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ORIGINAL ARTICLE

Effects of interactive power toothbrush with or without application assistance on the plaque, gingivitis, and gingival abrasion among dental students: a randomized controlled clinical trial

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Abstract

Objective The purpose of this randomized controlled study is to determine if an interactive power toothbrush (PTB) with application (app) promotes additional benefit on dental plaque, gingivitis, and gingival abrasion to that of a manual toothbrush (MTB).

Materials and methods Ninety participants (dental students) diagnosed with gingivitis were randomly assigned, into three groups, 1:1:1 ratio, given an app-assisted interactive PTB (PTB-A) (Oral-B Genius® Rechargeable 8000 PTB with CrossAction brush head) or the same PTB without app-assistance (PTB-NA) or a regular MTB for home-use. Plaque was assessed using the Turesky modification of the Quigley and Hein Plaque Index (QHPI-TM), and gingivitis was evaluated using the Bleeding on Marginal Probing Index (BOMP) at baseline (T0), week 2 (T1), and week 8 (T2). Gingival abrasions were recorded at T1 and T2. Exit survey was used to assess brushing time and visual-analogue-scale (VAS) scores.

Results PTB improved QHPI-TM significantly in terms of time-dependent changes, irrespective of app-assistance. BOMP was observed to be statistically lower in PTB-A than in MTB only at T2. Brushing times were longer in PTB-A than in MTB. Gingival abrasion was less in both PTB than MTB. PTB-A had better results to MTB in cleaning ability according to subject-reported outcomes.

Conclusions Both PTBs were more effective to MTB; however, the app-assisted interactive PTB was similar to the non-assisted one in plaque removal efficacy, gingivitis reduction, and incidence of gingival abrasion, yet better than MTB in cleaning ability.

Clinical relevance Developing an application software to prevent gingival abrasion might be clinically beneficial regardless of the individual factor.

Trial registration ClinicalTrial.gov ID: NCT05150132.

Keywords Gingivitis · Dental plaque · Interactive power toothbrush · Gingival abrasion · Application · Randomized clinical trial

Introduction

Effective tooth brushing is known to be essential in controlling dental plaque and preventing periodontal diseases and tooth loss. According to the 2015 oral and dental health guideline by the UK's National Institute for Health and Care Excellence (NICE), among those who brushed their teeth on a daily basis, 33% had dental plaque as the leading cause of periodontal disease, and 31% had calculus in at least one site. These results indicate the ineffective and inadequate oral hygiene despite regular tooth brushing [1].

The power toothbrush (PTB) was developed in the 1960s for patients with poor motor skills, orthodontic

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patients unable to maintain oral hygiene, and geriatric patients with reduced fine motor skills [2]. Over the past decades, PTBs have become as an alternative to manual toothbrushes (MTBs) since they are easier to use, require minimal effort, and can clean hard-to-reach areas [3]. While PTBs have different functioning modes, such as oscillation-rotation (OR), sonic (lateral vibration), cross-vibration, rotation, and ultrasonic; however, OR and sonic toothbrushes that provide up to 48,000 vibrations per minute have been preferred lately.

It has been suggested that the recently developed interactive PTBs provide the most successful results in plaque control and effective use of brushing time by enabling patient collaboration and self-treatment, thanks to mobile phone application features [4–6]. In recent years, motivational interviewing has been at the fore of changing oral health behaviours. Theories on behavioural change are being developed in research on oral health promotion. A newly published systematic review has suggested that while communication techniques and alternative methods that promote oral hygiene behavioural changes are widely researched, especially in orthodontic patients, their effects on periodontal diseases have not been investigated [7]. It is thought that the sense of responsibility of patients can be increased by a mobile app that allows patients to maintain good oral health by improving communication between patients and dental professionals [8]. Synchronizing interactive PTB use with smart phone apps allows for increased brushing performance by providing real-time feedback, digital visualization, and timer (session length), thus preventing excessive brushing force and using position detection technology to focus brushing in specific areas.

