Comparative assessment of plaque removal and motivation between a manual toothbrush and an interactive power toothbrush in adolescents with fixed orthodontic appliances: A single-center, examiner-blind randomized controlled trial

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Introduction: The objective of this 2-arm parallel trial was to determine the plaque removal efficacy (main outcome) and the motivation assessment (secondary outcome) comparing a manual versus an interactive power toothbrush in orthodontic patients. **Methods:** Sixty adolescents with fixed orthodontic appliances in both arches were randomized in a 1:1 ratio in this parallel, randomized, examiner-blind controlled clinical trial. Eligibility criteria included at least 16 natural teeth, 1-6 "focus care areas," plaque score of ≥1.75, no severe caries, gingivitis and periodontitis, no dental prophylaxis, no smoking, no antibiotics, and no chlorhexidine mouth rinse. Subjects were to brush unsupervised with either an interactive power toothbrush (Oral-B Professional Care 6000, D36/EB20) with Bluetooth technology or a regular manual toothbrush (Oral-B Indicator 35 soft). Focus care areas were each brushed for 10 additional seconds. Plaque removal was assessed with the use of the Turesky Modification of the Quigley-Hein Plaque Index (TMQHPI) to determine change from baseline at 2 and 6 weeks. Supervised brushing at screening and post-treatment visits recorded actual brushing times. Subject-reported motivational aspects were recorded at screening and week 6. **Results:** Fifty-nine subjects aged 13-17 years completed the study. The interactive power toothbrush provided significantly ($P < 0.001$) greater plaque reduction versus the manual toothbrush at 2 and 6 weeks according to the whole-mouth TMQHPI. The treatment difference in adjusted mean plaque change from baseline was 0.777 (95% CI 0.614-0.940) at week 2 and 0.834 (0.686-0.981) at week 6. Mean reductions in the number of focus care areas were also significantly greater ($P < 0.001$) in the power brush group at weeks 2 and 6. Brushing times increased significantly at weeks 2 and 6 ($P \leq 0.013$) versus baseline in the interactive power brush group only. Subject-reported motivation was significantly increased in the interactive power brush group at week 6 versus screening ($P \leq 0.005$). **Conclusions:** An interactive power toothbrush generated increased brushing times and significantly greater plaque removal versus a manual brush. (Am J Orthod Dentofacial Orthop 2019;155:462-72)

Adolescents are at increased risk for caries and gingivitis by virtue of converging challenges common to this age group: lessening parental oversight of oral hygiene, frequent consumption of high sugar and acidic drinks and snacks, and increased social and academic demands and distractions that can

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affect motivation to perform regular, conscientious toothbrushing.[1-4] Individually and collectively, these factors can contribute to greater levels of undisturbed dental plaque, which could promote caries formation and gingival disease in susceptible individuals via the production of acid-producing, cariogenic, and pathogenic microbiota in the plaque biofilms.[5-8]

Undesirably high rates of gingivitis and caries in adolescents have been found across diverse geographies and populations.[9-14] If youth also have fixed orthodontic appliances—which are common in the teen years—the risk is even greater. Orthodontic arch wires, brackets, and other appliance components impede easy access to oral hygiene on tooth surfaces and at the gumline, heightening the propensity for disease without consistent, intentional efforts at thorough plaque disruption.[15-18]

With fixed orthodontics, an oral hygiene protocol that incorporates effective and convenient home care products to remove plaque, particularly in difficult-to-access areas, is key to improving patient compliance and avoiding disease. Power (electric) toothbrushes have been evaluated across a broad array of population groups and study designs and have demonstrated similar or significantly greater (for the oscillating-rotating class) plaque removal compared with standard manual toothbrushes.[19-26] Some additionally offer options for targeted needs, such as orthodontic brush heads to improve interbracket cleaning.

Beyond their clinically proven efficacy in removing plaque, power toothbrushes can enhance patient motivation, leading to increased toothbrushing frequency and duration.[27-29] In a randomized trial of 40 subjects, participants using an oscillating-rotating power brush brushed longer than those using a manual toothbrush and were more compliant with twice-daily 2-minute brushing sessions than participants using a manual toothbrush.[30] Improving compliance is particularly salient for the adolescent orthodontic population because research has revealed that substandard oral hygiene in teens is prevalent even without the added burden of obstruction to tooth surfaces generated from wires and brackets.[4,31-33]

Combining oral hygiene aids with technology-based features that resonate with the teen demographic is a novel way to encourage compliance with toothbrushing. The impetus originates in the knowledge that adolescents, in developed and emerging countries alike, are high users of mobile technology and assimilate it into many aspects of daily life, including the use of smartphone wireless device applications ("apps").[34,35] Health and fitness apps are increasingly popular. In 2015 the Pew Research Center revealed that 62% of surveyed smartphone owners reported using their phone to investigate health conditions in the previous year.[36] Consistent with these trends, an oscillating-rotating power brush has been linked to wireless Bluetooth technology to provide real-time feedback to help improve brushing habits. The 2-way communication between the smartphone-connected mobile app and the power toothbrush means the user gets instant information about variables such as session length and excessive brushing force, and personalized reminders to focus on preselected areas of special concern as identified by their dental professional. Other features, such as access to a newsfeed and calendar while brushing, are intended to increase engagement with toothbrushing.

A recent clinical trial explored the plaque-reducing efficacy of this interactive Bluetooth-connected power toothbrush versus a standard manual toothbrush in a population of adolescent volunteers without orthodontics. After 2 weeks, the interactive power brush produced a 34% mean plaque reduction relative to baseline, compared to a 1.7% reduction for the regular manual brush.[37] Based on the results of that study, the question emerged of whether similar improvements in plaque removal versus a control would be afforded from the interactive power brush with Bluetooth technology in adolescents wearing fixed orthodontic appliances and therefore with greater oral hygiene challenges. The results of this investigation are the first to be published evaluating the impact of an interactive power toothbrush on plaque removal and compliance attributes among this patient population.

