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Interproximal access efficacy of three manual toothbrushes with extended, x-angled or flat multitufted bristles

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Abstract: *Purpose:* This laboratory research study was conducted to evaluate three manual toothbrushes for their ability to remove artificial plaque from interproximal sites. *Materials and methods:* Interproximal access efficacy (IAE) was evaluated using a pressure-sensitive artificial plaque substrate placed around simulated anterior and posterior teeth with horizontal and vertical brushing motions. Efficacy was determined as the maximum width of artificial plaque removed from around the teeth. Testing was conducted on three manual toothbrushes with different bristle configurations coded as: Extended [Aquafresh® Between Teeth (also marketed as Dr. Best® Zwischenzahn®)], X-angled (Oral-B® CrossAction®) and Flat multitufted (Oral-B® Indicator®). Twenty-four tests on each toothbrush design were conducted, and the results were statistically analysed using two-sample *t*-tests, assuming unequal variances. *Results:* The individual mean IAE values on anterior and posterior tooth shapes with vertical and horizontal brushing were significantly ($P < 0.001$) higher for the toothbrush with extended bristles (Aquafresh® Between Teeth) than for the other two toothbrush designs tested. When the data were combined to give an overall average, the IAE for the toothbrush with extended bristles (Aquafresh® Between Teeth) was significantly ($P < 0.001$) higher than the IAE value for the toothbrushes containing x-angled (Oral-B® CrossAction®) or flat multitufted bristles (Oral-B® Indicator®). *Conclusion:* Based on the demonstrated predictability of the IAE assay for clinical interproximal plaque removal, the manual toothbrush with extended bristles should be an effective brush for cleansing the dental interproximal sites.

Key words: bristles; interproximal access; laboratory studies; plaque; toothbrush(es)

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Introduction

Plaque removal with manual toothbrushes remains the primary method for beneficial at-home tooth care (1). While conventional toothbrushes can be highly effective for cleaning broad tooth surfaces and are capable of removing up to 1 mm of subgingival plaque, they are considered less effective in removing plaque from interproximal areas (2). Two factors that may affect manual toothbrush efficacy are brushing technique and duration (3). Attempts to improve brushing efficiency have focused on professional instruction of brushing techniques such as brush angulation at the tooth and gingival margin and tooth brushing motions (4, 5).

However, clinical documentations of tooth brushing techniques show that horizontal brushing with the toothbrush placed at an angle of 90° remains the primary brushing pattern (6, 7). Brushing time, also, is poorly perceived; people assume that they are brushing 2–3 min, whereas recorded times are approximately 1 min or less (7–9).

Development of a new toothbrush involves multiple and complex interactions including design, fabrication, quality control and stability testing (10). The focus of the recently developed toothbrush has been to improve interproximal access of toothbrush bristles that may result in improved tooth cleaning with a variety of tooth brushing techniques. The unique feature that has been incorporated into the new toothbrush head was designed to contain two types of tufting: a lower level containing multitufted bristles and a raised level with fine interspersed bristling. The fine bristle filaments are 4 mm longer than the lower bristles. The fine filaments are conical shaped and the end-rounded bristle ends of the extended slim filaments are up to twice as fine as those of the conventional bristles. The fine bristles are embedded in tufts of the conventional filaments (11). Alignment of the extended toothbrush bristles on a dental Typodont results in the displacement of these bristles into interproximal sites as shown in Fig. 1.

Prior to the clinical evaluations of new toothbrush designs for safety and effectiveness, which may be long term and expensive, initial evaluations for plaque removal efficacy in a laboratory method may be useful. Several rapid and reproducible laboratory methods have been developed that mimic clinical brushing. Improved interproximal plaque removal has been documented with novel manual toothbrush modifications compared with standard commercially available toothbrushes (4, 5, 12).

The method of Nygaard Ostby *et al.* (13), which focuses on interproximal cleaning, has been most widely used to evaluate plaque removal by a variety of toothbrush designs. Originally, this method was conducted using dry tooth brushing to physically remove the plaque substrate. In 1995, Shi *et al.* developed a simulated plaque substrate that enabled testing in the presence of water, saliva, or dentifrice products (14). When significant differences between toothbrush designs were demonstrated, using dry brushing, similar findings were obtained with the newly developed plaque substrate. Overall, interproximal access efficacy (IAE) results of laboratory evaluations using either dry or wet brushing conditions have been predictive of clinical plaque removal (4, 12). In 2000, Beals *et al.* (7) developed a laboratory method that documented efficacy of an x-angled manual toothbrush; this method also has been documented to be predictive of clinical efficacy for this toothbrush (15).

Fig. 1. Toothbrush bristle penetration on Typodont teeth.

Recently, tapered filaments have been incorporated into the tufting of several manual toothbrushes; Hotta and his group developed three laboratory test methods designed to evaluate various cleaning aspects of these toothbrushes (16–18). Using the method of Nygaard Ostby *et al.* (13), interproximal access and plaque removal by two manual toothbrush designs containing tapered bristle tufts have been demonstrated (19, 20). These findings have been confirmed in two clinical plaque efficacy studies (21, 22).

