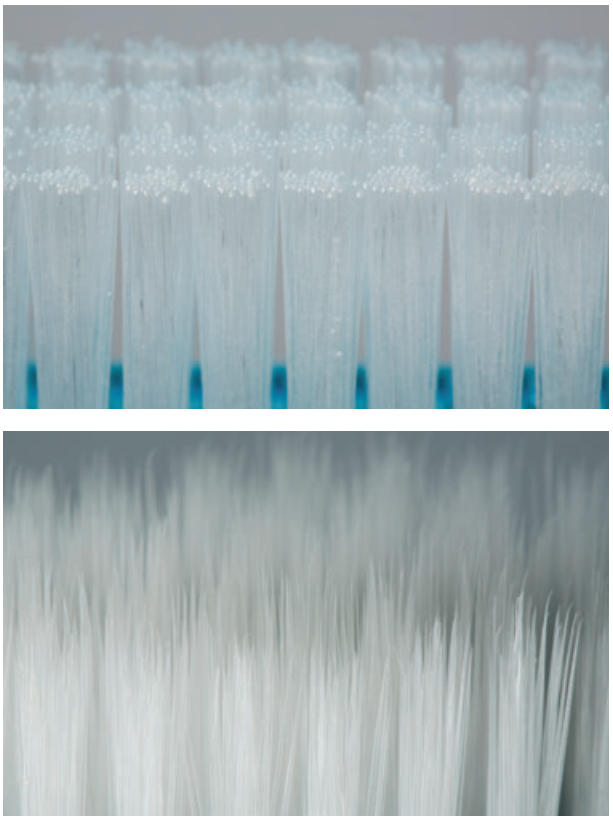

Fig. 1. From left to right a close-up of end-rounded and tapered filaments.

(ADA) with respect to cause gingival abrasion. A secondary objective was to evaluate plaque removal and improvement of the gingival condition following an experimental gingivitis model where the subjects refrained from oral hygiene for 21 days to allow development of gingivitis before commencement of the treatment. A further objective was to assess the subjects' attitudes towards the two toothbrushes.

Materials and methods

Toothbrush design

The Meridol® toothbrush (GABA Intl., AG, Switzerland) (further depicted as 'TFTB') has tapered (conical) filaments with micro fine filament ends resulting in a high level of flexibility. The conical filaments have a diameter at the base of 0.18 mm and at the end a diameter of 0.05 mm. The brush has 37 tufts and approximately 46 filaments per tuft. The handle consists of both soft and hard components (see Fig. 2). The control brush was the ADA reference brush. (further depicted as 'ADA') This brush has end-rounded cylindrical filaments. The brush has 37 tufts and approximately 40 filaments per tuft. The filaments have a diameter of approximately 0.23 mm. The handle is rectangular shaped and consists only of hard material (Fig. 3).

Fig. 2. The tapered filament toothbrush with tapered filaments.

Subjects

A total of 35 subjects were selected for this study which was carried out at the department of Periodontology of the Academic Centre Dentistry of Amsterdam, The Netherlands. To participate, subjects were required to fulfil the following inclusion criteria: non-smokers; a minimum of five evaluable teeth in each quadrant in the lower jaw (with no partial dentures, orthodontic banding or wires); absence of oral lesions and or periodontal pockets >5 mm; a level of gingival bleeding of more than 25%. In addition, subjects were only accepted if they used a manual toothbrush at home and were right-handed. All subjects were informed about the aims and objectives of the study, and gave written informed consent. This study was approved by the Medical Ethical Committee of the Academic Medical Centre (AMC) of Amsterdam (MEC 97/171).

Study design

The study design is based on protocols of which the rationale is described by Van der Weijden *et al.* (9). The study had a three-phase, randomized, examiner-blind, split-mouth design. The three phases comprised: a familiarization phase (so subjects became acquainted with the use of both toothbrushes), an experimental gingivitis phase (no oral hygiene for 21 days in the lower jaw that a reasonable level of gingivitis developed i.e., ≥ 40% bleeding on marginal probing; BOMP) and a treatment phase (for assessment of the effect of the toothbrushes on the gingival condition).

Fig. 3. The ADA reference brush.

Phases

Familiarization phase

All subjects received the TFTB and the ADA. They were given brief verbal instruction in their use and a written Dutch instruction of the 'Bass method' which has proven its worth both for people with healthy gums and for patients with gingivitis and periodontitis patients (10). Subjects were instructed to brush twice daily for two minutes using a standard dentifrice (Everclean, Hema, Amsterdam, The Netherlands). Each toothbrush was used on alternate days, and the time at which they brushed was recorded on a calendar. After 1 week, subjects received professional oral hygiene instruction in the use of the manual toothbrushes and were provided a new brush calendar. After 2 weeks, subjects returned for the start of the experimental gingivitis phase.