Specific objectives or hypotheses

The objectives of this study were to evaluate (1) the plaque removal efficacy and (2) the motivation assessment with the use of an interactive power toothbrush versus a regular manual brush in an adolescent population with orthodontic fixed appliances.

METHODS

Trial design and any changes after trial commencement

This was a parallel-group, randomized, active-controlled trial with a 1:1 allocation ratio.

Participants, eligibility criteria, and settings

The study was conducted at the Department of Orthodontics and Dentofacial Orthopedics, University Medical Center of the Johannes Gutenberg University, Mainz, Germany, from September 7, 2015, to November 5, 2015. Sixty adolescent subjects with fixed orthodontic

appliances (0.22″ slot; Roth Prescription) in both well aligned arches were randomized to test groups in this examiner-blind study. All participants enrolled were required to be in good general health, be routine manual toothbrush users, and satisfy all other study entrance criteria at the screening visit: at least 16 natural teeth (excluding third molars) with facial and lingual scorable surfaces; at least 1, but not more than 6, "focus care areas" (defined in Experimental Protocol below); a whole-mouth average screening Turesky Modified Quigley-Hein Plaque Index (TMQHPI) plaque score of ≥ 1.75[24,38]; familiarity with smartphone use; no severe or untreated caries, severe gingivitis, or active or advanced periodontitis requiring treatment; no smoking or any other type of tobacco use; no antibiotics or chlorhexidine mouth rinse use within the 2 weeks before screening; and no dental prophylaxis within the 4 weeks before screening.

In accordance with the ethical standards established in the 1964 Declaration of Helsinki and its later amendments, the Institutional Review Board of Johannes Gutenberg University (code 837.485.14 (9724)) reviewed and approved the study protocol and the subject consent form before study inception. Each subject and guardian provided written and informed consent before participation.

Interventions

Two different toothbrushes were evaluated for their comparative efficacy in plaque removal over a 6-week period: (1) the interactive power brush with Bluetooth technology, consisting of an Oral-B Professional Care 6000 (D36) rechargeable power brush with Oral-B Precision Clean brush head (EB20; Procter & Gamble, Cincinnati, Ohio), charger, and smartphone (Samsung Galaxy S3; Samsung Electronics Co, Suwon, South Korea) equipped with Oral-B Application v2.1, OB2 phone app (Procter & Gamble); and (2) the manual brush control, Oral-B Indicator 35 soft manual toothbrush (Procter & Gamble). Subjects used their assigned test products at home unsupervised for the study duration, brushing twice daily—morning and evening—for 2 minutes with Blend-a-Med Classic (1450 ppm NaF; Procter & Gamble, Gross Gerau, Germany) dentifrice either in their customary manner (manual brush group) or according to the manufacturer's instructions, including use of the Oral-B phone application (interactive power brush group). All subjects were directed to brush each individual focus care area for an additional 10 seconds after the overall brushing.

To quantify plaque formation at screening for eligibility, baseline, and the 2-week and 6-week efficacy assessments, a qualified examiner blinded to individual subject treatment assignments performed the TMQHPI[39,40] on subjects with disclosed plaque. Scorable teeth (up to 28, excluding third molars, crowns, and surfaces with cervical restorations) were graded on buccal and lingual surfaces for up to 56 sites on tooth surfaces exclusive of bracketed areas as follows: 0 = no plaque; 1 = separate flecks of plaque at the cervical margin; 2 = a thin, continuous band of plaque (up to 1 mm) at the cervical margin; 3 = a band of plaque wider than 1 mm, but covering less than one-third of the side of the crown of the tooth; 4 = plaque covering at least one-third but less than two-thirds of the side of the crown of the tooth; 5 = plaque covering two-thirds or more of the side of the crown of the tooth.

To assess plaque levels on vestibular tooth surfaces where orthodontic appliances were present, a Modified Quigley-Hein Index (MQH), as prescribed by Kossack and Jost-Brinkmann,[41] was used. MQH plaque scores for orthodontics patients are as follows: 0 = no plaque; 1 = single plaque areas; 2 = appearance of discreet plaque lines; 3 = plaque extension up to one-third of the tooth surface and thin plaque strip around the wire; 4 = plaque extension up to two-thirds of the tooth surface and broad plaque strip; 5 = plaque extension more than two-thirds of the tooth surface.

For each subject, areas in the dentition showing considerable dental plaque accumulation and thus indicating the need for oral hygiene improvement were identified by the clinical examiner (C.E.) at the screening visit and recorded as focus care areas. Subjects were instructed to dedicate extra brushing time to these zones throughout the trial, as described previously. For the interactive power brush group, the Oral-B application was programmed with the individually designated focus care areas, and operated like an interactive reminder, prompting subjects via pictograms regarding the additional brushing time needed. Designated focus care areas were communicated to the manual control group via verbal instruction, in customary clinician-patient interactions. At the final visit, focus care areas were again chosen by the clinical examiner in the same manner as at screening to ascertain whether the quantity and location of these special need areas had changed.

To determine whether the use of the interactive power and manual control toothbrushes would affect the length of toothbrushing sessions, the number of seconds that subjects brushed under supervision was recorded at the screening visit (subjects using their own at-home manual toothbrush as they normally do) and at the post-treatment 2- and 6-week visits after plaque evaluations. Subjects were told to brush as they normally would with

their assigned products while clinical site personnel discreetly recorded the brushing session length.

Multiple measures were incorporated in the study design to avoid confounding factors and ensure data integrity. Subject selection criteria allowed for only regular manual brush users who would not have previous experience with the power toothbrush and app, as well as for participants with smartphone familiarity so there would not be a disparate learning curve or novelty factor bias. For validity of the plaque assessments, before each afternoon study visit participants were directed to refrain from toothbrushing and from performing any other oral hygiene procedures after their morning brushing (and no later than 8:00 am). Subjects were also instructed to cease eating, drinking, or chewing gum for 2 hours before their appointment, other than small sips of water up to 45 minutes beforehand. Furthermore, subjects were questioned at all visits to confirm that each study criterion continued to be met, including the nonuse of non–study-assigned oral hygiene products.

