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In vitro tooth cleaning efficacy of electric toothbrushes around brackets

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SUMMARY This *in vitro* study assessed the cleaning efficacy of different electric toothbrushes around upper incisor brackets.

Standard and Mini Diamond™ brackets were fixed on black-stained teeth. The teeth were coated with white titanium oxide and brushed in a machine twice for 1 minute each. Twelve different brush heads with either a wiping or an oscillating–rotating action were tested. After brushing, the teeth were scanned, the black surfaces were assessed planimetrically and a modified plaque index for orthodontic patients (PIOP) was introduced. Tooth areas, which were black again after brushing indicated tooth surface contact of the filaments and were expressed as a percentage of total area. The remaining white areas around the brackets indicated 'plaque-retentive' niches. Analysis of variance was used for individual comparison of the brush types. Bonferroni/Dunn adjustment was applied for multiple testing.

The Sonicare® toothbrush handle with the brush head 'Compact ProResults' (81.7 per cent) and the brush head 'Standard ProResults' (80.8 per cent), as well as the sonic Waterpik® toothbrush SR 800E with the standard brush head (78.2 per cent), showed statistically significantly better cleaning efficacy than all others. The poorest cleaning efficacy was observed for the oscillating–rotating Braun Oral-B Professional Care with the brush head 'Ortho' (less than 50 per cent). The planimetric findings were in correspondence with the results of the PIOP assessment.

Cleaning efficacy of electric toothbrushes around brackets on upper incisors was different between the tested brushes. The PIOP was practicable, effective, and easy to use, although it has to be verified in a clinical study.

Introduction

Efficient plaque control is an important factor in the maintenance of dental health during fixed orthodontic appliance therapy (Zachrisson, 1976; Mitchell, 1992; Atack *et al.*, 1996). These patients are at higher risk of developing white spot lesions (Zachrisson, 1976; O'Reilly and Featherstone, 1987) and gingival inflammation (Legott *et al.*, 1984; Huser *et al.*, 1990) due to the altered oral hygiene situation. Brackets, archwires, and other appliance components are both a focus for plaque accumulation and an obstruction to plaque removal, leading to increasing numbers of *Streptococcus mutans* and lactobacilli (Liu *et al.*, 2004). The presence of fixed orthodontic appliances also increases the skill and effort required to maintain a good level of oral hygiene.

Applications of fluoride and/or antibacterial agents are recommended to reduce these unwanted side-effects (Øgaard *et al.*, 1980, 1988). A systematic review on the caries-inhibiting effect of preventive measures during orthodontic treatment with fixed appliances confirmed the demineralization-inhibiting tendency of toothpaste and gel with a high fluoride concentration of 1500–5000 ppm or of complementary chlorhexidine (Derks *et al.*, 2004). Such measures are, however, dependent on either frequent professional oral hygiene or patient compliance. Sealing of the enamel surface with resin-based bonding agents or even the application of veneers have been proposed to protect enamel against demineralization (Miwa *et al.*, 2001; Fornell *et al.*, 2002). In the above mentioned systematic review, the use of a polymeric tooth coating around the brackets showed almost no inhibiting effect on demineralization (Derks *et al.*, 2004). Further clinical trials are needed to give evidence-based advice on the optimal caries-prevention strategy.

Plaque removal by toothbrushing is still the most effective preventive method (Hotz, 1998). It is not clear, however, if the use of a standard toothbrush alone is sufficient for adequate plaque removal. Numerous types of toothbrushes have been designed and promoted for orthodontic patients. In recent *in vitro* studies, staged and V-shaped brush head designs outperformed planar brushes in cleaning efficacy of teeth with fixed orthodontic attachments (Sander *et al.*, 2005; Schätzle *et al.*, 2009).

The introduction of powered toothbrushes has tended to improve general efficacy and patient acceptance. Today, many different designs and action modalities are available, and all claim to be more effective than manual toothbrushes. This issue is, however, still controversial. Manufacturers have also developed specifically designed electric brush heads to improve brushing efficacy for orthodontic patients. However, there are no conclusive results in the literature (Thienpont *et al.*, 2001; Hickman *et al.*, 2002; Moritis *et al.*, 2002; Costa *et al.*, 2007). So far, no study has reported results on the cleaning efficacy of different electric toothbrushes and brush heads on teeth with fixed orthodontic appliances under standardized *in vitro* conditions.

The purpose of this investigation was to assess the cleaning efficacy of 12 different brush heads of two electric toothbrush actions (wiping and oscillating–rotating) currently marketed in Switzerland, under standardized laboratory conditions using a well-established test method (Imfeld *et al.*, 2000; Schätzle *et al.*, 2009), and to quantify enamel areas with inadequate filament contact in a custom-made model of an upper anterior segment with bonded brackets.