Experimental gingivitis phase

This phase started with an assessment (day 0) of gingival abrasion, plaque and gingival bleeding in the lower jaw. Subsequently subjects received a dental prophylaxis so they entered the study with equally clean teeth. They were instructed to refrain from brushing the mandibular teeth for the next 21 days. During this period they brushed for, their upper jaw on alternate days with one of the two brushes for further familiarization. Use of mouthrinses, dental floss, or wood sticks was prohibited. After 21 days they returned for the start of the treatment phase.

The purpose of the familiarization phase and the experimental gingivitis phase was twofold: first to get the subjects acquainted with the toothbrushes and to receive proper instruction, and secondly to have a reasonable level (40% BOMP) of gingivitis developed.

Treatment phase

Subjects were scored for plaque and gingival bleeding in the lower jaw (day 21). Only those with at least 40% of bleeding in each quadrant entered the treatment phase of the study. All subjects received new brushes and a new brushing calendar. During the 4-week treatment phase, subjects were instructed to brush their teeth with the supplied standard dentifrice according to a split-mouth design, whereby either the right or left side of the mouth was brushed for a period of 1 min per side with the TFTB or ADA, and the opposing side for one extra minute with the alternative brush such as randomly assigned.

Randomization of toothbrush allocation was performed using true random numbers (http://www.random.org). To encourage compliance and ensure that subjects brushed the correct quadrant with the correct brush, a reminder photo sticker for the bathroom mirror was provided (11). A timer was provided to keep track of time. Use of any other oral hygiene measures

such as mouthrinses, dental floss, or woodsticks during this phase of the study was forbidden. Subjects returned after 1, 2, and 4 weeks for an assessment of the level of gingival abrasion, plaque, and gingival bleeding in the lower jaw. At the end of the study (4 weeks), all subjects completed a questionnaire designed to evaluate their preferences for, and attitudes towards, the two toothbrushes used. They were questioned about their preference for either toothbrush, their perception of efficacy and pleasantness. For all questions visual analogue scales (VAS) were used to assess the subjects' attitudes. Subjects were requested to mark a point on a 10 cm long straight continuous line without any markings of which the two ends were annotated with each of the extremes of each query. The negative extreme response (0) at the left end and the positive extreme (10) at the right end. The distance of the left end to the response marking was measured in cm as a representation of the attitude that was measured.

At the end of the experimental period subjects returned to their habitual oral hygiene procedures.

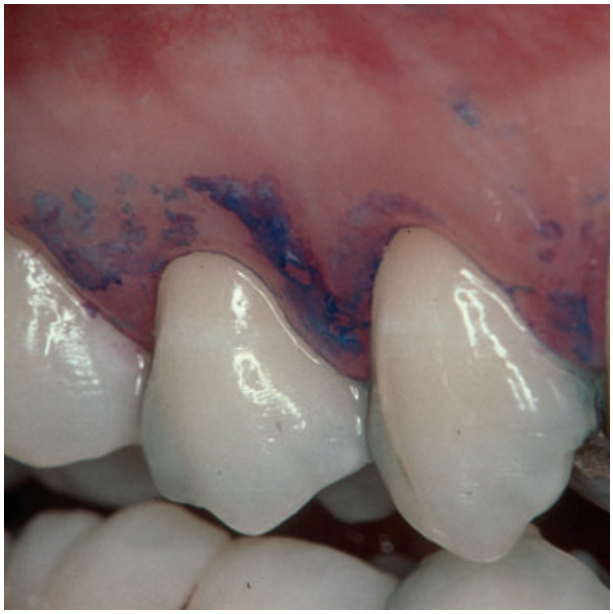

Fig. 4. A clinical photo of the gingival abrasion lesions.