Outcomes (primary and secondary)

For analysis of motivational aspects related to toothbrushing with the interactive power toothbrush, subjects in the interactive power brush group responded to queries about their inclination to brush twice daily, and to brush for at least 2 minutes per brushing session at screening and again at study end. Responses were coded as scores 1-5, with 1 indicating highest motivation or agreement, and 5 lowest.

To determine whether the subjects understood the home use toothbrushing oral and written instructions, clinical staff supervised all subjects' brushing after their baseline visit plaque assessments and gave reinstruction as necessary.

Sample size calculation

The sample size of 60 randomized subjects (30 per group) was chosen for logistical considerations.

Interim analyses and stopping guidelines

Not applicable.

Randomization (random number generation, allocation concealment, implementation)

Randomization in 1:1 allocation to the 2 test groups was achieved via a computer-generated program, which also stratified qualified subjects based on gender, baseline whole-mouth TMQHPI-MQH ($\leq$3.8 vs $>$3.8), age (13-14 y vs 15-17 y), and number of focus care areas ($\leq$5 vs 6).

Blinding

Both the assignment process and the test products distribution were conducted in a protected area to ensure examiner blinding to group assignments.

Statistical analyses (primary and secondary outcomes, subgroup analyses)

Demographic and baseline variables were summarized by treatment group. The TMQHPI and MQH data were combined into a single dataset representing both fixed orthodontia and orthodontia-free tooth surface scores, and the evaluation results are labeled herein as TMQHPI-MQH. Statistical analyses for plaque efficacy were based on average whole-mouth TMQHPI-MQH change from baseline score. The 2- and 6-week plaque reduction was analyzed separately for treatment differences with the use of an analysis of covariance (ANCOVA) with baseline whole mouth TMQHPI-MQH score as the covariate. Similar analysis was carried out for determining treatment differences in the identified focus care areas. The within-treatment difference from baseline scores for each end point was tested versus zero with the use of a paired t test.

The brushing times (in seconds) collected at screening, week 2 and week 6 were summarized, and the changes from screening-visit brushing times were analyzed for treatment group differences with the use of the Wilcoxon rank sum test because the data were determined to be non-normally distributed. The distribution of the number (and percentage) of subjects in each focus care area was computed at the screening and week 6 visits. In addition, the mean change (from screening) in number of focus care areas at week 6 was analyzed with the use of a nonparametric ANCOVA analysis because the data were determined to be non-normally distributed. The mean changes in toothbrushing motivation after treatment compared with baseline were analyzed with the use of a 1-sample t test based on the difference between post-treatment and baseline values, with no correction for multiple testing. All treatment comparisons were 2 sided with an $\alpha = 0.05$ significance level.

RESULTS

Participant flow

Sixty adolescent subjects 13-17 years of age (mean 14.5 years) with fixed orthodontic appliances in both arches were randomized in a 1:1 allocation to test groups in this single-blind study, with 59 participants completing all study visits (Fig 1).

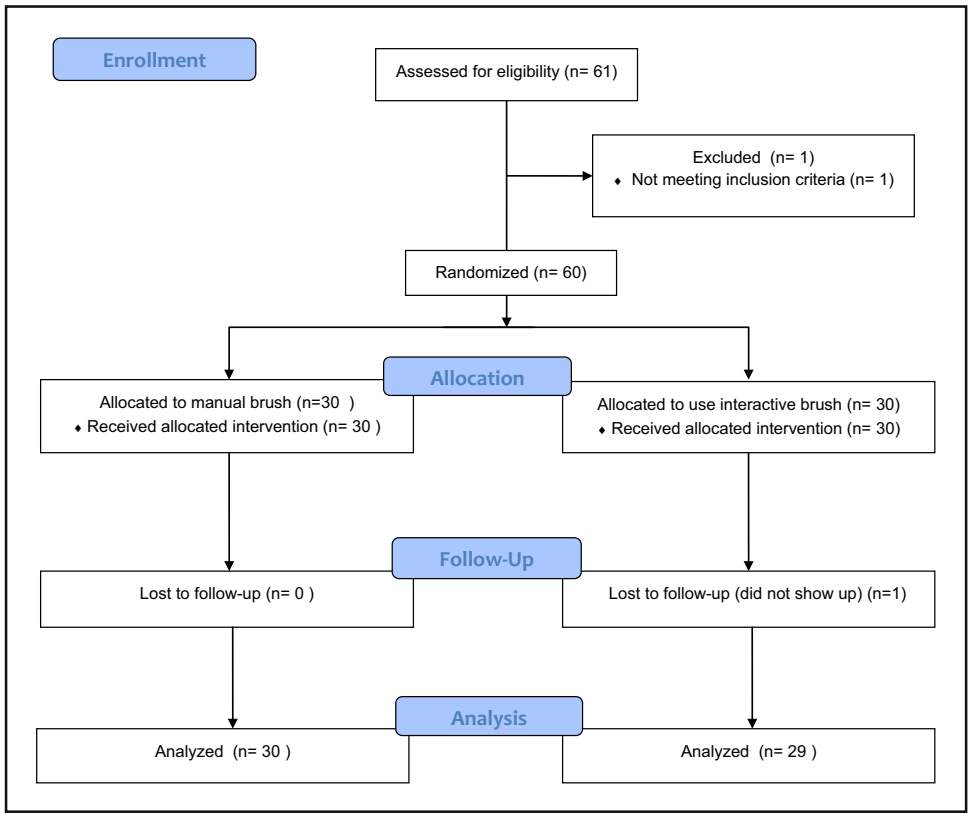

Fig 1. CONSORT flow diagram.

