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In vitro tooth cleaning efficacy of manual toothbrushes around brackets

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SUMMARY The purpose of this laboratory study was to assess the potential cleaning efficacy of nine different toothbrushes around brackets *in vitro*.

Standard and Mini Diamond™ brackets were fixed on coloured teeth in a special model, coated with white titanium oxide, brushed in a machine with different manual toothbrushes (three different types: planar, staged, and v-shaped bristle field), and tested with a horizontal motion for 1 minute. After brushing, the teeth were scanned and the black surfaces were planimetrically assessed using a grey scale. Tooth areas which were black again after brushing indicated tooth surface contact of the filaments. The remaining white tooth areas around the brackets indicated 'plaque-retentive' niches. Statistical analysis was carried out using the Kruskal–Wallis one-way test of variance for individual comparison. Bonferroni adjustment was used for multiple testing, and comparison of bracket size with Wilcoxon signed rank test.

In the most critical area of 2 mm around the brackets, there was no statistically significant difference between the different toothbrushes evaluated. The untouched area ranged from 11 to 26 per cent of the initially whitened tooth surface. By pooling the toothbrushes according to their design, the median cleaning efficacy of the v-shaped (73.1 per cent) and staged (75.6 per cent) toothbrushes resulted in significantly superior cleaning efficacy than planar toothbrushes (60.7 per cent) for standard brackets. For mini bracket type, staged toothbrushes showed a significantly better mean cleaning efficacy (77.8 per cent) than planar (65 per cent) and v-shaped (72.4 per cent) toothbrushes.

Staged and v-shaped brush designs resulted in superior cleaning efficacy of teeth with fixed orthodontic attachments than toothbrushes with a planar bristle field. None of the tested toothbrushes showed a consistent, significantly higher cleaning efficacy than the others in this *in vitro* experiment.

Introduction

Patients undergoing orthodontic treatment with fixed appliances face a challenging oral hygiene situation. Orthodontic bands, brackets, and wires are impediments to brushing and flossing, thus facilitating the accumulation of plaque and compromising gingival health. It is well documented that orthodontic treatment with fixed appliances is accompanied by an increased risk of caries (Zachrisson, 1976; O'Reilly and Featherstone, 1987) and gingivitis (Legott *et al.*, 1984; Huser *et al.*, 1990). Microbiological changes after the insertion of orthodontic appliances have been demonstrated. Increasing numbers of *Streptococcus mutans* and lactobacilli after bonding of fixed appliances have been described (Liu *et al.*, 2004). Other reports revealed statistically significant increases in suspected periodontal pathogens such as spirochaetes, motile rods, and other gram-negative organisms (Perinetti *et al.*, 2004).

Applications of fluoride and/or antibacterial agents are recommended to reduce these unwanted side-effects (Øgaard *et al.*, 1980, 1988). 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).

Effective brushing of teeth is, however, still the most important preventive measure. Numerous types of toothbrushes have been designed and promoted for orthodontic patients. However, no study has so far reported efficacy results of different orthodontic toothbrushes under standardized *in vitro* conditions.

The purpose of this study was to assess the cleaning efficacy of nine different toothbrushes currently marketed in Switzerland under standardized laboratory conditions using a well-established test method (Imfeld *et al.*, 2000) and to quantify enamel areas with inadequate filament contact in a custom-made model of an upper anterior segment with bonded brackets.

Material and methods

The nine toothbrushes tested are listed in Table 1 and depicted in Figure 1. The brush heads were 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.

Table 1 Technical data of toothbrushes tested in the present study.

