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ORIGINAL ARTICLE

Plaque removal efficacy of power and manual toothbrushes: a comparative study

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Abstract The aim of this study was to compare the plaque removal efficacy of a new oscillating/rotating/pulsating toothbrush [Oral-B® Professional Care® 8500 (PC 8500)] with two manual toothbrushes [Oral-B® CrossAction™ Vitalizer (CAV) and Oral-B® Indicator™ (IND), respectively]. The safety of the PC 8500 was also assessed. The study was a single-use, observer-masked, randomised 3×3 Latin square crossover design balanced for carryover effects. The enrolled subjects (n=66) refrained from brushing for 23–25 h before each clinical examination. Plaque scores were recorded before and after brushing with the allocated toothbrush using the Turesky et al. modification of the Quigley and Hein plaque index. The safety was assessed evaluating the soft tissue conditions present after 30 days of the use of the PC 8500. The PC 8500 toothbrush was better in plaque removal efficacy compared with the CAV and IND brushes for full mouth and approximal surfaces (P<0.01). When marginal surfaces were considered, the PC 8500 was significantly more effective than the IND (P<0.01). No significant differences were found between PC 8500 and CAV (P>0.05). The latter was shown to be significantly more effective than the IND at all tooth surfaces (P<0.01). Safety examinations revealed the onset of only two small gingival abrasions after the 30-day use of the PC 8500. The PC 8500 toothbrush demonstrated to be more effective in plaque control than the CAV and IND in the full mouth and approximal surfaces and similar to the CAV in the marginal surfaces. The PC 8500 was safe to oral tissues in long-term use.

Keywords Randomised, crossover single-use study · Power toothbrush · Manual toothbrush · Plaque removal · Plaque index · Safety

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Introduction

The importance of dental plaque removal in the prevention and control of periodontal diseases is well established [1]. Regular plaque removal with a manual toothbrush represents the most frequently used method of oral hygiene in Western society. When used correctly and for a sufficient period of time, the manual toothbrush efficiently removes supragingival plaque [2, 3]. Unfortunately, despite encouragement and instruction by dental professionals, many users fail to brush their teeth effectively or regularly and risk a decline in periodontal health [3]. The challenge is therefore to design a toothbrush that will access missed areas and compensate for human failing.

One development aimed at addressing poor brushing technique and improving plaque removal has been the introduction of power toothbrush. Their efficacy in comparison with that of manual toothbrushes has been evaluated in a large number of short- and long-term clinical studies [4-7]. Only power toothbrushes with a rotation/oscillation action were shown to be superior, with results demonstrating greater plaque removal and, as a consequence, greater improvement in periodontal condition compared with that achieved by a manual toothbrush [8, 9]. Despite such evidence of efficacy, a number of studies

failed to confirm greater cleaning efficacy when power toothbrushes with an oscillating/rotating action were compared with manual brushes [5, 7]. In addition, power toothbrushes have been shown to be well received by patients and so to have the potential to improve compliance [10, 11].

Recently, a new power toothbrush has been introduced, the Oral-B® Professional Care® 8500 (PC 8500; Procter & Gamble, Cincinnati, OH, USA), which incorporates the novel three-dimensional action combining the oscillating/rotating action with a high-frequency pulsating movement in the direction of the long axis of the filament. Toothbrushes utilising this technology were shown to offer advantages over a number of standard manual toothbrushes in plaque control [12]. To the best of our knowledge, however, no studies are available which compare the PC 8500 with advanced manual toothbrushes, such as Oral-B® CrossAction® Vitalizer (CAV; Procter & Gamble). The Oral-B® CrossAction® brush head was developed with bristle tufts positioned at 16° to the vertical along the horizontal brush head axis. This design was proven to improve elimination of plaque from gingival margins and approximal spaces [13].

Another concern regarding the use of toothbrushes is their safety. In fact, some people may traumatise the gingival tissues as a result of brushing, which leads in time to gingival recession [14]. Electric toothbrushes have been shown to be as safe as manual brushes, with maintenance of gingival health [15, 16]. However, little information regarding gingival abrasion due the oscillating/rotating/pulsating electric toothbrushes appears to be available [17].

The aim of this study was to compare the plaque removal efficacy of the PC 8500 power toothbrush with two leading manual toothbrushes [Oral-B® CrossAction® Vitalizer (CAV) and Oral-B® Indicator® (IND)] and to assess the safety of PC 8500.