Baseline data

Baseline characteristics were similar in both groups. Table I provides additional detail about the demographic variables of the study population and the evaluable dataset. Baseline (pretreatment) whole-mouth mean TMQHPI-MQH plaque scores did not differ significantly between the brush test groups ($P = 0.835$), with means of 3.93 and 3.89 for the interactive power brush and manual brush control groups, respectively. The 2 groups also had similar baseline (pretreatment) mean TMQHPI-MQH plaque scores for focus care areas ($P = 0.697$; Tables II and III).

Table I. Baseline subject characteristics (randomized subjects)

Characteristic	*Interactive power brush (n = 30)*	*Manual control (n = 30)*	*Total (n = 60)*
Mean age, y	14.5 ± 1.14	14.5 ± 1.27	14.5 ± 1.20
Age range, y	13-17	13-17	13-17
Female, n (%)	15 (50%)	15 (50%)	30 (50%)
Male, n (%)	15 (50%)	15 (50%)	30 (50%)
White, n (%)	26 (86.7%)	27 (90%)	53 (88.3%)
Nonwhite, n (%)	4 (13.3%)	3 (10%)	7 (11.7%)

Two-sample *t* test, chi-square test, and Fisher Exact test were used to compare balance of demographic characteristic between the groups ($P = 1.000$).

Numbers analyzed for each outcome and subgroup analyses, estimation and precision

Regarding the efficacy of the 2 brushes, the interactive power brush provided a significantly higher plaque removal benefit compared with the manual control brush at weeks 2 and 6 ($P < 0.001$), with between-treatment differences in whole-mouth TMQHPI-MQH adjusted mean score changes from baseline of 0.777 (95% CI 0.614-0.940) and 0.834 (0.686-0.981), respectively. Both groups produced significant reductions in whole-mouth TMQHPI-MQH scores versus baseline at weeks 2 and 6 (Table II).

Regarding comparative efficacy for focus care areas, at weeks 2 and 6 the interactive power brush produced a significantly greater focus care area plaque removal benefit compared with the manual control brush ($P < 0.001$). Between-treatment differences for TMQHPI-MQH adjusted mean score changes from baseline at weeks 2 and 6 were 0.881 (95% CI 0.687-1.074)

Table II. Week 2 and week 6 whole-mouth mean TMQHPI-MQH efficacy results for evaluable subjects

Group	Baseline mean ± SD	Adjusted mean change from baseline (95% CI)	% change from baseline*	P value†	Between-treatment difference (95% CI)	Treatment comparison P value
Week 2						
Interactive power brush (n = 29)	3.926 ± 0.2674	1.414 (1.300-1.528)	36.2%	<0.001	0.777 (0.614-0.940)	<0.001
Manual control brush (n = 30)	3.894 ± 0.2643	0.637 (0.525-0.749)	16.3%	<0.001		
Week 6						
Interactive power brush (n = 28)	3.926 ± 0.2674	1.808 (1.704-1.912)	46.2%	<0.001	0.834 (0.686-0.981)	<0.001
Manual control brush (n = 30)	3.894 ± 0.2643	0.974 (0.874-1.074)	24.9%	<0.001		

*% change from baseline = 100 × (adjusted mean change divided by overall baseline mean); †Within-group difference from baseline TMQHPI-MQH was tested versus zero with the use of a paired *t* test.

Table III. Week 2 and week 6 focus care areas mean TMQHPI-MQH efficacy results for evaluable subjects

Group	Baseline mean ± SD	Adjusted mean change from baseline (95% CI)	% change from baseline*	P value†	Between-treatment difference (95% CI)	Treatment comparison P value
Week 2						
Interactive power brush (n = 29)	4.499 ± 0.3395	1.696 (1.561-1.831)	37.6%	<0.001	0.881 (0.687-1.074)	<0.001
Manual control brush (n = 30)	4.531 ± 0.2971	0.815 (0.683-0.947)	18.1%	<0.001		
Week 6						
Interactive power brush (n = 28)	4.499 ± 0.3395	2.114 (2.003-2.225)	46.8%	<0.001	0.990 (0.832-1.148)	<0.001
Manual control brush (n = 30)	4,531 ± 0.2971	1.124 (1.017-1.231)	24.9%	<0.001		

*% change from baseline = 100 × (adjusted mean change divided by overall baseline mean); †Within-group difference from baseline TMQHPI-MQH was tested versus zero with the use of a paired *t* test.

and 0.990 (0.832-1.148), respectively. Similar to whole-mouth plaque data, both groups produced significant reductions in mean plaque scores for focus care areas versus baseline at weeks 2 and 6 (Table III; Fig 2).

In considering overall focus care area frequency, the mean number across the entire study population at screening was 5.3 (median 5), and the treatment groups were balanced, with 5.2 and 5.5 focus care areas for the interactive power and manual groups, respectively ($P = 0.142$). After 6 weeks, the interactive power brush provided a mean reduction in the total number of focus care areas compared with screening of 2.4 areas, compared with a drop of 1.5 for the manual control brush. The between-group difference favored the interactive power brush group with significantly greater reduction in focus care area prevalence compared with the manual group ($P = 0.009$; Fig 2).

In both brush groups, focus care areas were most commonly found in 3 regions of the dentition at both screening and week 6: the posterior upper left buccal, posterior upper right buccal, and front lower facial regions. The prevalences of focus care areas in these 3 regions before treatment were 87%-93% for the interactive power brush and 97%-100% for the manual control brush groups. At week 6, the frequency of focus care areas in these regions had declined to 54%-64% in the interactive power brush group compared with 80%-87% in the manual brush group.