Materials and methods

Five electric toothbrushes (Oral-B Professional Care 9500, Braun Oral-B Sonic complete, Philips Sonicare Elite 9000, Waterpik sensonic, and Waterpik Sensonic SR 800E) of two different modalities (wiping and oscillating–rotating) with a total of 12 different brush heads were tested (Table 1 and Figure 1). Each toothbrush was mounted on a single-place automated brushing machine, which moved them over a custom-made tooth model of an anterior segment.

The gum line represented mild gingival recession. The model teeth were black and had brackets bonded to the labial surfaces (Figure 2). On teeth 11 and 12, standard Twin Diamond™ (Ormco Europe AG, Al Amersfoort, Netherlands) brackets were placed, whereas on teeth 21 and 22 Mini Diamond™ (Ormco Europe AG) brackets were bonded with Transbond™ XT (3M Unitek, Monrovia, California, USA) according to the manufacturer's guidelines. A 0.016 × 0.022 inch stainless steel archwire was incorporated in the bracket slots. Before brushing, all black tooth surfaces were coated with white titanium oxide simulating 100 per cent plaque accumulation on the tooth surfaces. Tooth surfaces reappearing black after brushing had been touched by the filaments of the tested brushes and were regarded as potentially cleaned. The total areas to be cleaned around the brackets were approximately 119 mm^2 for the teeth with standard brackets (tooth 11: 70 mm^2 and tooth 12: 49 mm^2) and 127 mm^2 for the teeth with mini brackets (tooth 21: 75 mm^2 and tooth 22: 52 mm^2).

Due to the fact that at high loads soft or fine bristles may become twisted resulting in a lower cleaning efficacy (Sander *et al.*, 2005), the tracking force was varied in relation to the brush head area in order to achieve a constant force (Load/Area; Table 1).

Table 1 Technical data for the different toothbrushes and brush heads tested in the present study.

Toothbrush	Brush head	Filament diameter (mm)	Filament height (mm)	Number of filaments per		Contact area (mm^2)	Tracking force (g)	Load/Area (g/mm^2)
				Hole	Brush head			
Oscillating–rotating toothbrush								
A Oral-B Professional	a Micro Pulse EB 25	0.15–0.16	7–8.2	66–80	1362	125	118	0.94
Care 9500 (Triumpf;	b Precision Clean	0.15	7–8	58	1508	113	106	0.94
Procter & Gamble Co.,	c Ortho	0.18	7–8	40	720	105	100	0.95
Cincinnati, Ohio, USA)	d Dual Clean	0.15	7–8	52–62	2588	218	210	0.96
Sonic toothbrushes								
B Braun Oral-B Sonic	e Sonic CrissCross	0.15 and 0.18	8.5 and 10	4656	1488	184	173	0.94
complete (Procter &	f Sonic sensitive	0.15 and 0.18	9–10.5	52–60	1416	184	173	0.94
Gamble Co.)								
C Philips Sonicare	g Standard ProResults	0.15 and 0.18	8–11	42–64	1772	180	169	0.94
Elite 9000 (Philips Oral	brush head							
Healthcare, Inc., Snoqualmie,	h Compact ProResults	0.15 and 0.18	8.2–10.5	40–60	1120	125	117	0.94
Washington, USA)	brush head							
D Waterpik Sensonic	i Advanced Brush	0.18	9–12	46–56	1496	213	200	0.94
(Waterpik Technologies Fort	2SRB-2W							
Collins, Colorado, USA)	j Small Brush SRSB-2	0.18	9–11.5	48–52	1004	120	117	0.98
E Waterpik SenSonic	k Standard Brush	0.18	7–10.4	50	1300	213	200	0.94
SR 800E (Waterpik	SRBL-2I							
Technologies)								
	l Small Brush SR1B-2I	0.18	7.7–10.5	50	900	120	117	0.98

Figure 1 Illustration of the 12 toothbrush heads tested.

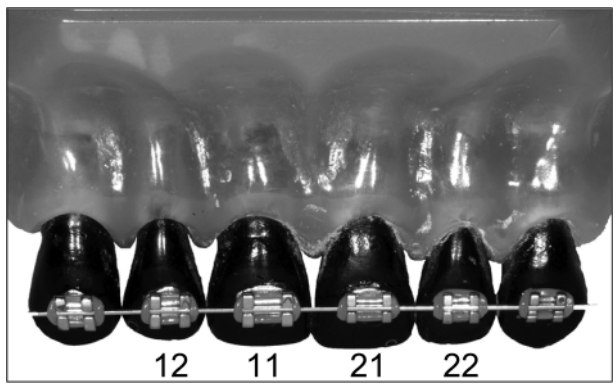


Figure 2 Custom-made tooth model of an anterior segment with brackets bonded to the labial surfaces (on teeth 11, 12, and 13: standard Twin Diamond™ brackets; on teeth 21, 22, and 23: Mini Diamond™ brackets).