Materials and methods

Study population

A total of 66 healthy subjects (38 men and 28 women; mean age, 36.5±10.1; range, 18–59 years), derived from the general population, volunteered to participate in this study. Screening and selection of volunteers were carried out by a single investigator who explained the study and obtained a witnessed and signed consent to participate. The subjects were selected from 82 individuals on the basis of being dentate with at least 20 natural teeth with two scorable surfaces (i.e. facial and lingual). Exclusion criteria included any physical limitation or restriction that might preclude normal oral hygiene procedures, the wearing of removable prosthesis or orthodontic appliances, recession ≥2 mm and other signs of periodontitis, malocclusions and habits. All the volunteers were in good general health and had no medical or pharmacotherapy histories that could affect the conduct of the study. In particular, no subject had received mouthrinses, gels or chewing gum containing antimicrobial agents in the preceding 3 months, and the females were not pregnant or nursing. Subjects who had received instructions on self-performed toothbrushing techniques or were using a power toothbrush at home were also excluded from the study.

Subjects refrained from all oral hygiene procedures and chewing gum for 23–25 h and from eating, drinking or smoking for 4 h prior to the study. Eligible participants had a whole mouth pre-brushing plaque score ≥2 based on the Turesky et al. modification of the Quigley and Hein plaque index (TQHPI) [18, 19].

The study design was approved by the local ethics committee and was found to conform to the requirements of the "Declaration of Helsinki" as adopted by the 18th World Medical Assembly in 1964 and subsequently revised [20].

Study design

The study was a single-use, observer-masked cross-over design with subjects randomly allocated to one of six treatment sequences according to two replicates of a 3×3 Latin square, incorporating balance for any carryover [21, 22]. The safety of the PC 8500 was evaluated further in all subjects over a 30-day period of twice daily usage.

During a 2-week preparatory period, participants with obvious gingivitis were given a professional dental prophylaxis. At the end of the preparatory period, all subjects had clinically healthy gingiva.

Before each visit, volunteers were asked to refrain from all oral hygiene measures in the preceding 23–25 h and to refrain from eating, drinking or smoking in the preceding 4 h. At each visit, participants received an oral examination of hard and soft tissue and were scored for plaque after disclosing with erythrosine (GUM® Red-Cote, Sunstar Suisse S.A., Ecublens, Switzerland). Plaque scoring was performed using the TQHPI on the mesial, distal and mid surfaces on buccal and lingual areas [18]. Each subject swished with 20 drops of solution for 15 s, rinsed with 10 ml of tap water for a further 10 s and then was scored for plaque under the same conditions by a single examiner throughout the study. Following the measurement of pre-brushing plaque scores, all the subjects used the allocated toothbrushes. Participants brushed under supervision with their assigned toothbrush for a timed period of 60 s, without the use of a mirror. Oral tissues were then reexamined, and after disclosure, post-brushing plaque scores were recorded. In order to assess the intra-examiner reproducibility,

duplicate measurements were carried out in all subjects. The interval between the two measurements was 10 min. After the scoring, subjects received a polishing to remove all plaque and tooth stain, if present. These procedures were repeated until each subject had used each of the three toothbrushes for a total of three study periods.

All toothbrushes were supplied in white boxes and numbered according to the randomisation schedule. The brushing was supervised by a single investigator who did not make the plaque assessment. To maintain the impartiality of the examiner, subjects brushed out of his/her view, the toothbrushes were collected immediately after brushing, and the records of the earlier examinations were not available at the time of reexamination.

No instruction in manual toothbrushing technique was provided and subjects were asked to use their usual manner of brushing. However, immediately before the timed brushing session, subjects were instructed to use the power toothbrush, in accordance with instructions provided by the manufacturer.

Safety assessment

At the end of the third visit, volunteers were provided with their previously used PC 8500 toothbrush and were instructed to use it at home twice daily for a 30-day period. Each subject recorded their brushing times and any comments on a brushing diary sheet. All subjects abstained from the use of interdental cleaning products, chewing gum and mouth rinses over a 30-day period and then received an examination of oral soft and hard tissue. Both soft and hard oral tissues, including the lips, tongue, gingiva, sublingual area, inner surface of the cheeks, mucobuccal folds, hard and soft palate and pharyngeal area, as well as cervical area of all the teeth were examined. The parameters observed were colour, texture, soft tissue abrasion and any irregularities and effects on hard tissues and/or dental restoration. Soft tissue examination was performed after disclosing with Mira-2-Ton fresh solution (Hager & Werken GmbH & Co. KG, Duisburg, Germany) [14]. The Mira-2-Ton solution was used to better see and identify the number and site location of any mucosal abrasion. Abnormal findings were recorded together with any adverse events reported. Gingival abrasions were assessed and recorded using the method adapted from Danser et al. [14]. The gingival tissues were divided into three areas: marginal (cervical free gingiva), approximal (papillary free gingiva) and mid-gingival (attached gingiva). The Williams periodontal probe, placed across the long axis of the lesions, was used to measure the size of the abrasion, and the greatest diameter of the lesion was recorded. The lesions were assessed as small (≤2 mm), medium (≥3 but <5 mm) or large (≥5 mm), with those between 2 and 3 mm assigned as small or medium according to nearest millimetre mark on the probe [14].