At screening, the 2 brush groups were not dissimilar in their recorded median (±SD) brushing session time ($P = 0.411$): 126 ± 52.74 seconds and 118 ± 44.52 seconds for the interactive power brush and manual control brush groups, respectively. After treatment, subjects in the interactive power brush group had significantly longer recorded median brushing times than the manual control brushers ($P < 0.001$). At week 2 the median brushing time for the power brush group had increased to 177 ± 30.07 seconds, and at week 6 it was

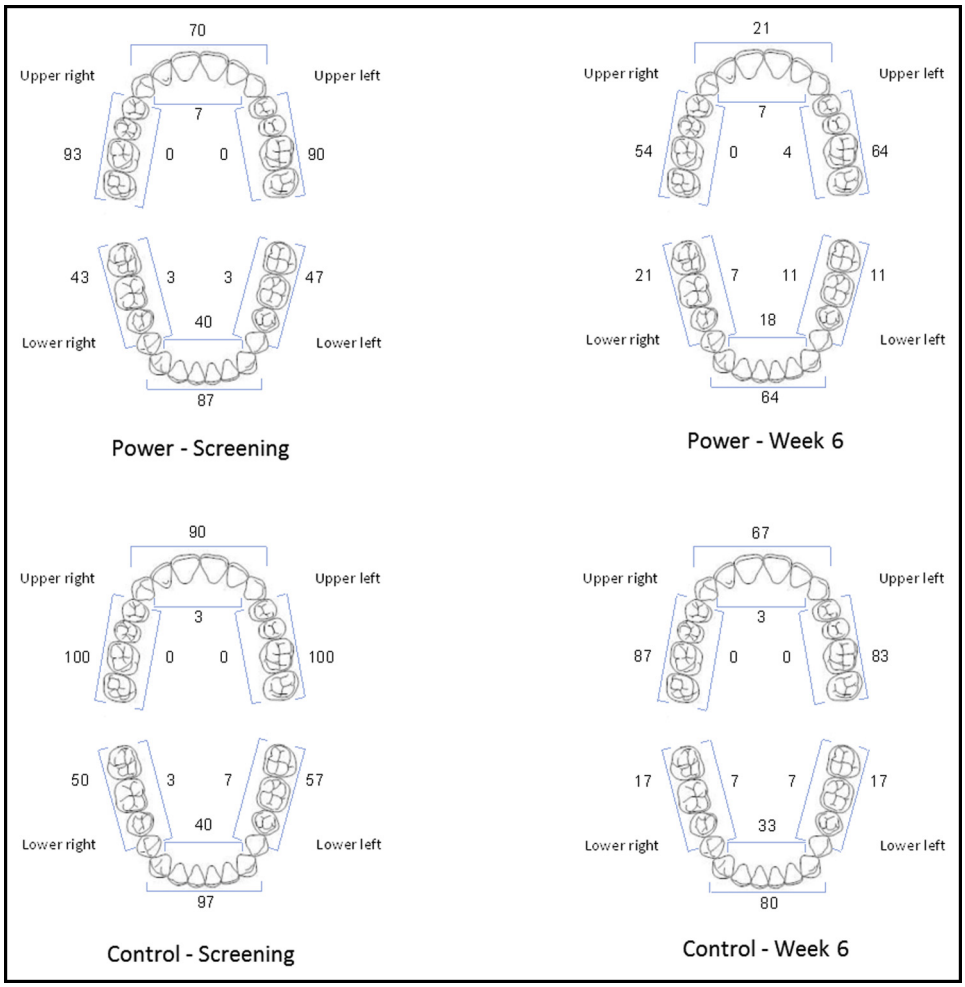

Fig 2. Percentage of subjects with focus care areas: interactive power brush group (top) and control (bottom).

181 ± 44.26 seconds. Median brushing session lengths for the manual control group were 130 ± 45.92 seconds and 114 ± 40.61 seconds at weeks 2 and 6, respectively. The changes in brushing time across the study duration were not significant ($P \geq 0.099$) for the manual brush control group, although the gains in median brushing session time in the interactive power brush control group of 51 seconds and 55 seconds at weeks 2 and 6, respectively, were statistically significant ($P \leq 0.013$; Fig 3).

Before test brush assignment, subjects in the interactive power brush group were asked about their motivation to brush 2 times per day, on a scale of 1 to 5, with 1 indicating the highest motivation. The mean baseline score was 2.63 ± 1.00, with 43.3% of respondents answering with an assessment of 1 or 2. After 6 weeks of test brush usage, the same question was asked and the mean score was 1.93 ± 0.78, with 86.7% ranking their motivation as 1 or 2. This mean improvement of 0.70 units over the course of the study in the motivation for brushing twice daily was significant ($P = 0.0005$).

Subjects in the interactive power brush group were also queried as to their motivation to brush for the recommended brushing time (≥2 minutes). At baseline, the mean response was 2.30 ± 0.88, with 56.7% of the subjects giving a response of 1 or 2. Their motivation was assessed again at study end and the mean score was 1.83 ± 0.83, with 73.3% of the group giving a response of 1 or 2. This 0.47-unit mean increase in motivation compared with baseline also was significant ($P \leq 0.0054$).