	Toothbrush	Brush field	Filament diameter (mm)	Filament height (mm)	Number of filaments per	
					Hole	Brush head
A	Paro M43 (Esro AG, Kilchberg, Switzerland)	Planar	0.20	11	43	1548
B	Curaprox CS 5460 'ultra soft' (Healthco Breitschmid, Kriens, Switzerland)	Planar	0.10	8.4	170	6630
C	Meridol (GABA, Therwil, Switzerland)	Planar	0.18	11.4	38–52	1406–1924
D	Oral-B Ortho (Procter & Gamble, Schwalbach a. T., Germany)	V shaped	0.2	10.5	46	1380
E	Curaprox CD 060 ortho (Healthco Breitschmid)	V shaped	0.17	7–9.9	42	1344
F	Candida Parodin (Bürstenfabrik Ebnat-Kappel, Ebnat-Kappel, Switzerland)	Staged	0.17 (conical), 0.15 (round)	9–11.25	54 (conical), 6 (round)	2252–2416
G	Ortho Pro (Orthodontic store, Gaithersburg, Maryland, USA)	Staged	0.18	8.5–9.5	50	1700
H	Paro Ortho (Esro)	Staged	0.17 and 0.18	8.5–9.5	50	1250
I	Emoform sensitive (Dr. Wild & Co AG, Basel, Switzerland)	Staged	0.20	8.8–10.6	30	1110

The model teeth were black and had brackets glued to the labial surfaces (Figure 2). On teeth 11 and 12, standard Twin Diamond™ (Ormco Europe AG, Al Amersfoort, The 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. Before brushing, all black tooth surfaces were coated with white titanium oxide simulating 100 per cent plaque accumulation on the tooth surfaces. Tooth surfaces that reappeared black after brushing had been touched by the filaments of the tested toothbrushes 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, tooth 12: 49 mm^2) and 127 mm^2 for the teeth with mini brackets (tooth 21: 75 mm^2, tooth 22: 52 mm^2).

The load applied under the chosen experimental conditions was 250 g. Only horizontal movements were used for 1 minute (30 mm excursion/60 strokes) to simulate the most frequently used ineffective brushing method and to simulate a worst case scenario. One brush of each type was used six times on the same model with the bristles perpendicular to the tooth surfaces.

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 using custom-made software with a grey scale threshold. The measurements were made at three zones of interest, namely the cervical, the incisal, and the bracket area. The latter was defined as extending 2 mm around the brackets (Figure 3).

Statistical analysis was performed with StatView Version 4.51 (Abacus Concepts Inc., Berkeley, California, USA). The results of the cleaning efficacy, expressed as a percentage of the cleaned area, were reported using median values and interquartile ranges. The Kruskal–Wallis one-way test of variance was used for individual comparison of the brush types. Bonferroni adjustment was applied for multiple testing.

To compare the two different bracket sizes, the Wilcoxon signed rank test was applied for each toothbrush type. The level of significance was set at $\alpha = 0.05$.

Results

The results of planimetric assessment of the median cleaning efficacy (cleaned or uncleaned area expressed as a percentage of the total area) of the tested toothbrushes for the three evaluated areas are depicted in Table 2.

Regarding the effect in the area 2 mm around the brackets, there was no statistically significant difference between the nine different toothbrushes. The uncleaned areas ranged from 11 to 26 per cent of the initially coated tooth surfaces. This corresponds to a cleaning efficacy of 74 to 89 per cent.

In the cervical area, no statistically significant differences could be found. Only the Candida Parodin brush showed a superior cleaning performance compared with all other brushes and yielded cleaning percentages of almost 100.

In the incisal regions of the custom-made tooth model, no toothbrush showed statistically superior results. All brushes left only minute remaining white areas thus showing a 96 to 100 per cent cleaning efficacy.

For all toothbrush types, there were no statistically significant differences between for the two types of brackets.