The safety assessment was performed by the same examiner under the same conditions.

Statistical analysis

Assuming α=0.05, the present design ensured a 91.4% chance of detecting a difference of 0.25 at a standard deviation 0.4.

The data were analysed for normality of distribution through the use of the Kolmogorov–Smirnov test. An analysis of variance was performed to determine differences amongst products tested. In the presence of significant differences, pairwise comparisons were made through the use of the Student–Newman–Keuls (SNK) test. The pre-brushing plaque scores were tested in an analysis of covariance as possible explanatory variables for the differences observed in the post-brushing plaque scores. Data of side effects were analysed using the Pearson's chi-square test; the Fisher exact test was used when the number observed was quite small. Intra-examiner agreement was measured according to percentage of agreement and kappa score statistic.

The significant level was set at $p<0.05$. Data management and analysis were performed using StatView 5.0.1 (SAS Institute, Inc. Cary, NC, USA).

Results

Plaque removal efficacy

The means and standard deviations for full mouth, marginal and approximal plaque scores for each toothbrush are shown in Tables 1, 2 and 3, respectively, together with the means and standard deviations of plaque reduction. Percentage reductions in plaque scores are shown in Fig. 1.

Each toothbrush was effective in removing plaque from all tooth surfaces after a single use. The PC 8500, CAV and

Table 1 Full mouth pre- and post-brushing plaque scores and plaque reduction (mean ± SD)

Toothbrushes	Plaque scores		Plaque reduction
	Pre-brushing	Post-brushing	
PC 8500	3.4±0.67	2.43±0.78	0.97±0.43*§
CAV	3.42±0.69	2.65±0.86	0.78±0.38*†
IND	3.36±0.8	2.86±0.9	0.49±0.33§†

*, §, † Significant (P<0.01; SNK test). There was statistically significant difference between toothbrushes having the same symbol (P<0.01)

Table 2 Marginal pre- and post-brushing plaque scores and plaque reduction (mean ± SD)

Toothbrushes	Plaque scores		Plaque reduction
	Pre-brushing	Post-brushing	
PC 8500	2.27±0.54	1.41±0.53	0.86±0.39*
CAV	2.28±0.48	1.55±0.57	0.73±0.38§
IND	2.22±0.58	1.69±0.62	0.52±0.41*§

*, § Significant (P<0.01; SNK). There was statistically significant difference between toothbrushes having the same symbol (P<0.01)

IND demonstrated significant reductions in mean plaque scores from pre-brushing to post-brushing levels for full mouth, marginal and approximal surfaces (P<0.0001).

Analysis of variance revealed that PC 8500 was better in plaque removal efficacy compared to CAV and IND for full mouth (P<0.01). Moreover, CAV was shown to be significantly more effective in plaque removal than IND (P<0.01). A similar trend was detected for approximal surfaces (P<0.01). When the marginal surfaces were considered, PC 8500 and CAV were significantly more effective than IND (P<0.01), whereas no significant differences were found between PC 8500 and CAV (P> 0.05). Analysis of covariance showed that the pre-brushing plaque scores (covariate) were not significantly different between toothbrushes (P>0.1 for full mouth, approximal and marginal surfaces).

The percentage reductions in plaque for the full mouth, marginal and approximal surfaces were 28.52%, 37.88%, 26.83% with the PC 8500 toothbrush; 22.51%, 32.01%, 19,84% with the CAV brush; and 14.88%, 23.87, 13.99% with the IND brush.

Safety

No adverse events were reported during the study. No post-brushing changes in oral tissues or restorations were reported or observed with any toothbrush after single use.