In a preliminary trial, it was observed that when the brush heads were placed in the centre of the brackets and in a perpendicular direction, there was only minimal filament–tooth surface contact and poor cleaning efficacy (data not shown). By shifting the brush head by half its diameter, either incisally or cervically, in such a way that the wire would just be touched by the most external filaments, the efficacy was significantly improved. To improve the cleaning efficacy further, the sonic toothbrushes were mounted in a slightly angulated position (5–10 degrees) and the oscillating–rotating brushes were angulated 45 degrees towards the brackets. The slightly angulated brush head position with the best cleaning efficacy as preliminarily observed was chosen for this *in vitro* study.

Only horizontal movements, simulating the widespread 'scrub technique', were applied for one minute (30 mm excursion/60 strokes) on the incisal and cervical side of the brackets to mimic the most frequently used ineffective brushing method and the worst case scenario. One brush head of each type was used six times on the same model to reduce bias. For toothbrushes with multiple speed levels, cleaning was performed at maximum speed.

After every treatment, the teeth were scanned (Hewlett Packard C1750A, Houston, Texas, USA), the images were digitized, and the percentage of cleaned surface (reappearing black) was measured planimetrically on the cervical and incisal sides of the archwire using custom-made software with a grey scale threshold. Four different cleaning patterns were found. Based on these observations, a modified plaque index for orthodontic patients (PIOP) was created and evaluated for its possible future clinical use (Figure 3).

Statistical analysis was performed using StatView Version 4.51 (Abacus Concepts Inc., Berkeley, California, USA). The results of the cleaning efficacy, expressed as a percentage of the total area, were reported using median values and interquartile ranges. Analysis of variance was used for individual comparison of the brush types. Bonferroni/Dunn adjustment was applied for multiple testing. The level of significance was set at $\alpha = 0.001$.

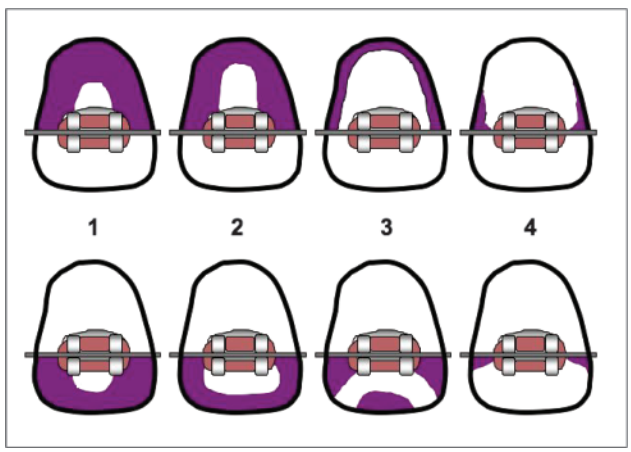


Figure 3 Modified plaque index for orthodontic patients. Score 1: only cleaning of the convex profile of the incisal/cervical crown along the bracket (3/4 remained uncleaned); Score 2: cleaning of the convex profile along the bracket extending (more than 1/2 of the surface remained uncleaned); Score 3: border of the clinical crown including the slight concave part crown part/gingival margin remain uncleand, (1/4 to 1/2 remained uncleaned); Score 4: most of the clinical crown/gingival margin cleaned, only small uncleaned area (less than 1/4 remained uncleaned).

Results

The results of the planimetric assessment of the median and mean cleaning efficacy (cleaned or uncleaned area expressed as a percentage of the total area) of all the tested toothbrushes and brush heads are depicted in Figures 4 and 5.

The mean uncleaned areas ranged from 18.3 to 55.5 per cent of the initial titanium oxide-coated tooth surfaces (Table 2 and Figure 5). This corresponds to a cleaning efficacy of 45.5–81.7 per cent. The lateral incisors (mean uncleaned area, tooth 12: 33 per cent; tooth 22: 31 per cent) tended to be less clean than the central incisor (mean uncleaned area, tooth 11: 27 per cent; tooth 21: 29 per cent). The bracket size, however, had no statistically significant influence on the cleaning efficacy of any tested brush heads and respective electric handles.