Various studies have indicated that both PTB and MTB may cause gingival abrasion, which is a localized reversible lesion of the gingival epithelium [3, 9, 10]; however, the exact causes of gingival abrasion are not yet clear, and arguments on the effect of brushing force are ongoing [10, 11]. It is possible to control the force applied by PTB force through the mobile app, and these high-speed rotating brushes are known to control plaque effectively, but there is not enough evidence regarding their effect on gingival abrasion.

The purpose of this randomized clinical trial (RCT) is to determine whether app-assisted interactive PTB provides an additional benefit for plaque removal efficacy and reduction of gingival inflammation. This study also aims to identify the effect of app-assisted PTB on gingival abrasion by comparing it to that of PTB without app-assistance and regular MTB. The null hypothesis of the study regarding gingival abrasion is that app-assisted interactive PTB do not show a significant difference compared to the other types of toothbrush.

Materials and methods

Ethical aspects

This study was conducted in line with the principles of the 1964 Declaration of Helsinki as a prospective RCT with a three-arm parallel design concerning the comparison of PTB with and without app and MTB. The study was reviewed and approved by the Ethics Committee of Gazi University, Ankara, Turkey (ethics approval number: 2017/146). A participant flow chart was designed following the guidelines by CONSORT (http://www.consort-statement.org/) (see Fig. 1). Informed consent was obtained from all the participants involved in the study after they were verbally informed about the process and presented a written information letter. They were asked to complete a questionnaire on their general state of health and checked by the inspector for eligibility based on inclusion and exclusion criteria.

Sample size and eligibility criteria

Regarding power analysis, a pilot study was conducted by taking QHPI, which is the primary outcome of the study, at baseline, at 2 weeks, and at 8 weeks in a total of 30 patients to determine sample size. A priori power analysis was performed with GPower 3.1. In a two-way repeated measures ANOVA, the calculated intragroup eta squared value was 0.796, and the corresponding effect size was 1.9753, while the intergroup eta squared value was 0.443 with the effect size as 0.8918. Moreover, the calculated eta squared for the interaction term was 0.455, and the effect size was 0.9137. Based on these calculations, the sample size was found to be at least 9 with an alpha error level of 0.05 and a power of 95%. In accordance with the minimum sample size obtained from the power prior, a higher number of participants was included, under the assumption that there might be fewer interpersonal differences since the study group consisted of dental students. In the event of potential dropouts, 30 participants per group were sought.

A total of 120 dental students were screened for eligibility, and 90 participants were included in the study. Voluntary participants who were (i) diagnosed with gingivitis (clinical measurements: probing pocket depths ≤ 3 mm, whole mouth QHPI-TM ≥ 1.75, and with a bleeding site of at least 40% or more), (ii) aged between 18 and 25, (iii) non-smokers, (iv) who had no systemic disease, (v) no ongoing orthodontic treatment, (vi) no crowding, and (vii) who had not received periodontal treatment in the last 3 months (viii) who had no gingival abrasion were included in the study as a result of the examinations at