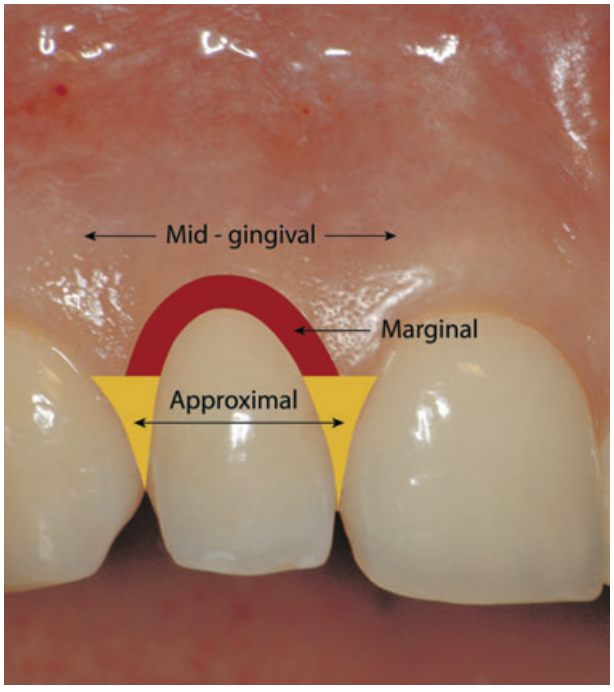

Fig. 5. Gingival abrasion.

Assessments

Throughout the study, subjects were instructed to brush between 2 and 3 h before their appointment to avoid the risk of increased bleeding on probing as a result of tooth brushing (12).

For the assessment of gingival abrasion the gums were disclosed by Mira-2-Tone disclosing solution for better visualization of areas where the surface of the oral epithelium has been abraded (Mira-2-Tone, Hager and Werken, GMBH & Co., Duisburg, Germany) (13, 14). Each quadrant was disclosed using a new cotton swab with fresh disclosing solution. The gingival tissues were divided into three areas (Figs 4 and 5): marginal (cervical free gingiva), proximal (papillary free gingiva) and mid-gingival (attached gingiva), and the number and site location of any gingival abrasions were then recorded (excluding the third molar and central incisor regions). A PQ-William's periodontal probe (Hu-Friedy Mfg. Co., Inc., Chicago, IL, USA), placed across the long axis of the lesions, was used to measure the size of the abrasions. The greatest diameter of the abrasion lesion determined the size. The number of abrasion sites was scored according to the method as described by Versteeg *et al.* (11). The lesions were assessed as small (≤2 mm), medium (≥3 but ≤5 mm) and large (>5 mm) (15). Those between 2 and 3 mm were assigned a score of small or medium according to the nearest mm mark on the probe.

Plaque was assessed after disclosing with Mira-2-Tone® (Hager & Werken GmbH & Co. KG., Duisburg, Germany), using the modification of the Quigley & Hein (16) index, as described in detail by Paraskevas *et al.* (17). Six sites per tooth were scored. Absence or presence of plaque was recorded on a scale of 0–5 (0 = no plaque, 5 = plaque covered more than two-thirds of the tooth surface).

The level of gingival inflammation was assessed using the BOMP index, where the gingival margin was probed at an angle of approximately 60° to the longitudinal axis of the tooth

and the absence or presence of bleeding was scored within 30 s of probing on a scale of 0–2 (0 = non-bleeding, 1 = pinprick bleeding, 2 = excess bleeding) (18, 19).

Throughout the study all examinations were performed by one and the same examiner (MP) under the same conditions. The study coordinator was responsible for allocation concealment. The examiner was blind to treatment randomization and records of earlier examinations were not available at each time of re-examination. Third molar and central incisor regions were excluded from the data analysis. The rationale not to include central incisors was to avoid results from overlapping brushing of adjacent quadrants.

Data analysis

This study was designed such that small differences between the two toothbrushes could be detected. Efforts were taken, therefore, to give the study a high statistical power. This included the split mouth design to exclude inter-individual variation with a predetermined randomized, a supervised brushing schedule and a sufficient sample size to assure adequate power. With an SD of 1.905 (pooled standard deviation of all four assessment and both brushes) it was possible to detect a difference of 0.97 in abrasion scores with a power 80% with 32 subjects.

The mean number of gingival abrasion sites was calculated and sorted by size. The mean bleeding and plaque scores were calculated for all sites. Gingival abrasion data were analyzed using Wilcoxon tests to compare scores for both brushes at each assessment. Overall scores were tested and explorative analysis of scores for the size categories (small, medium, large) was performed. Comparisons between brushes were made for both plaque and bleeding indices using a three-level repeated measures analysis with measurements at week 1, week 2, and week 4 as dependent variables and both scores before and after experimental gingivitis phase as covariates. Residuals analyses were performed to confirm validity of the calculated p-values. For analysis of the questionnaire data, Wilcoxon tests were used with the VAS-scores and binomial tests for questions concerning binomial choices. Values of $P < 0.05$ were considered as statistically significant.