Nearly all subjects assigned to the interactive power brush group (93.1%) indicated with a score of 1 or 2 their agreement with the statement, "With the app, I can do

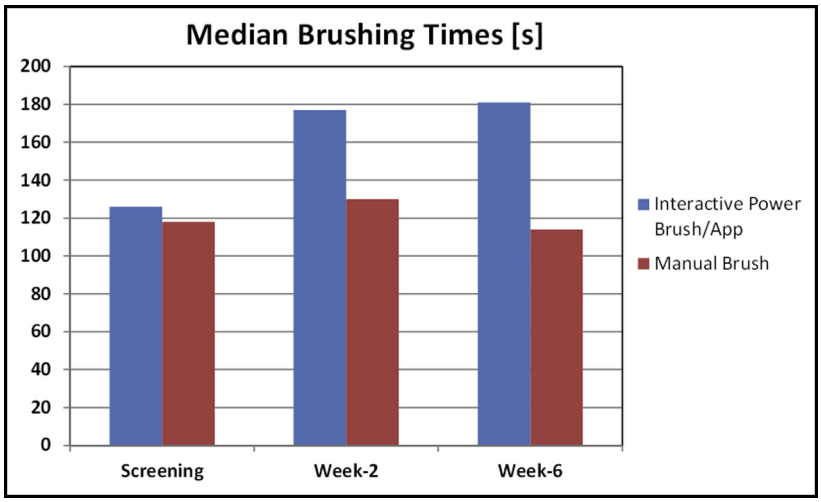

Fig 3. Median brushing times (126 and 118 seconds for the power and manual brushes, respectively) were similar at screening ($P = 0.411$). At week 2 (177 s for power and 130 s for manual) and week 6 (181 s for power and 114 s for manual), power brush users brushed significantly longer ($P \leq 0.002$) than manual brush users.

more for my oral care," and 90% similarly responded with a 1 or 2 to the statement, "With the app, time goes faster during brushing."

Harms

Both before test product assignment and at all post-treatment visits, a comprehensive assessment of the oral soft and hard tissues was conducted via visual examination of the oral cavity and perioral area, including the gingiva (free and attached), hard and soft palate, oropharynx/uvula, buccal mucosa, tongue, floor of the mouth, labial mucosa, mucobuccal/mucolabial folds, lips, perioral area, and integrity of the dental surfaces. Both brushes were well tolerated. No adverse events were noted or reported during the study. No serious harm was observed.

DISCUSSION

Main findings in the context of the existing evidence, interpretation

Although power toothbrushes with varying modes of operation are widely available (eg, sonic, side-to-side action), meta-analyses from the Cochrane Review Group have concluded that a single class—oscillating-rotating power toothbrushes—has substantiated greater reductions in plaque and gingivitis than side-to-side electric brushes and standard manual toothbrushes.[19,20] The power toothbrush used in the present study is in the family of oscillating-rotating power toothbrushes with statistically and clinically significant antiplaque and antigingivitis benefits documented in more than 250 laboratory and clinical published investigations.[21] Expanding on this established efficacy, the novel technology platform used in this clinical trial combines the interactive oscillating-rotating brush with Bluetooth technology.

Adolescents may be among the most formidable populations in which to effect change regarding oral hygiene.[1,3,4,31-33] In a previous similarly designed trial of shorter duration with German adolescents who did not have fixed orthodontics, the interactive power brush provided significant 34% and 38% mean reductions versus baseline in whole-mouth and focus care area plaque, respectively, at week 2.[37] The results of the present trial in an analogous age group but with fixed orthodontic appliances parallel those findings, with significant week 2 whole-mouth and focus area mean post-treatment plaque reductions of 36% and 38%, respectively, for the interactive power brush users. Therefore, even under more demanding cleaning conditions inherent to orthodontics wearers, unsupervised brushing with this interactive power brush yielded significantly greater plaque reductions than brushing with a standard manual brush, with results as substantial as those seen when subjects were not wearing fixed appliances after just 2 weeks. Furthermore, the longer duration of the present study at 6 weeks revealed that the TMQHPI-MQH plaque reduction benefits compared with baseline grew larger with continued use of the interactive power brush, as did the magnitude of the between-group performance gap.

Even in the absence of orthodontics, areas of the dentition that are more difficult to access during toothbrushing are at greater risk for gingivitis and caries incidence.[42-45] Brackets, arch wires, and other fixed orthodontic components can be breeding grounds for trapped food and debris and undisturbed plaque growth, particularly in adolescents who may lack hygiene acumen and motivation. The concept of focus care areas acknowledges that certain regions of the dentition may require extra brushing time and attention owing to challenging access, obstruction with orthodontics, or other patient-specific limitations (eg, dexterity) that predispose to excessive plaque build-up. When these sites can be identified by the dental professional, the patient can then work collaboratively to focus additional time where needed to remove more plaque and reduce disease risk. In the present trial, subjects in the interactive power brush group saw greater reductions than the manual brush group in both the overall number of focus care areas and the percentage of high-frequency intraoral sites with focus care areas. This suggests that the power brush subjects were in fact responding to app reminders to pay extra attention to these problem areas, whereas the manual brush group would have needed to remember their verbal instructions. In actual clinical-patient relationships, where a 6-month recall interval is typical, it is likely that only the highly motivated patient will remember to follow through at each brushing in the absence of a novel system promoting greater accountability such as the app reminders.

Increased toothbrushing time per brushing session has been demonstrated by Creeth et al and others to remove more plaque. One trial using single-use manual toothbrushing found that 26% more plaque was removed when brushing for 120 seconds versus 45 seconds.[45] Plaque has an established correlation with gingivitis and caries, and several studies show adolescents have much shorter than recommended average brushing times, so the need for effective oral hygiene tools that will be used by teens and improve their habits is paramount.[4,5,31-33] In the present trial, after 2 and 6 weeks of unsupervised brushing, there was no significant gain in mean brushing time in the manual brush group, and, in fact, the mean was slightly lower at 6 weeks than at 2 weeks and baseline. In contrast, the interactive power brush group was brushing 55 seconds longer on average compared with baseline by study end. This exceeds the 34-second increase seen for power brush users in the previous similar trial.[37] The likely explanation for the increase in brushing time for the power brush group with no similar gains in the manual brush group is attributable to the interactive format and personalized reminders to brush for 2 minutes. Notably, the clinical site-recorded brushing time gains were supported by responses to the subject-assessed queries at week 6: The interactive power brush subjects' perception of their brushing motivation changed favorably over the course of the trial, with significant gains in the proportion of subjects who were motivated to brush twice daily and brush for 2 minutes or more after the study compared with before they had used the interactive power brush.