The brush heads, Compact ProResults (81.7 per cent) and Standard ProResults (80.8 per cent), of the Sonicare® toothbrush and the standard head of the Waterpik® SR 800E toothbrush (78.2 per cent) performed significantly better than all other brush heads with their corresponding powered handles (Tables 2 and 3, and Figure 5). The Braun Oral-B Micro Pulse EB 25 brush head showed the best cleaning efficacy of all oscillating–rotating brush heads tested. In contrast, the oscillating–rotating Braun Oral-B Ortho brush head showed significantly the poorest cleaning efficacy. Its overall cleaning efficacy was less than 50 per cent. All other toothbrush heads showed a cleaning efficacy of approximately 65–73 per cent. These findings correspond to the PIOP. All toothbrush heads

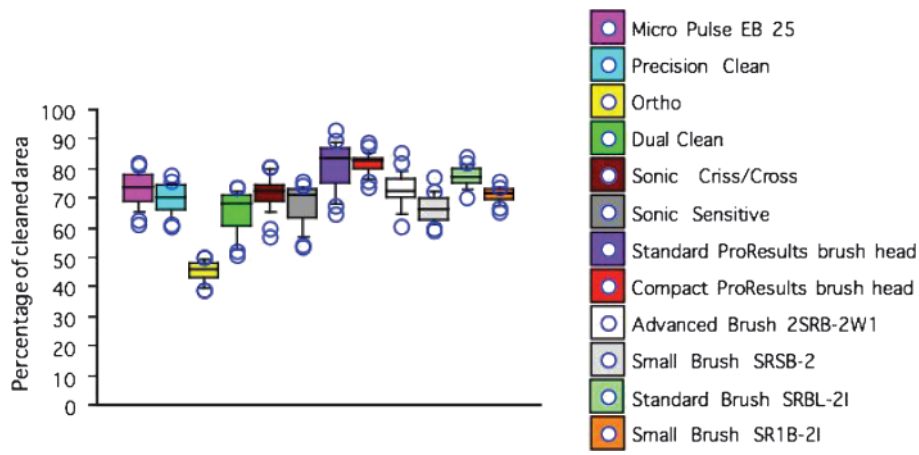
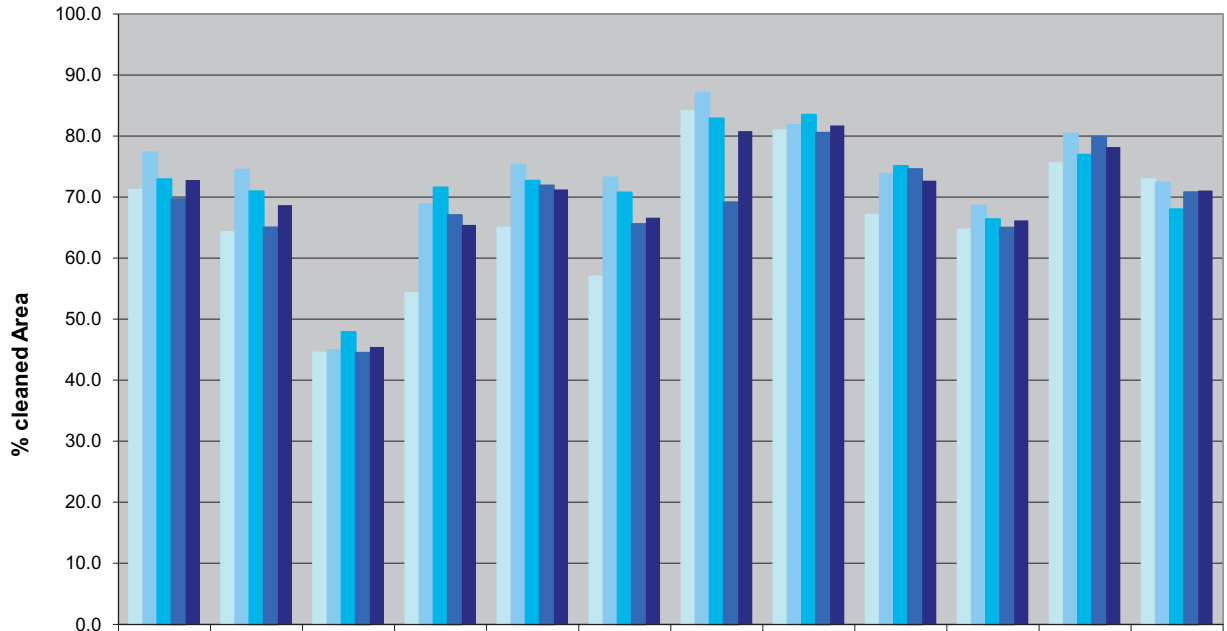


Figure 4 Box plot depicting the percentage of touched (cleaned) tooth surfaces for the respective toothbrushes (Horizontal bars: Medians; Boxes: interquartile areas; Error bars: 10th and 90th percentile; dots: extreme values).