Results

Subject population

Of the 35 subjects which entered the study 32 subjects completed the protocol. Three individuals dropped out of the study for reasons unrelated to the study products. The subject population comprised nine males and 23 females with a mean age of 24.0 years (range, 21–42 years). All subjects had good general health and were not taking any medication that could interfere with the study outcomes. According to the returned brush calendars, compliance of the twice daily brushing regimen during the 4-week treatment phase was almost 100% for all subjects. No adverse events were reported.

Gingival abrasion

Table 1 shows the overall gingival abrasion scores which ranged from 0.81 to 1.06 for the TFTB and from 1.28 to 2.44 for the ADA (Table 2). At 2 weeks the difference between both

Table 1. **Mean (SD) gingival abrasion scores for both brushes at each assessment**

n = 32	Day 0†	1 week brushing	2 weeks brushing	4 weeks brushing	Repeated measures analysis (*P*-value)
All					
Test (TFTB)	0.94 (1.52)	0.81 (1.71)	1.06 (1.42)	1.03 (1.79)	
P-value*		0.015	0.0003	0.425	0.1009
Control(ADA)	1.28 (1.87)	2.16 (2.97)	2.44 (2.11)	1.44 (1.85)	
Small					
Test (TFTB)	0.91 (1.44)	0.75 (1.61)	1.00 (1.34)	0.94 (1.78)	
Control (ADA)	1.09 (1.57)	2.06 (2.97)	1.91 (1.89)	1.13 (1.56)	
Medium					
Test (TFTB)	0.03 (0.17)	0.06 (0.25)	0.06 (0.25)	0.09 (0.30)	
Control (ADA)	0.16 (0.45)	0.09 (0.39)	0.25 (0.44)	0.25 (0.51)	
Large					
Test (TFTB)	0.00 (0.00)	0.00 (0.00)	0.00 (0.17)	0.00 (0.00)	
Control (ADA)	0.03 (0.18)	0.00 (0.00)	0.28 (0.73)	0.06 (0.35)	

*anova with 'day 0' as covariate.
†At this stage this mean figure represent the scores of the quadrant assigned to the two toothbrushes during the treatment phase after experimental gingivitis.

Table 2. **Mean (SD) overall plaque and bleeding scores for both brushes at each assessment**

n = 32	Day 0	Day 21	1 week brushing	2 weeks brushing	4 weeks brushing
Plaque					
Test (TFTB)	1.86 (0.56)	3.01 (0.28)	2.05 (0.48)	1.79 (0.47)	1.62 (0.45)
P-value*			< 0.0001*	< 0.0001*	0.0003*
Control (ADA)	1.87 (0.53)	3.00 (0.31)	1.60 (0.56)	1.37 (0.50)	1.33 (0.45)
Bleeding					
Test (TFTB)	1.45 (0.30)	1.86 (0.15)	1.66 (0.22)	1.47 (0.31)	1.35 (0.34)
P-value*			0.1471*	0.0001*	0.0426*
Control (ADA)	1.43 (0.30)	1.86 (0.17)	1.60 (0.26)	1.25 (0.34)	1.21 (0.38)

*anova with 'day 0' and 'day 21' scores as covariate.

brushes was most pronounced in favour of the TFTB ($P = 0.0003$). Further explorative analyses are shown in Table 1. Most abrasion sites were small, few were medium, and large sites were a rare observation with either toothbrush.

Plaque

During the experimental gingivitis phase (day 0 to day 21), the plaque index scores increased notably (Table 2). Plaque was significantly reduced by the first week of treatment by both toothbrushes. After 4 weeks of use of the product, plaque levels changed from 3.01 (day 21) to 1.62 for the TFTB, and from 3.00 (day 21) to 1.33 for the ADA. After 1, 2 and 4 weeks of brushing, plaque levels were significantly lower with the ADA compared with the TFTB (Table 1). After 4 weeks of product use, mean plaque scores were significantly reduced below day 0 values with both toothbrushes.

Bleeding

During the experimental gingivitis phase (day 0 to day 21), the bleeding index increased, at day 21 scores were 1.86 for the TFTB and ADA (Table 2). After 4 weeks of use of the product, bleeding levels changed from 1.86 (day 21) to 1.35 for the TFTB, and from 1.86 (day 21) to 1.21 for the ADA. Statistically significant differences were found between brushes at 2 and 4 weeks of product use. After 4 weeks of product use, mean bleeding scores were reduced below day 0 values with both toothbrushes ($P = 0.0049$).