The median cleaning efficacy of the three toothbrush types (planar, v-shaped, and staged) and bracket sizes (standard twin and mini) are depicted in Figure 4. For the standard bracket type, v-shaped (73.1 per cent) and staged (75.6 per cent) toothbrushes resulted in significantly superior

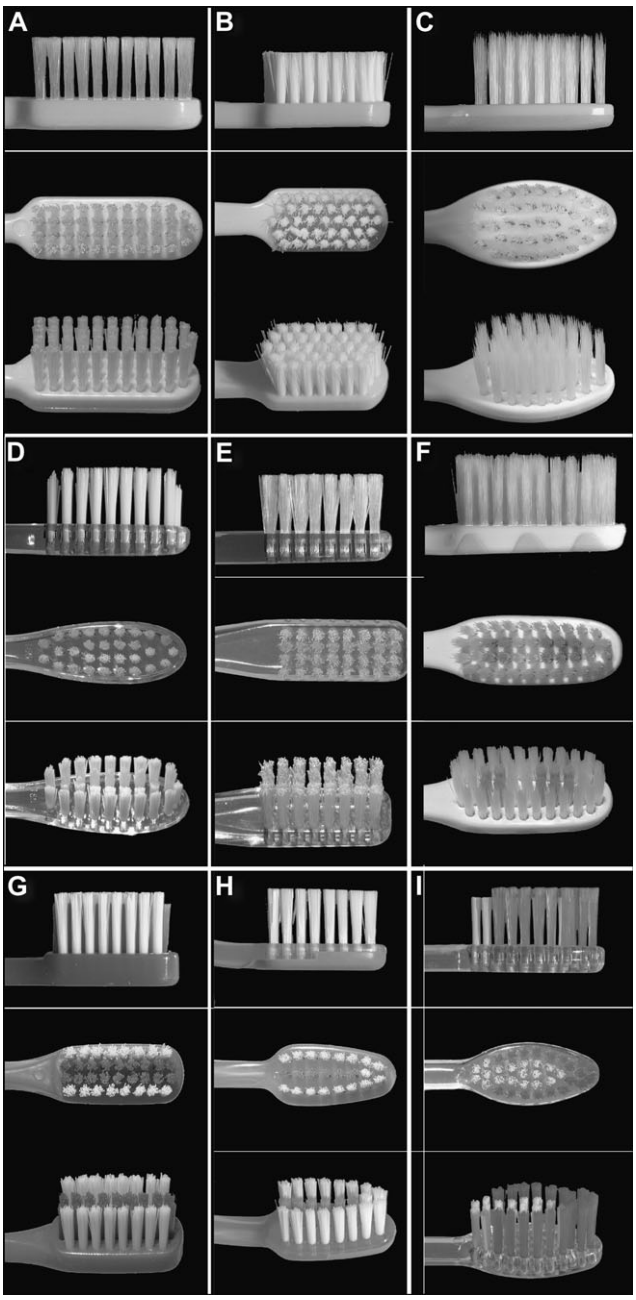

Figure 1 Illustration of the nine toothbrushes tested.

cleaning values than planar toothbrushes (60.7 per cent). Even though there was no significant difference between the v-shaped and staged toothbrushes, the latter tended to achieve a better result in its cleaning ability. For teeth with mini brackets (teeth 21 and 22), however, staged toothbrushes showed a significantly better median cleaning efficacy (77.8 per cent) than planar toothbrushes (65 per cent) and also yielded better results than v-shaped brushes (72.4 per cent). The v-shaped toothbrushes showed a higher median percentage of cleaned tooth surfaces than the planar brushes, but this did not reach significance.

Discussion

This study used an established method with model teeth and a brushing machine to evaluate the efficacy of nine toothbrushes to tooth surfaces around bonded brackets. An additional aim was to reveal the problem zones when brushing horizontally. The tuft designs of the manual brushes were plane, v-shaped, or staged.

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.*, 1998). The present study found no statistical differences in the efficacy of the nine brushes tested. No brush was superior at the smooth, bracket, or incisal surfaces. The percentages of uncleaned tooth areas for each brush at smooth surfaces were consistently lower than at the bracket areas. All brushes failed to reach the area around the brackets as well as the interbracket span. The cervical and incisal tooth areas, as well as the gingival margins, also proved to be difficult to clean.