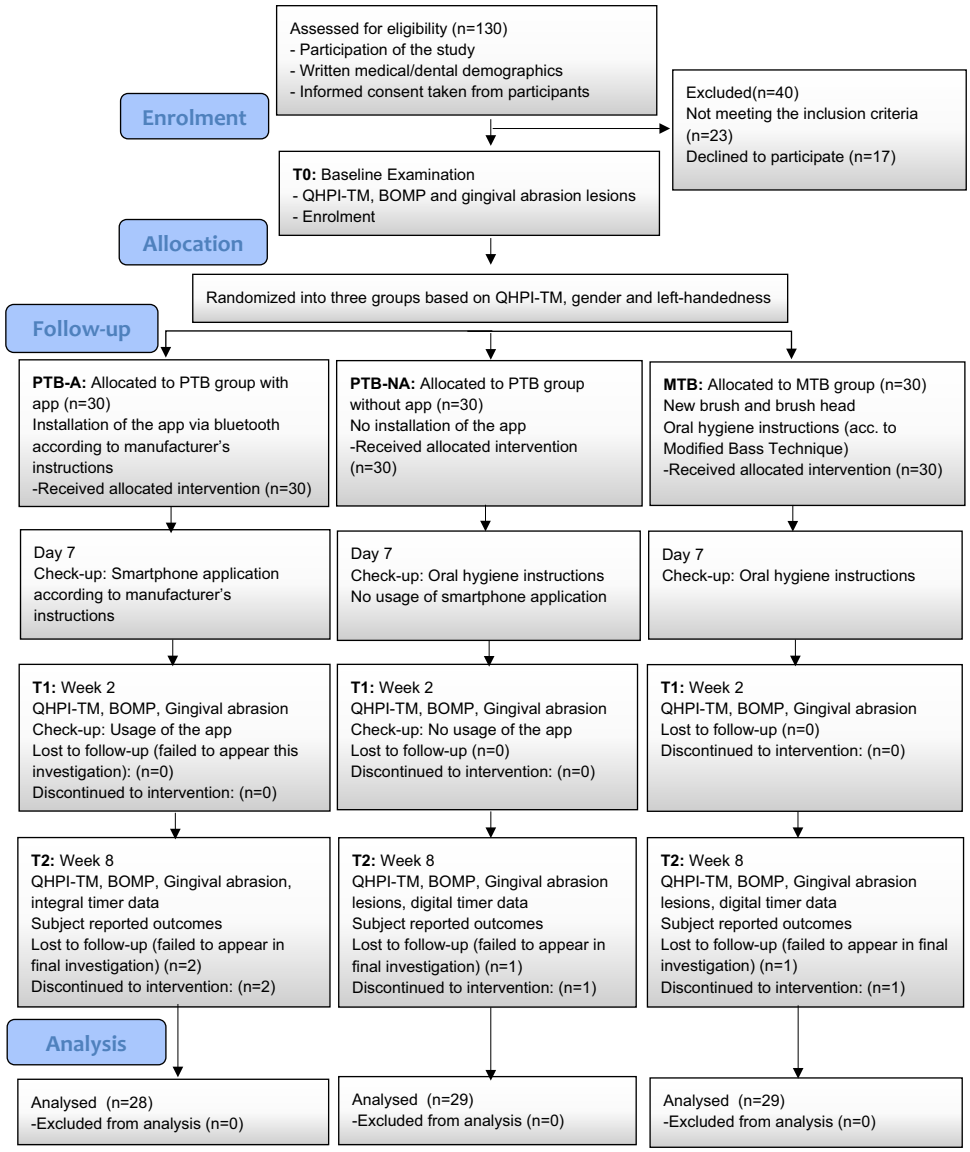


Fig. 1 Participant flow chart through the randomized clinical trial (RCT) according to CONSORT guidelines

the Department of Periodontology, Gazi University. In the meantime, individuals (i) who had ever used PTB, (ii) who had been using medications that might affect the periodontium, and who had (iii) mucogingival problems, (iv) a dental problem requiring urgent care, and (v) probing pocket depth ˃ 3 mm were not included in the study.

Study design and test products

One of the three brush types was randomly distributed to each participant using the generated random numbers (www.random.org). Allocation concealment was held by an independent examiner (EC) who was not involved in the recording of clinical parameters, and each product was labelled with a participant identification number.

PTB-A (*PTB with app*) ($n = 28$): Oral-B Genius® Rechargeable 8000 toothbrush with Cross Action brush head, Bluetooth® 4.0 connection, and smartphone app (Procter & Gamble, Cincinnati, Ohio): PTB group with app-assistance, using visually position detection feature included in the triple pressure control system.
PTB-NA (*PTB without app*) ($n = 29$): Oral-B Genius® Rechargeable 8000 with Cross Action® brush head without Bluetooth® 4.0 connection (Procter & Gamble, Cincinnati, Ohio): PTB group without app-assistance warned only by the brush itself without using the visual feature in the triple pressure control system.
MTB (*manual toothbrush*) ($n = 29$): Oral B® Clinic Line Pro-Flex Soft (Procter & Gamble, Cincinnati, Ohio).