The purpose of this study was to evaluate three toothbrush products, having bristle configurations described as extended, x-angled or flat multitufted, for efficacy in the IAE procedure of Nygaard-Ostby *et al.* (13) laboratory method using wet brushing conditions (14). For comparative purposes, a toothbrush with x-angled bristles was selected, as laboratory and clinical plaque removal evaluations of this product have been published (7, 15). The flat multitufted commercially available toothbrush also was included, as this product has been a standard control in many laboratory and clinical evaluations (4, 7, 12, 19, 20).

Materials and methods

Three toothbrush products, Aquafresh® Between Teeth (also marketed as Dr. Best® Zwischenzahn®), medium texture with extended orange bristles (GlaxoSmithKline Consumer Healthcare, Buehl, Germany), Oral-B® CrossAction® 40 medium texture with x-angled bristles and Oral-B® Indicator® 40 medium texture with flat multitufted bristles (Procter & Gamble, Weybridge, Surrey, UK), were evaluated in this study. All toothbrushes were provided by GlaxoSmithKline Consumer Healthcare GmbH & Co. KG, Buehl, Germany. Lateral views of the toothbrushes tested are depicted in Fig. 2. Six toothbrushes from each product group were tested four times for a total of 24 tests on each toothbrush design. Toothbrushes were stored in our laboratory at a temperature of 67-70°F for more than 48 h before testing. Brushes were selected for testing in a randomized manner.

The laboratory equipment used was fabricated to the design of Nygaard Ostby *et al.* (13) The toothbrush head was submerged in tap water for 75 s and the artificial plaque substrate placed around the teeth was sprayed with water at 15 s intervals during this period prior to the start of brushing. The toothbrush to be tested was attached to the brushing device by the handle. The tooth brushing technique involved independent evaluations of each toothbrush in a vertical and horizontal brushing motion, tooth shapes simulating anterior and

Fig. 2. Lateral views of toothbrushes tested. Left to right: Aquafresh® Between Teeth, Oral-B® CrossAction® 40 and Oral-B® Indicator® 40.

posterior teeth and a brushing weight of 250 g. The brushing apparatus was set to brush 15 s at two strokes per second with a 50 mm stroke. Toothbrush bristles were placed at an angle of 90° to the tooth surface and brushing was performed for 15 s at two strokes per second with 50 mm strokes. The artificial plaque substrate was removed from the teeth, and the maximum width of plaque removed (IAE) was recorded in cm using Vernier calipers. The same examiner performed all evaluations.

The analysis of variance (ANOVA) was performed on the mean scores from each test of the toothbrush products. Significant differences between the toothbrushes were identified using two-sample *t*-tests, assuming unequal variances.

Results

Interproximal access efficacy results with vertical brushing are presented in Table 1. Bristle penetration into the interproximal areas of posterior teeth after vertical brushing with the toothbrush with extended bristles is depicted in Fig. 3.

The mean IAE on anterior tooth shapes with vertical brushing is significantly higher ($P < 0.001$) for the toothbrush with extended bristles product than for the toothbrushes with x-angled and flat multitufted bristling. The x-angled product is superior ($P < 0.01$) to the flat multitufted product.

The mean IAE on posterior tooth shapes with vertical brushing is significantly ($P < 0.001$) higher for the toothbrush with extended bristles than for the x-angled and flat multi-

Table 1. **Interproximal access efficacy on anterior or posterior shaped teeth with vertical brushing**

Toothbrush bristle design			
Tooth shape	Extended	X-angled	Flat multitufted
Mean (SD) [cm]			
Anterior	1.35 (0.05)	0.84 (0.08)	0.78 (0.06)
Posterior	1.50 (0.02)	0.99 (0.04)	1.03 (0.04)

Fig. 3. Toothbrush bristle penetration on simulated posterior teeth.

Table 2. **Interproximal access efficacy on anterior or posterior shaped teeth with horizontal brushing**

Toothbrush bristle design			
Tooth shape	Extended	X-angled	Flat multitufted
Mean (SD) [cm]			
Anterior	1.21 (0.06)	0.89 (0.06)	0.67(0.07)
Posterior	1.29 (0.10)	0.82 (0.10)	0.82(0.10)

Table 3. **Overall interproximal access efficacy**

Toothbrush bristle design		
Extended	X-angled	Flat multitufted
Mean (SD) [cm]		
1.34 (0.12)	0. 89 (0.10)	0.82 (0.16)