In this context, however, the Candida Parodin tended to be the most effective brush moving horizontally in a largely uncontrolled manner, back and forth over the rows of vestibular teeth parallel to the occlusal plane (simulating a 'scrub technique'). This is the most widespread technique mainly used by children, whose manual dexterity lags behind that of adults (Unkel *et al.*, 1995; Peretz and Gluck, 1999) despite the efforts of the dental profession to instruct patients to adopt other more convenient brushing techniques. However, different studies comparing the plaque-removing efficacy of different toothbrushing methods have shown small or no differences (Shifter *et al.*, 1983). Improvement in oral hygiene may not be as dependent upon the development of correct brushing methods as upon improved performance by the those using any one of the accepted methods (Frandsen, 1985).

In an attempt to facilitate plaque control in orthodontic patients, however, specially designed manual toothbrushes have been developed. Brushes with v-shaped longitudinal grooves trimmed into the bristle field were manufactured to improve brushing around brackets and archwires, although their effectiveness in reducing gingivitis compared with conventional brushes is questionable (Williams *et al.*, 1987). Such staged brushes showed significantly superior cleaning efficacy in this *in vitro* experiment independent of the bracket area size.

The findings (Figure 4) confirm the results of a previous *in vitro* study (Sander *et al.*, 2005) which showed that different bristle arrangements, such as lowered bristles in the middle of the brushfield, have improved cleaning efficacy than planar bristle fields. Toothbrushes with a flat profile proved to be unsatisfactory for the cleaning of teeth with brackets. It has, however, also been shown that certain toothbrushes

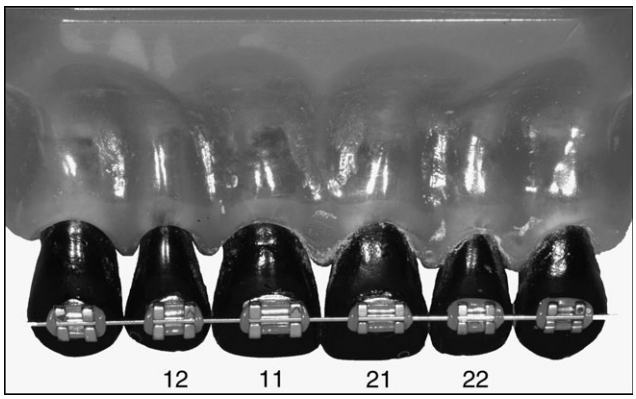

Figure 2 Custom-made tooth model of an anterior segment with standard Twin Diamond™ brackets attached to teeth 11, 12 and 13 and Mini Diamond™ brackets on teeth 21, and 22 and 23.

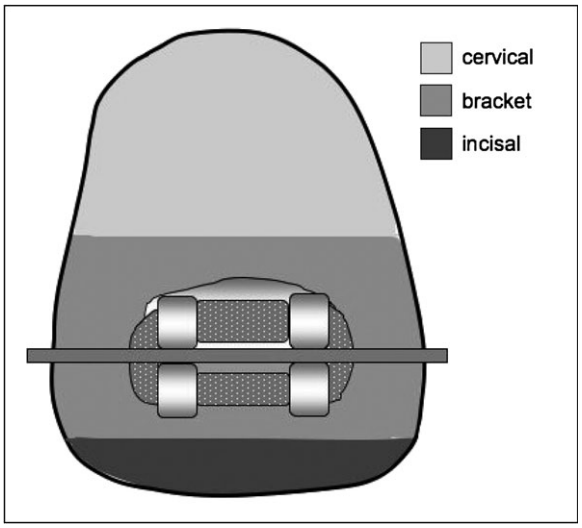

Figure 3 Three zones of interest: the cervical, the incisal, and the bracket area. The latter was defined as extending 2 mm around the brackets.

have different cleaning effects when used with varying degrees of force application. At high load, soft or fine bristles may become twisted resulting in a lower cleaning efficacy. With low force, interaction with the tooth surfaces increases, since soft bristles allow penetration into the interproximal and interbracket area (Sander *et al.*, 2005).

Since manually applied contact force may vary during brushing (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 toothbrush should be drawn from the present experiment.