	Micro Pulse EB 25	Precision Clean	Ortho	Dual Clean	Sonic CrissCross	Sonic Sensitive	Standard ProResults brush head:	Compact ProResults brush head	Advanced Brush 2SRB-2W	Small Brush SRSB-2	Standard Brush SRBL-2I	Small Brush SR1B-2I
Tooth 12	71.2	64.3	44.5	54.3	65.0	57.0	84.1	81.0	67.1	64.7	75.6	73.0
Tooth 11	77.3	74.5	44.9	68.9	75.3	73.2	87.1	81.8	73.8	68.6	80.4	72.4
Tooth 21	72.9	71.0	47.9	71.6	72.7	70.8	82.9	83.5	75.1	66.4	76.9	68.0
Tooth 22	69.7	65.0	44.5	67.1	71.9	65.6	69.2	80.6	74.6	65.0	79.9	70.8
over all teeth	72.8	68.7	45.5	65.4	71.2	66.6	80.8	81.7	72.7	66.2	78.2	71.0

Figure 5 Percentage of touched (cleaned) area for each tooth surface and overall cleaning efficacy.

Table 2 Percentage of touched (cleaned) tooth surfaces of teeth 12, 11, 21, and 22 and when considering all teeth (±SD).

Toothbrush	Brush head	Tooth 12	Tooth 11	Tooth 21	Tooth 22	All teeth
Oscillating–rotating toothbrush						
Oral-B Professional Care 9500	Micro Pulse EB 25	71.2 ± 4.8	77.3 ± 2.6	72.9 ± 6.0	69.7 ± 6.9	72.8 ± 5.8
	Precision Clean	64.3 ± 3.8	74.5 ± 2.5	71.0 ± 3.0	65.0 ± 3.4	68.7 ± 5.3
	Ortho	44.5 ± 3.2	44.9 ± 2.6	47.9 ± 2.3	44.5 ± 4.0	45.5 ± 3.2
	Dual Clean	54.3 ± 2.8	68.9 ± 2.7	71.6 ± 1.7	67.1 ± 2.4	65.4 ± 7.2
Sonic toothbrushes						
Braun Oral-B Sonic complete	Sonic CrissCross	65.0 ± 5.7	75.3 ± 3.4	72.7 ± 5.1	71.9 ± 4.1	71.2 ± 5.8
	Sonic sensitive	57.0 ± 2.7	73.2 ± 2.0	70.8 ± 2.3	65.6 ± 4.3	66.6 ± 6.9
Philips Sonicare Elite 9000	Standard ProResults brush head	84.1 ± 5.3	87.1 ± 4.0	82.9 ± 4.3	69.2 ± 3.5	80.8 ± 8.1
	Compact ProResults brush head	81.0 ± 3.1	81.8 ± 2.7	83.5 ± 2.3	80.6 ± 5.4	81.7 ± 3.5
Waterpik Sensonic	Advanced Brush 2SRB-2W	67.1 ± 5.5	73.8 ± 2.3	75.1 ± 6.3	74.6 ± 4.1	72.7 ± 5.5
	Small Brush SRSB-2	64.7 ± 4.6	68.6 ± 5.5	66.4 ± 4.4	65.0 ± 3.4	66.2 ± 4.5
Waterpik SenSonic SR 800E	Standard Brush SRBL-2I	75.6 ± 3.6	80.4 ± 2.3	76.9 ± 2.5	79.9 ± 2.3	78.2 ± 3.3
	Small Brush SR1B-2I	73.0 ± 1.4	72.4 ± 1.3	68.0 ± 1.6	70.8 ± 1.2	71.0 ± 2.3

tended to have a better cleaning efficacy in the incisal/coronal area (PIOP range: 2.1–4; Figure 6), whereas more uncleaned areas remained on the cervical side of the brackets after the brushing cycles (PIOP range: 2.3–3.6; Figure 7).

In the incisal area of the custom-made tooth model, only the oscillating–rotating Braun Oral-B Ortho brush head failed to clean more than 50 per cent of the area, whereas all other brush heads yielded a PIOP of 3 or more.

In the cervical area, the sonic Sonicare® toothbrush with the Compact ProResults brush head and the Standard ProResults brush head showed a superior cleaning efficacy compared with all other brushes and yielded a PIOP of

Table 3 Statistical parameters (mean difference and *P*-values of comparisons).