All participants brushed their teeth using the same fluoride toothpaste (Oral-B® Pro-Expert Professional Protection- Ipana, Gross-Gerau, Germany) twice a day. Verbal and practical instructions for the use of toothbrushes were given beforehand. In the verbal instructions for the use of toothpaste, the expression "a pea-sized amount", which corresponds to an average of 0.25 g, was specified as a guide to equalize the self- and inter-individual use of participants during application [12]. The Oral-B app was installed and activated on the smartphones of the PTB-A group. According to the manufacturer's recommendations, the PTB-A group participants were instructed to use their app-assisted interactive PTB's having a triple pressure control system, which stops vibration, gives a visual warning, and reduces rotation speed, in daily cleaning mode-1. The PTB-NA group participants were instructed to set their PTB to the same mode and brush head but were not allowed the mobile application (i.e. no access to the position detection system). As for the MTB group, the participants were instructed to brush their teeth by pushing the bristles to the marginal gingiva or groove at a 45-degree angle to the long axis of the tooth with a vibrational motion, and from the gingiva to the tooth with a sweeping motion (modified Bass). These instructions were given by an independent examiner (ZTC).

Participants were restricted from using other oral hygiene products, such as interdental toothbrush, water jet, and mouthwash. To ensure the validity of plaque evaluations, study participant visits were scheduled in the morning. Participants were instructed not to brush their teeth and to avoid any oral administration, eating or chewing gum for 12 h, and drinking (anything other than small sips of water) for at least 4 h before each visit, to ensure an overnight plaque presence [13, 14].

Clinical assessments and subject-reported outcomes

An index form was prepared to obtain a systematic record of all clinical measurements. Upon the assignment of new toothbrushes, the clinical data were obtained at baseline (T0), at week 2 (T1), and at week 8 (T2). The present study flow and relevant examinations are summarized in Fig. 1. First, QHPI was measured. Following the plaque scores, gingival abrasions were recorded. Then, BOMP measurements were taken. The latest VAS questions were asked.

The study examinations were performed under standardized conditions by a skilled and blinded researcher (SG). Mira-2 Ton® disclosing solution (Hager & Werken GmbH Co. KG, Duisburg, Germany) was used either to determine plaque levels on tooth surfaces or to identify the number and size of gingival abrasions. The plaque levels were assessed by the Turesky et al. modification of the Quigley-Hein Plaque Index (QHPI-TM) [15, 16]. The evaluations were made using the Williams periodontal probe on six sites of each tooth except the third molars (Nordent Manufacturing Inc. Elk Grove Village, IL, USA). The evaluation was based on six scores as follows: score 0 = no plaque, score 1 = plaque stains on the cervical edge of the tooth, score 2 = a thin, continuous band of plaque (up to 1 mm) at the cervical edge of the tooth, score 3 = a band of plaque wider than 1 mm but covering less than one-third of the crown, score 4 = plaque covering from one-third to two-thirds of the crown, score 5 = plaque covering more than two-thirds of the crown.

Gingival bleeding was evaluated with the bleeding on the marginal probing index (BOMP) [14]. WHO probe (0.5 mm type ball) [14, 17] was used for BOMP assessment. The presence or absence and amount of bleeding were graded on a 0–2 scale within 30 s upon probing the gingival margin at an angle of approximately 60° to the long axis of the tooth (0 = no bleeding, 1 = pin-prick bleeding, 2 = excessive bleeding).

In order to detect the sites of gingival abrasion, the gingiva was stained with Mira-2 Tone® adapted from Danser et al. [10]. Blue or purple visible abrasions were classified by measuring with the Williams periodontal probe placed along the long axis of the lesions ("small" if ≤ 2 mm, "moderate" if ≥ 3 mm but ≤ 5 mm, and "large" if > 5 mm).

At the end of the study, the participants in PTB-NA and MTB groups were asked to record their brushing times with a digital timer. As for the PTB-A group, the last brushing time records were sent to the researcher via e-mail by using the integral timer in the mobile app of the toothbrush.