These outcomes, which show efficacy and compliance benefits for the interactive power toothbrush, are clinically meaningful. The patient population—adolescent patients with fixed orthodontics and high levels of plaque—represent a large segment of patients in a typical orthodontic practice. The efficacy outcomes, including a 46% plaque removal benefit, have positive implications for gingival health. Finally, the increase in brushing time of nearly 1 minute and the improvement in motivation are clinically relevant, because compliance is one of the primary obstacles to effective oral hygiene.

Populations at higher risk for oral disease, such as adolescents with orthodontics, require targeted and practical oral hygiene strategies that take into account their unique needs and lifestyle factors. The relevance and saturation of personal wireless technology usage in this age group can not be overstated. Mobile devices increasingly function as convenient portals for instant remote accessibility to applications, with apps that both entertain and educate. In the class of knowledge-boosting apps, the medical, wellness, and condition-tracking category is growing exponentially to meet the demand for individualized health promotion. In 2015 an estimated 500,000,000 people were predicted to use health care mobile apps, increasing to one-half of smartphone/tablet users by 2018.[46] Beyond just engaging, these apps have been documented in outcomes-based research across a broad spectrum of diseases and fitness conditions to provide quantifiable health and cost benefits.[47] The dental and oral health app subset has also grown, offering dentistry information, training, and motivational tools. Building on these trends in the oral health category at a more sophisticated level, the fusion of Oral-B's most advanced power toothbrush and a custom-tailored app for use with the personal mobile technology adolescents increasingly see as vital has now been shown in 2 well controlled trials to provide superior cleaning and increased brushing time in adolescents compared with a manual toothbrush.

Limitations

Blinding of the examiner was feasible at the intervention stage, and outcome assessment also was blind. Therefore, the risks of observation and detection biases are considered low.

Generalizability

The generalizability of these results might be limited because the investigation was performed in a single center by 1 trained clinician (C.E).

CONCLUSIONS

Based on this randomized trial, an interactive power toothbrush generated increased brushing times and significantly greater plaque removal overall and in focus care areas versus a manual toothbrush. Adolescents are often inconsistent at oral hygiene, but their wireless mobile technology use can be harnessed to improve brushing motivation and cleaning efficacy.

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REFERENCES

1. Babey SH, Wolstein J, Goldstein H. Still bubbling over: California adolescents drinking more soda and other sugar-sweetened beverages. UCLA Center for Health Policy Research and California Center for Public Health Advocacy; 2013. Available at: http://healthpolicy.ucla.edu/publications/search/pages/detail.aspx?PublD=1228. Accessed September 19, 2016.
2. Broughton D, Fairchild RM, Morgan MZ. A survey of sports drinks consumption among adolescents. Br Dent J 2016;220:639-43.
3. Bourke E. Australians still eating too much sugar, teenagers particularly at risk, research shows. The World Today: 2016. Available at: http://www.abc.net.au/news/2016-03-21/australian-sugar-intake-remains-high-research/7263200. Accessed September 19, 2016.
4. McMurray C. Teens and teeth: most brush, few floss. Gallup: 2004. Available at: http://www.gallup.com/poll/13009/teens-teeth-most-brush-few-floss.aspx. Accessed September 19, 2016.
5. Crall JJ. Optimising oral health throughout childhood: the importance of caries risk assessment and strategic interventions. Int Dent J 2007;57:221-6.
6. Löe H, Theilade E, Jensen SB. Experimental gingivitis in man. J Periodontol 1965;36:177-87.
7. Theilade E, Wright WH, Jensen SB, Löe H. Experimental gingivitis in man II. A longitudinal and bacteriological investigation. J Periodont Res 1966;1:1-13.
8. Page RC. The etiology and pathogenesis of periodontitis. Compend Contin Educ Dent 2002;23(Suppl 5):11-4.
9. Dye BA, Thornton-Evans G, Li X, Iafolla TJ. Dental caries and sealant prevalence in children and adolescents in the United States 2011-2012. NCHS data brief, no 191. Hyattsville, Md: National Center for Health Statistics; 2015.
10. Rebelo MA, Lopes MC, Vieira JM, Parente RC. Dental caries and gingivitis among 15- to 19-year-old students in Manaus, AM, Brazil. Braz Oral Res 2009;23:248-54.
11. Hugoson A, Koch G, Rylander H. Prevalence and distribution of gingivitis-periodontitis in children and adolescents. Epidemiological data as a base for risk group selection. Swed Dent J 1981;5:91-103.
12. Botero JE, Rösing CK, Duque A, Jaramillo A, Contreras A. Periodontal disease in children and adolescents of Latin America. Periodontol 2000 2015;67:34-57.
13. Durward CS, Wright FA. The dental health of Indo-Chinese and Australian-born adolescents. Aust Dent J 1989;34:233-9.
14. Wei SH, Shi Y, Barnes DE. Needs and implementation of preventive dentistry in China. Community Dent Oral Epidemiol 1986;14:19-23.
15. Zachrisson S, Zachrisson BU. Gingival condition associated with orthodontic treatment. Angle Orthod 1972;42:26-34.
16. Atassi F, Awartani F. Oral hygiene status among orthodontic patients. J Contemp Dent Pract 2010;11:E025-32.
17. Smiech-Slomkowska G, Jablonska-Zrobek J. The effect of oral health education on dental plaque development and the level of caries-related *Streptococcus mutans* and *Lactobacillus* spp. Eur J Orthod 2007;29:157-60.
18. Arab S, Nouhzadeh Malekshah S, Abouei Mehrizi E, et al. Effect of fixed orthodontic treatment on salivary flow, pH and microbial count. J Dent (Tehran) 2016;13:18-22.
19. Robinson PG, Deacon SA, Deery C, et al. Manual versus powered toothbrushing for oral health. Cochrane Database Syst Rev 2005;(2):CD002281.
20. Deacon SA, Glenny A-M, Deery C, et al. Different powered toothbrushes for plaque control and gingival health. Cochrane Database Syst Rev 2010;(12):CD004971.
21. Warren P. The scientific evidence behind oscillating-rotating-pulsating brush technology. Available at: https://www.dentalcare.com/-/media/dentalcareus/research/pdf/oralb/oralbpowerclinicalcompendium2012.pdf?la=en&tv=1-201604260320. Accessed September 19, 2016.
22. Rosema NA, Timmerman MF, Versteeg PA, van Palenstein Helderman WH, van der Velden U, van der Weijden GA. Comparison of the use of different modes of mechanical oral hygiene in prevention of plaque and gingivitis. J Periodontol 2008;79:1386-94.
23. Dentino AR, Derderian G, Wolf M, et al. Six-month comparison of powered versus manual toothbrushing for safety and efficacy in the absence of professional instruction in mechanical plaque control. J Periodontol 2002;73:770-8.
24. Klukowska M, Grender JM, Conde E, Milleman KR, Milleman JL. Plaque reduction efficacy of an oscillating-rotating power brush with a novel brush head utilizing angled bristle tufts. Compend Contin Educ Dent 2014;35:702-6.
25. Warren PR. Development of an oscillating/rotating/pulsating toothbrush: the Oral-B Professional Care series. J Dent 2005;33S1:1-9.
26. Warren PR, Chater B. The role of the electric toothbrush in the control of plaque and gingivitis: a review of 5 years clinical experience with the Braun Oral-B Plaque Remover (D7). Am J Dent 1996;9:S5-11.
27. Milleman K, Putt M, Master A, Jenkins W, Souza S, Sturm D. Comparison of brushing compliance with Sonicare Xtreme e3000 series versus a manual toothbrush in preteens and teens. Brushing duration of manual versus sonic toothbrushes in preteens/teens. J Dent Res 2006;85(Spec Iss B):1306.
28. Stålnacke K, Söderfeldt B, Sjödin B. Compliance in use of electric toothbrushes. Acta Odontol Scand 1995;53:17-9.
29. Warren PR, Ray TS, Cugini M, Chater BV. A practice-based study of a power toothbrush: assessment of effectiveness and acceptance. J Am Dent Assoc 2000;131:389-94.