Brush head	Micro Pulse EB 25		Precision Clean		Ortho care		Dual Clean		Sonic CrissCross	
	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value
Micro Pulse EB 25			4.1	ns	27.3	***	7.4	***	1.6	ns
Precision Clean	−4.1	ns			23.2	***	3.3	ns	−2.6	ns
Ortho Care	−27.3	***	−23.2	***			−20.0	***	−25.8	***
Dual Clean	−7.4	***	−3.3	ns	20.0	***			−5.8	***
Sonic CrissCross	−1.6	ns	2.6	ns	25.8	***	5.8	***		
Sonic sensitive	−6.2	***	−2.0	ns	21.2	***	1.2	ns	−4.6	ns
Standard ProResults brush head	8.0	***	12.1	***	35.4	***	15.4	***	9.6	***
Compact ProResults brush head	8.9	***	13.0	***	36.2	***	16.3	***	−10.5	***
Advanced Brush 2SRB-2W	−0.1	ns	4.0	ns	27.2	***	7.2	***	1.4	ns
Small Brush SRSB-2	−6.6	***	−2.5	ns	20.7	***	0.8	ns	−5.1	ns
Standard Brush SRBL-2I	5.4	***	9.5	***	32.7	***	12.8	***	6.9	***
Small Brush SR1B-2I	−1.7	ns	2.4	ns	25.6	***	5.6	***	−0.2	ns

Analysis of variance was used for individual comparison of the brush types. Bonferroni/Dunn adjustment was applied for multiple testing.
ns, not significant; ***$P < 0.001$.

3.6. All other brush heads tested tended to reach a PIOP of 2.3 to 3, irrespective of their action.

Discussion

In patients undergoing orthodontic treatment with fixed appliances, effective plaque removal is significantly compromised and accumulation of plaque and the development of gingival inflammation and overgrowth are well-acknowledged problems (Heasman *et al.*, 1998a).

The purpose of this study was to assess the cleaning efficacy of 12 different brush heads of two powered toothbrush modalities (wiping and oscillating–rotating) under standardized laboratory conditions using a well-established test method (Imfeld *et al.*, 2000; Schätzle *et al.*, 2009) and to quantify tooth surface areas with inadequate filament contact in a custom-made model of an upper anterior segment with bonded brackets.

The present findings showed that the Sonicare® toothbrush handle in combination with the Compact and Standard ProResults brush heads as well as the Waterpik® SR 800E with the standard brush head performed statistically significantly better than all others in combination with their corresponding powered handle. The cervical area and the gingival margins proved to be especially difficult to clean. In this critical area, the Sonicare® toothbrush heads outperformed all other brush heads tested. This is in contrast to clinical findings comparing manual versus powered toothbrushes (for review see Robinson *et al.*, 2005). This systematic review found that powered toothbrushes with a rotating–oscillating motion removed more plaque than manual brushes. Other powered brushes produced a less consistent reduction of plaque.

It has been shown, *in vitro,* that some toothbrushes have different cleaning effects when used with varying force applications. At a high load, soft or fine bristles may become twisted resulting in a lower cleaning efficacy. With low force, interaction with the toothsurfaces increases since soft bristles allow penetration into the interproximal and interbracket area (Sander *et al.*, 2005). To overcome this phenomenon and to assess the effect of various high contact forces, the pressure (load/brush field surface) in the present study was kept constant.

In an attempt to facilitate plaque control in orthodontic patients, specially designed manual and electric toothbrush heads have been marketed. For manual toothbrushes, experimental studies have shown that staged and V-shaped brush head designs outperformed planar brushes in the cleaning efficacy of teeth with fixed orthodontic attachments (Sander *et al.*, 2005; Schätzle *et al.*, 2009). Their effectiveness in clinically reducing gingivitis is, however, questionable (Williams *et al.*, 1987). The Braun Oral-B Ortho brush head, designed for orthodontic patients, yielded the poorest cleaning efficacy with the simulated scrub technique. Despite this ineffective experimental performance, the Braun Oral-B Ortho brush head was as effective as a manual toothbrush at cleaning around fixed orthodontic appliances in a clinical trial. Furthermore, for subjects using a powered toothbrush with an orthodontic head, the most marked improvement in oral health was in interdental bleeding (Hickman *et al.*, 2002).

The simulated scrub technique is most widespread and characterized by horizontal movements in a largely uncontrolled manner, parallel to the occlusal plane. It is mainly used by children, whose manual dexterity is poorer than that of adults (Unkel *et al.*, 1995; Peretz and Gluck, 1999).

Table 3 (Extended).