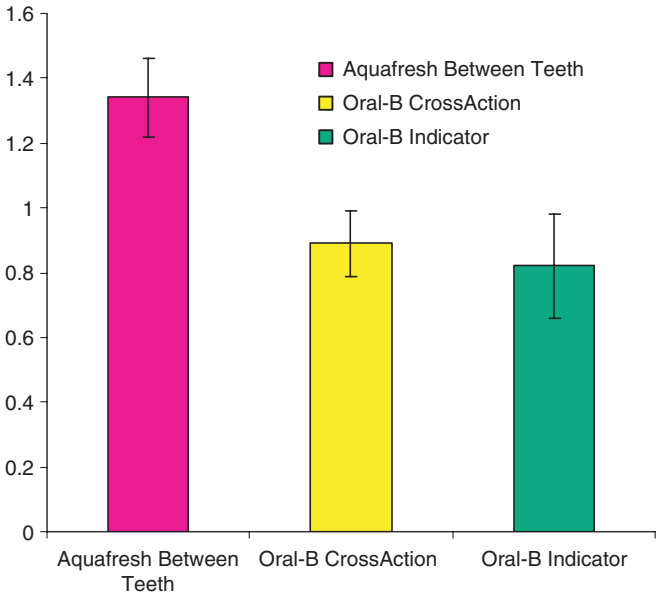

Fig. 4. Overall interproximal access efficacy mean values.

tufted toothbrushes. The flat multitufted toothbrush is superior to the x-angled toothbrush ($P < 0.001$) on posterior tooth shapes.

Interproximal access efficacy results with horizontal brushing are presented in Table 2.

The mean IAE value on anterior tooth shapes with horizontal brushing is significantly higher ($P < 0.001$) for the toothbrush product with extended bristles than for the toothbrushes with x-angled or flat multitufted designs. In this assay, the x-angled product is significantly higher ($P < 0.001$) in IAE mean value compared with the flat multitufted product. The mean IAE on posterior tooth shapes with horizontal brushing is significantly ($P < 0.001$) higher for the toothbrush with extended bristles than for the products with x-angled or flat multitufted bristles. In this assay, there is no significant difference ($P > 0.05$) in the IAE mean values for the x-angled or flat multitufted bristle designs.

Overall mean values combining all brushing motions and teeth shapes are shown in Table 3 and Fig. 4.

The overall IAE mean for the toothbrush with extended bristles is statistically ($P < 0.001$) higher than the overall mean values for the x-angled and the flat multitufted toothbrushes. Overall, the product with x-angled bristles is superior to the product with a flat mutitufted design ($P < 0.001$).

Discussion

While tooth brushing is the most widely used at-home tooth cleaning procedure, brushing alone cannot completely remove plaque from interdental sites and adjacent gingivae. Additional tooth cleaning with floss or interdental brushes is time consuming, technically demanding and is performed by 10% of the population (2, 3, 23). People with poor oral hygiene habits are more apt to develop gingivitis and periodontitis at interdental sites. Plaque at these tooth sites also has been reported to be more acidogenic than at other areas, and thus the potential for caries incidence is increased in interproximal areas (24).

One focus of the new toothbrush developments has been to increase the ability of brush bristles to penetrate deeper into and remove more plaque from interproximal areas compared with flat multitufted toothbrushes that have been the primary commercially available products and the standard design available from the American Dental Association (4–7, 9, 10, 12–14, 19, 20). One of the first more effective products was a toothbrush with raised rows of bristles on the lateral sides of the toothbrush head (4, 5). Further attempts at improved designs included variation in bristle heights, and/or angulation throughout the brush head. Laboratory assessments on these products yielded useful information on bristle design for lateral and toe-to-head movements of the toothbrush bristles and their ability to remove interproximal deposits (4–7, 9, 10, 12, 13). Changes in individual toothbrush bristle shapes are a more recent approach to improve interproximal cleaning. The use of bristles with diameters smaller than the standard 5–8 mils, coupled with tapered ends, is a further attempt to enable these bristles to penetrate into interproximal sites compared with standard circular bristles. In publications located, fine tapered bristles have been incorporated into tufts having an overall design with a flat profile or with varying heights (16–21).

The newly developed toothbrush, Aquafresh® Between Teeth, evaluated in this study contains several fine filaments that extend from tufts containing standard width bristles. This allows for increased flexion of the extended bristles and facilitates their penetration into interproximal areas as shown in Typodont models and simulated teeth (Figs 1 and 3).

In all of the individual IAE laboratory assays reported here, the IAE of the toothbrush design with extended bristles was consistently and significantly superior to the IAE of the x-angled and flat multitufted products tested. The x-angled and flat multitufted products differed in IAE efficacy using vertical brushing. With anterior shaped teeth, the IAE for the x-angled toothbrush was superior to the flat multitufted product. However, on posterior tooth shapes, the flat multitufted brush was superior to the x-angled results. With horizontal brushing, on both anterior and posterior teeth, the x-angled product was significantly superior in IAE compared with the flat multitufted product. When the data from vertical and horizontal brushing and anterior and posterior tooth shapes were combined to yield overall IAE means, the IAE of the toothbrush design with extended bristles was significantly superior to the IAE of the x-angled and flat multitufted products; the x-angled toothbrush design was significantly superior in overall IAE compared with that of the flat multitufted design.

Conclusion

Based on the demonstrated efficacy and the predictability of this laboratory IAE assay, the manual toothbrush with extended bristles should provide effective cleansing of the dental interproximal sites.

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