30. Walters PA. A novel oscillating-rotating power toothbrush with Smart Guide: designed for enhanced performance and compliance. J Contemp Dent Pract 2007;1 8:1-9.
31. Macgregor ID, Rugg-Gunn AJ. Toothbrushing duration in 60 uninstructed young adults. Community Dent Oral Epidemiol 1985; 13:121-2.
32. Macgregor ID, Balding JW, Regis D. Flossing behaviour in English adolescents. J Clin Periodontol 1998;25:291-6.
33. Kasmaei P, Amin Shokravi F, Hidarnia A, et al. Brushing behavior among young adolescents: does perceived severity matter? BMC Public Health 2014;14:8.
34. Lenhart A. Majority of American teens report access to a computer game, console, smartphone and a tablet. Pew Research Center; 2015. Available at: http://www.pewinternet.org/2015/04/09/a-majority-of-american-teens-report-access-to-a-computer-game-console-smartphone-and-a-tablet/. Accessed September 19, 2016.
35. Poushter J. Smartphone ownership and internet usage continues to climb in emerging economies. Pew Research Center; 2016. Available at: http://www.pewglobal.org/2016/02/22/smartphone-ownership-and-internet-usage-continues-to-climb-in-emerging-economies/. Accessed September 19, 2016.
36. Smith A. US smartphone use in 2015. Pew Research Center; 2015. Available at: http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/. Accessed September 19, 2015.
37. Erbe C, Ccahuana-Vasquez RA, Ferrari-Peron P, Klees V, Timm H, Grender J, et al. A comparative assessment of plaque removal and toothbrushing compliance between a manual and an interactive power toothbrush among adolescents: a single-center, single-blind randomized controlled trial. BMC Oral Health 2018; 18:130.
38. Büchel B, Reise M, Klukowska M, et al. A 4-week clinical comparison of an oscillating-rotating power brush versus a marketed sonic brush in reducing dental plaque. Am J Dent 2014;27:56-60.
39. Turesky S, Gilmore ND, Glickman I. Reduced plaque formation by the chloromethyl analogue of victamine C. J Periodontol 1970;41: 41-3.
40. Quigley GA, Hein JW. Comparative cleansing efficiency of manual and power brushing. J Am Dent Assoc 1962;65:26-9.
41. Kossack C, Jost-Brinkmann PG. Plaque and gingivitis reduction in patients undergoing orthodontic treatment with fixed appliances-comparison of toothbrushes and interdental cleaning aids. A 6-month clinical single-blind trial. J Orofac Orthop 2005;66:20-38.
42. Cancro LP, Fischman SL. The expected effect on oral health of dental plaque control through mechanical removal. Periodontol 2000;8:60-74.
43. Tanner AC, Kent R, van Dyke T, Sonis ST, Murray LA. Clinical and other risk indicators for early periodontitis. J Periodontol 2005;76: 573-81.
44. White DJ. Dental calculus: recent insights into occurrence, formation, prevention, removal and oral health effects of supragingival and subgingival deposits. Eur J Oral Sci 1997;105(5 Pt 2):508-22.
45. Creeth JE, Gallagher A, Sowinski J, Bowman J, Barrett K, Lowe S, et al. The effect of brushing time and dentifrice on dental plaque removal in vivo. J Dent Hyg 2009;83:111-6.
46. Jahns R. 500m people will be using healthcare mobile applications in 2015. Research 2 Guidance: 2010. Available at: http://research2guidance.com/500m-people-will-be-using-healthcaremobile-applications-in-2015. Accessed September 19, 2016.
47. Blake H. Innovation in practice: mobile phone technology in patient care. Br J Community Nurs 2008;13:160: 162-165.