Table 3 Approximal pre- and post-brushing plaque scores and plaque reduction (mean ± SD)

Toothbrushes	Plaque scores		Plaque reduction
	Pre-brushing	Post-brushing	
PC 8500	3.95±0.86	2.92±0.97	1.02±0.49*§
CAV	3.98±0.87	3.19±1.06	0.79±0.43*†
IND	3.93±0.99	3.38±1.17	0.54±0.63§†

*, §, † Significant (P<0.01; SNK test). There was statistically significant difference between toothbrushes having the same symbol (P<0.01)

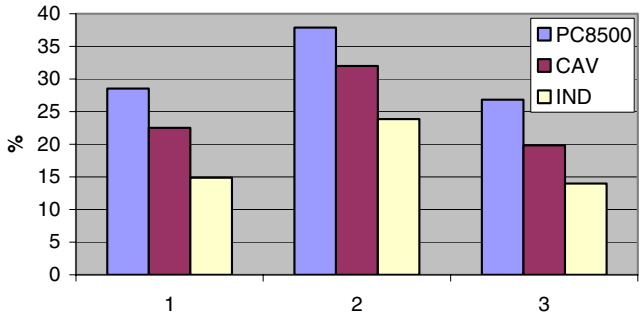

Fig. 1 Full mouth, marginal and approximal percentage reductions in plaque

A comparison of oral hard and soft tissue conditions present before and after 30 days of use with the PC 8500 revealed the onset of few side effects. The presence of small gingival abrasions after the 30-day use of PC 8500 was recorded in two subjects (3.03%). The lesions were located at the mid-gingival and approximal areas.

Discussion

The process of maintaining good oral hygiene is helped greatly by the use of an efficient modern toothbrush, be it manual or power. Advances in both manual and power toothbrushes have increased their ability to remove plaque, although the effectiveness of manual toothbrushes is still limited by the manual dexterity and skill of the user [3]. To some extent, power toothbrushes have overcome this limitation with the added advantage that they have a tendency to help the patient to use a better brushing technique and increase the motivation to brush regularly [10].

Power toothbrushes currently available vary greatly in brush head design, filament pattern and speed and type of motion. With such significant variation in design and action, toothbrushes may differ in their plaque removal efficacy. Clinical studies have shown that the power brushes provided with the oscillating/rotating action are significantly more effective than a manual toothbrush [9].

The PC 8500 is a recently introduced electric toothbrush incorporating a novel three-dimensional action combining the oscillating/rotating action with a high-frequency pulsating movement in the direction of the long axis of the filament. Moreover, this device features a small, circular brush head for tooth-by-tooth cleaning and easier access to approximal and marginal tooth surfaces and back teeth. This technology was shown to offer advantages over a number of standard manual toothbrushes in plaque control, but to the best of our knowledge, there is scant research on the efficacy of PC 8500 compared with a standard manual toothbrush [12]. Moreover, no studies are available which

compare the oscillating/rotating/pulsating toothbrushes with the advanced manual ones.

This study was designed to compare the plaque removal efficacy of PC 8500 with a standard ADA reference manual toothbrush (IND) and an advanced manual one (CAV) after single use. The standard manual toothbrushes have a head design with vertical bristle tufts and so can efficiently remove plaque from flat, accessible surfaces, but are less effective on gingival margins and in approximal spaces [13]. The CAV was developed in an effort to provide patients with the best possible cleaning action in these inaccessible areas. It incorporates the crisscross design (brush heads with tufts angled in opposing directions) and two lateral rows of non-latex rubber nubs, which may assist in cleaning hard-to-access surfaces.

In the present study, the single-use plaque assessment model was chosen as it provides a useful indication of the plaque removal ability of a toothbrush and facilitates the control of confounding variables such as compliance [23]. During each visit, participants used their assigned brushes for 1 min in order to reflect the normal home situation. One-minute brushing time was selected to broadly represent the time taken for oral hygiene [9, 24-26]. In our study, the post-brushing residual plaque in marginal and approximal surfaces was evaluated using the TQHPI [18, 19]. The use of this index permitted the evaluation of plaque in these areas which are commonly missed by toothbrushing, including the approximal ones. The evaluation of residual plaque in these areas is particularly useful when comparing CAV and PC 8500, as both claim to provide enhanced plaque removal from approximal surfaces. Moreover, the TQHPI has been shown to correlate well with the level of gingivitis. Therefore, if changes are found with this index, there may be a good chance of finding changes in gingivitis as well [23, 27]. Additional long-term clinical studies, however, are required to evaluate whether advantages in plaque removal have any influence on gingival health.

Results from the present study demonstrated that all the brushes tested were effective in plaque removal, with significant reductions in mean plaque scores from pre-brushing to post-brushing level for all tooth surfaces.