Conclusions

Staged and v-shaped brush head designs outperformed planar brushes in cleaning efficacy of teeth with fixed orthodontic attachments. None of the tested toothbrushes showed a significantly higher cleaning efficacy in this *in vitro* experiment. The test method proved to be practicable and effective, but the results must be clinically verified.

Table 2 Percentage and inter quartile range (IQR) of untouched (uncleaned) tooth surfaces of teeth 12, 11, 21, and 22.

	12 (IQR)	11 (IQR)	21 (IQR)	22 (IQR)
Bracket area				
Paro M 43	25 (7)	18 (4)	16 (5)	20 (5)
Curaprox CS 5460	26 (9)	23 (10)	18 (6)	20 (14)
Meridol	18 (9)	16 (6)	13 (6)	18 (5)
Candida Parodin	24 (8)	12 (9)	12 (6)	13 (5)
Oral-B Ortho	17 (4)	16 (8)	13 (4)	16 (9)
Curaprox CD 060 ortho	17 (5)	14 (5)	11 (1)	15 (4)
Ortho Pro	20 (3)	18 (6)	15 (5)	19 (1)
Paro Ortho	18 (8)	14 (7)	14 (7)	15 (8)
Emoform Sensitive	19 (4)	15 (2)	12 (2)	17 (2)
Cervical area				
Paro M 43	21 (7)	19 (3)	15 (2)	13 (7)
Curaprox CS 5460	9 (2)	10 (2)	7 (3)	11 (8)
Meridol	12 (17)	22 (17)	10 (14)	16 (19)
Candida Parodin	0 (0)	1 (3)	0 (0)	2 (2)
Oral-B Ortho	11 (4)	9 (4)	8 (3)	18 (3)
Curaprox CD 060 ortho	5 (4)	6 (5)	5 (6)	10 (4)
Ortho Pro	8 (3)	7 (2)	4 (2)	13 (5)
Paro Ortho	9 (2)	5 (4)	6 (3)	13 (7)
Emoform Sensitive	7 (6)	3 (2)	3 (2)	7 (3)
Incisal area				
Paro M 43	3 (2)	3 (2)	2 (2)	3 (2)
Curaprox CS 5460	4 (4)	2 (1)	2 (1)	4 (3)
Meridol	0 (0)	0 (0)	0 (1)	1 (2)
Candida Parodin	0 (0)	0 (0)	0 (0)	0 (0)
Oral-B Ortho	1 (1)	1 (1)	2 (1)	2 (1)
Curaprox CD 060 ortho	2 (1)	1 (1)	1 (1)	2 (1)
Ortho Pro	1 (2)	1 (1)	1 (1)	3 (2)
Paro Ortho	1 (2)	1 (1)	1 (1)	3 (2)
Emoform Sensitive	2 (5)	0 (1)	1(1)	1 (1)

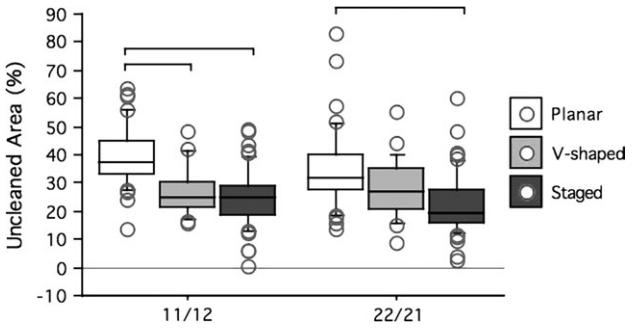

Figure 4 Corresponding box plots depicting the percentage of untouched (uncleaned) tooth surfaces of teeth 11/12 (standard Twin Diamond brackets) and 22/21 (Mini Diamond brackets) for planar, v-shaped, and staged toothbrushes (horizontal bars: medians; boxes: interquartile areas; error bars: 10th and 90th percentile; dots: extreme values). Significant differences are indicated with bars ($P < 0.05$).

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