Response to questionnaire

At the end of the last visit all subjects completed a questionnaire designed to evaluate their attitudes towards both brushes used in the study. Nearly all subjects stated that both toothbrushes were able to clean the teeth properly. Asking which one was best in removing plaque, 13 subjects chose the TFTB, 14 subjects chose the ADA ($P = 1.000$) and five subjects had no preference. Average VAS-scores for both brushes in terms of pleasantness of use (0 = unpleasant, 10 = very pleasant), are 7.1 for the TFTB and 5.8 for the ADA ($P = 0.033$).

Discussion

Abrasion

The cleaning performance of a toothbrush is among other factors influenced by its degree of hardness. The toothbrush should not be too hard, not to damage the gums. The harder the toothbrush filaments the greater the chance of gingival abrasion whereby the protective keratin layer is destroyed (20). Soft-tissue abrasion can be caused by the repetitive motion of directing the toothbrush forcefully in a lateral direction against the tooth and gingival tissue. The combination of dentifrice and toothbrush filaments that are not end-rounded could also damage hard tissue (8, 21). Convex rounding of filament ends has been shown to be a prerequisite for avoiding tissue damage (22). Danser *et al.* (13) evaluated two types of end-rounding and found an effect where the incidence of abrasions was higher with the more conical type of end-rounding. On the other hand the form to which the ends were rounded had no effect on the level of plaque removal. It was the purpose of the present study to test a manual toothbrush with tapered filaments in its potential to cause gingival abrasion and improve the gingival condition following a period of experimental gingivitis. With the use of tapered filaments more flexibility is introduced in the filaments which are presumably less harmful. The present study showed that there was a trend towards less abrasion with the tapered filaments. This was only significant at the 2 weeks assessment.

Efficacy

Toothbrush developers have several processes to test new toothbrush designs for their cleaning efficacy. The initial testing used

by many manufacturers is laboratory efficacy. Today a variety of laboratory assessments has been developed in order to compare one toothbrush to another, economically, quickly and accurately, under tightly controlled conditions. The efficacy of tapered toothbrush filaments has been tested in laboratory studies and it was found that they were able to reach into interproximal areas of teeth where plaque traditionally accumulates-along the gingival margin and under the gum line. The tapered filaments were more effective in all areas compared to a traditional toothbrush design with end-rounded filaments in a flat trimmed toothbrush head configuration (23, 24). In another study (25), tapered filaments appear to have an advantage for reaching into the fissure as compared to end-rounded filaments.

An '*in vivo*' single-brushing study by Dörfer *et al.* (26) was designed to detect any differences between the TFTB and the ADA reference toothbrush. It was concluded that the TFTB and the ADA removed a significant amount of plaque. The TFTB showed on most surfaces a statistically significant better plaque-removing efficacy compared to the standard flat trimmed toothbrush (47.4% TFTB and 44% with the ADA). This 3.5% difference between the two groups was statistically significant but small and the clinical relevance was doubted by these authors (26).

Kreifeldt *et al.* (27) studied tapering of the toothbrush filaments from a different angle of interest. They assessed the efficacy of worn toothbrushes and observed that as a result of wear the filaments showed a taper, proceeding from the insertion to the free end. For example, filaments were seen which tapered from 0.28 cm at one end to 0.20 to 0.15 cm at the free end. They concluded that among other wear factors, tapering contributed the most to loss of effectiveness. Their explanation for this observation was that the tapering will result in a reduction of filament diameter, and thus the brush will become softer and remove less plaque. These results are in line with the outcome of the present study were the flat trimmed end-rounded toothbrush was more effective than the tapered filament toothbrush. The results of the present study may be compromised by the fact that once the subjects started brushing with the test/control brush 3-week-old plaque was already present. Old plaque adheres better to the tooth surfaces due to the polysaccharides (28, 29). It seems feasible to expect that it was more difficult for the flexible tapered filament to remove this sticky old plaque.

Satisfaction

A recent study evaluated the subjective satisfaction of the TFTB (30). A satisfaction questionnaire was applied and a significantly higher percentage of subjects expressed that the TFTB was 'pleasant to use' as compared to the control, both at 30 days (77% versus 48%, $P = 0.02$) and 60 days (80% versus 54%, $P = 0.04$). These observations are in line with the present study where the TFTB received a higher 'pleasant to use score' than the ADA. However, how effective any toothbrushing method is, it will only be of real value if the patient is prepared to use it on a regular basis (31). Merely the patients' positive attitude may have a positive long-term effect on the efforts of tooth cleaning.

Conclusion

Both toothbrushes improved gingival health and effectively removed plaque. With a tendency towards fewer sites with gingival abrasion, the tapered filament toothbrush however was less effective than the control toothbrush (ADA-reference) in removing plaque biofilm and reducing bleeding. There was a higher subject satisfaction using the tapered filament toothbrush.

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