The PC 8500 demonstrated significantly greater plaque reduction than CAV and IND. This advantage in plaque reduction with the PC 8500 brush was evident for all surfaces when compared with IND. The power toothbrush with oscillating/rotating action was found to be overall significantly more effective than a manual one with regard to plaque removal [8, 9]. Our results also agree with those of the study of Sharma et al. [4] where the efficacy of the electric toothbrush after single use was significantly greater than that of the ADA manual brush for all comparisons. On the other hand, a study of Dörfer et al. [5] reported that a standard flat-trimmered manual toothbrush (Elmex 39; GABA GmbH, Lörrach, Germany) removed significantly more plaque than an oscillating/rotating power toothbrush (Dr. Best Powerclean, SmithKline Beecham, Bühl, Germany) for all surfaces with the exception of lingual ones. Moreover, several clinical studies have compared the oscillating/rotating toothbrush to standard manual ones for their ability to remove plaque over a period of up 6 months, and all of them showed significant differences between the brushes in favour of the power ones [8, 9]. Our results agree with these findings and provided additional information about the single-use performance of PC 8500 [12]. Moreover, a recent study demonstrated that an oscillating/rotating/pulsating toothbrush (Oral-B Triumph Professional Care 9000, Procter & Gamble) more effectively maintained lower plaque levels for 9 months compared to a standard ADA reference manual toothbrush [17].

Few studies have compared oscillating/rotating toothbrush and CAV for the cleaning efficacy, whereas no studies are available which compare the latter with PC 8500. In the present study, PC 8500 was revealed to be more effective than CAV in plaque removal ability for the full mouth and approximal surfaces. No significant difference in the performance of PC 8500 and CAV was detected for the marginal surfaces. Similar results were obtained by Nathoo et al. [28] who reported a statistically significant advantage in favour of an oscillating/rotating toothbrush (Actibrush, Colgate-Palmolive, New York, NY, USA). The findings of our study, however, were different from those of Cronin et al. [7] comparing an oscillating/rotating toothbrush (Actibrush) and the CAV, the last appearing to be more effective than the electric brush with regard to plaque removal in all the surfaces considered (whole mouth, approximal, buccal, lingual). Similar results were found when the clinical efficacy of CAV was compared with that of another oscillating/rotating electric brush (Dr. Johns Spin Brush Classic, now known as Crest Spin Brush, Procter & Gamble) [29]. The differences in the operation of the brushes considered could explain the different results regarding the efficacy of plaque removal. In the present study, CAV demonstrated greater amounts of plaque removal than IND in all the surfaces. These results are similar to those reported by studies comparing this advanced manual toothbrush with a large number of manual ones and confirm the greater ability of CAV to remove plaque compared to the standard manual toothbrushes [13, 30-34].

The greater efficacy showed by PC 8500 brush is likely to reflect differences in the design and operation of the three brushes. In fact, PC 8500 features a small, circular brush head for tooth-by-tooth cleaning and easier access to back teeth and with coextruded bifilaments to reduce axial stiffness, so that the filaments are softer and allow the interdental tips to have greater approximal penetration [12].

Moreover, PC 8500 incorporates a pulsating action at a frequency of 340 Hz along the direction of the long axis of filaments, giving three-dimensional head movement which improves the plaque removal from all dental surfaces, especially the approximal ones where the development of gingivitis is most prevalent [12, 35].

In our study, all the toothbrushes exhibited no post-brushing changes in oral tissues or restorations after the single use. A similar trend was found in previous short-term studies [13, 16, 34]. On the contrary, a study of Van der Weijden et al. [36] showed an increase in the incidence of small gingival abrasions after the single use of an oscillating/rotating toothbrush. The long-term (30 days) use of PC 8500 was associated with the onset of only two small abrasions in mid-gingival and approximal areas. These results were consistent with previously conducted long-term studies where the use of oscillating/rotating brushes was associated with the occurrence of little or no side effects [37-40]. Moreover, a 9-month study reported that an oscillating/rotating/pulsating brush is safe for oral tissues [17].

Conclusions

This single-use comparative study found that the PC 8500 is significantly more effective at controlling plaque than CAV and IND. The advantage in favour of the PC 8500 was evident for the full mouth and more difficult-to-reach approximal surfaces, whilst in the marginal surfaces, its ability was similar to that of CAV. Moreover, the PC 8500 was safe to hard and soft oral tissue over the 30-day study period.

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Conflict of interest The authors declare that they have no conflict of interest.

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