Sonic sensitive		Standard ProResults brush head		Compact ProResults brush head		Advanced Brush 2SRB-2W		Small Brush SRSB-2		Standard Brush SRBL-2I		Small Brush SR1B-2I	
Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value	Mean Difference	*P*-value
6.2	***	−8.0	***	−8.9	***	0.1	ns	6.6	***	−5.4	***	1.7	ns
2.0	ns	−12.1	***	−13.0	***	−4.0	ns	2.5	ns	−9.5	***	−2.4	ns
−21.2	***	−35.4	***	−36.2	***	−27.2	***	−20.7	***	−32.7	***	−25.6	***
−1.2	ns	−15.4	***	−16.3	***	−7.2	***	−0.8	ns	−12.8	***	−5.6	***
4.6	ns	−9.6	***	10.5	***	−1.4	ns	5.1	ns	−6.9	***	0.2	ns
		−14.2	***	−15.1	***	−6.0	***	0.5	ns	−11.6	***	−4.4	ns
14.2	***			0.9	ns	8.2	***	14.6	***	2.6	ns	9.8	***
15.1	***	0.9	ns			9.0	***	15.5	***	3.5	ns	10.7	***
6.0	***	−8.2	***	−9.0	***			6.5	***	−5.5	***	1.6	ns
−0.5	ns	−14.6	***	−15.5	***	−6.5	***			−12.0	***	−4.9	ns
11.6	***	−2.6	ns	−3.5	ns	5.5	***	12.0	***			7.2	***
4.4	ns	−9.8	***	−10.7	***	−1.6	ns	4.9	ns	7.2	***		

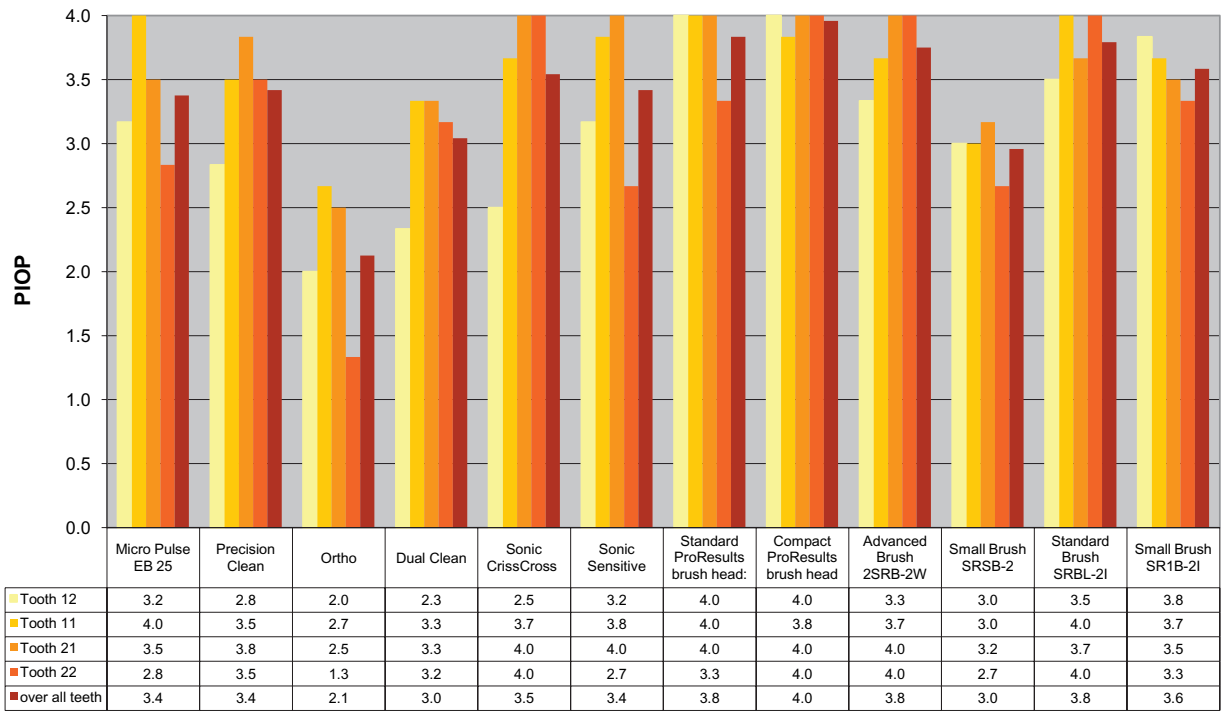
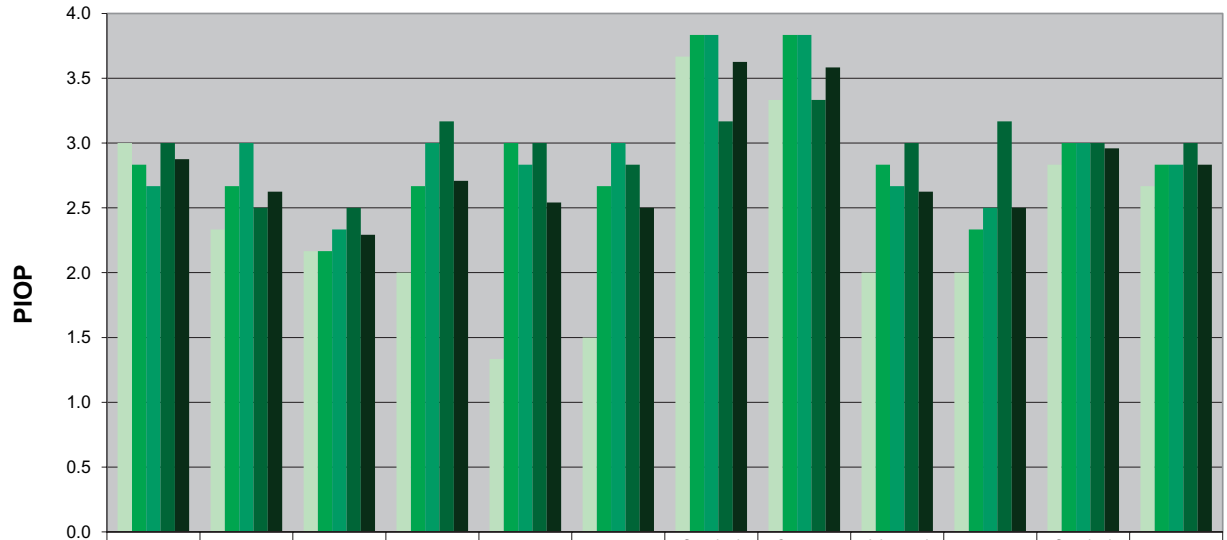


Figure 6 Mean plaque index for orthodontic patient (PIOP) scores for the area incisal of the archwire for the tested brushes.

Various studies comparing the plaque-removing efficacy of different toothbrushing methods have shown limited or no differences (Shifter *et al.*, 1983). Efficient oral hygiene may be less dependent on brushing methods than on the performance of the individual user applying any one of the accepted methods (Frandsen, 1985).

By comparing the present results with a previous experimental study using the same experimental model with manual toothbrushes (Schätzle *et al.*, 2009), no conclusive statement can be made. In clinical trials, there are also no conclusive results. Several studies comparing manual with electric toothbrushes in patients undergoing fixed orthodontic appliance therapy failed to show any difference in gingival, bleeding on probing, and plaque indices (Clerehugh *et al.*, 1998; Heasman *et al.*, 1998b; Thienpont *et al.*, 2001; Hickman *et al.*, 2002). Therefore, it was recommended that



	Micro Pulse EB 25	Precision Clean	Ortho	Dual Clean	Sonic CrissCross	Sonic Sensitive	Standard ProResults brush head:	Compact ProResults brush head	Advanced Brush 2SRB-2W	Small Brush SRSB-2	Standard Brush SRBL-2I	Small Brush SR1B-2I
Tooth 12	3.0	2.3	2.2	2.0	1.3	1.5	3.7	3.3	2.0	2.0	2.8	2.7
Tooth 11	2.8	2.7	2.2	2.7	3.0	2.7	3.8	3.8	2.8	2.3	3.0	2.8
Tooth 21	2.7	3.0	2.3	3.0	2.8	3.0	3.8	3.8	2.7	2.5	3.0	2.8
Tooth 22	3.0	2.5	2.5	3.2	3.0	2.8	3.2	3.3	3.0	3.2	3.0	3.0
over all teeth	2.9	2.6	2.3	2.7	2.5	2.5	3.6	3.6	2.6	2.5	3.0	2.8

Figure 7 Mean plaque index for orthodontic patient (PIOP) scores for the area cervical of the archwire for the tested brushes.

orthodontists should focus on enhancing their patients' dental awareness and oral hygiene along with professional prophylaxis and fluoride applications.

In another study, the tested sonic toothbrush was not superior to a manual toothbrush in reducing gingival inflammation in adolescent orthodontic patients, but plaque scores were decreased on the buccal surfaces of teeth with orthodontic brackets. In addition, the *Streptococcus mutans* counts were markedly decreased in the electric and ultrasonic groups (Costa *et al.*, 2007).

Since manually applied contact force may vary during the brushing cycle (Phaneuf *et al.*, 1962; Fraleigh *et al.*, 1967; Perinetti *et al.*, 2004), the present results must be clinically verified. Extrapolation to the clinical situation is not directly possible and no conclusive statements as to the cleaning efficacy of any specific brush head design and its electric handle modality (wiping and oscillating–rotating) should be drawn from the present experiment. However, the outcome of the experiment provides a first and essential indication regarding the cleaning efficacy of electric toothbrushes in orthodontic patients.

Conclusions

In this *in vitro* experiment, the Sonicare® toothbrush handle in combination with the Compact ProResults brush head and the Standard ProResults brush head as well as the sonic Waterpik® SR 800E with the standard head yielded a statistically significantly superior cleaning efficacy of teeth with fixed orthodontic attachments. The PIOP proved to be practicable and effective, although the results have to be verified in a clinical study.

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