Moreover, all the participants were requested to fill out a survey including four questions on post-brushing pain/tenderness, cleaning ability, manageability, and willingness to purchase the toothbrush, via the visual-analogue-scale (VAS). The participants were asked to mark a point on a 10 cm long uncalibrated line, with both ends interpreted as negative (left) or positive (right) [18].

Statistical analysis

A participant mean value was calculated for each clinical parameter. Descriptive statistics relating to demographic information were expressed with mean and standard deviation for age, and frequencies and percentages for gender and right-hand-use. The normality of quantitative data was checked with the one-sample Kolmogorov–Smirnov test. For the quantitative variables that met the parametric test conditions, intergroup differences were analysed with one-way analysis of variance, multiple comparisons with Tukey's HSD, cross-tabulations with chi-squared tests, and intergroup differences for non-normally distributed variables with Kruskal–Wallis and Mann Whitney *U* tests. A two-way repeated measures ANOVA was used to determine whether the use of different toothbrushes and the effect of time spent

brushing were significant. The significance level α was set at 0.05 in all tests, and data management and statistical analyses were performed using IBM SPSS software (SPSS v. 21, IBM, Chicago, IL, USA).

Results

In this RCT, the clinical effect of using different types of toothbrushes at home for 8 weeks was evaluated on 86 enrolled participants (age: 23.51 ± 1.10, 54 females, 32 males). During the study, there were four drop-outs due to unrelated issues (medical and scheduling problems). In total, 86 out of 90 participants completed the study (Fig. 1). There was no statistical difference between the groups regarding age, gender, and left-hand use (Table 1).

QHPI-TM and BOMP scores are shown in Table 2. There was no significant difference between the groups regarding the full mouth QHPI-TM and BOMP scores at baseline. At 2 and 8 weeks, QHPI-TM scores were significantly higher in the MTB group (1.97 ± 0.22 and 1.84 ± 0.17, respectively) than in the PTB-A group (1.58 ± 0.2 and 1.33 ± 0.24, respectively) and PTB-NA group (1.58 ± 0.24 and 1.43 ± 0.20, respectively) ($P < 0.001$). However, plaque scores did not significantly differ between the PTB-NA and PTB-A groups at 2 and 8 weeks. In all three groups, the QHPI-TM scores decreased at a statistically significant level during the study ($P < 0.001$).

The BOMP scores of the three toothbrush groups were not significantly different at 2 weeks (PTB-A: 0.63 ± 0.15, PTB-NA: 0.62 ± 0.10, and MTB: 0.69 ± 0.11). BOMP scores were significantly higher in the MTB group (0.66 ± 0.10), than in

Table 1 Demographic data of the participants

Characteristics	Power toothbrush with app (PTB-A)	Power toothbrush without app (PTB-NA)	Manual toothbrush (MTB)	Total	*P* value
Number of participants [*n* (%)]	28 (32.18)	29 (33.33)	29 (33.33)	86 (100)	
Age in years (mean ± S.D)	23.44 ± 1.05	23.59 ± 1.12	23.45 ± 1.15	23.51 ± 1.10	0.89*
Gender (female) [*n* (%)]	18 (64.3)	20 (69)	16 (55.2)	54 (62.8)	0.54**
Handedness (right) [*n* (%)]	26 (92.9)	26 (89.7)	26 (89.7)	78 (90.7)	0.89**

*One-way ANOVA, **chi-square test

Table 2 Comparison of full mouth QHPI-TM and BOMP among the groups at baseline (T0), week 2 (T1), and week 8 (T2) and brushing time results at week 8

	Groups			One-way ANOVA F *P* value among groups	Two-way repeated measures ANOVA F *P* value
	PTB-A *n* = 28	PTB-NA *n* = 29	MTB *n* = 29		
QHPI-TM	Mean ± SD	Mean ± SD	Mean ± SD		
T0	2.10 ± 0.27	2.13 ± 0.31	2.17 ± 0.27	0.354 0.703	Time: 306.922 **< 0.001**
T1	1.58 ± 0.2[a]*	1.58 ± 0.24[a]*	1.97 ± 0.22*	30.898 **< 0.001**	Time*Group: 17.919 **< 0.001**
T2	1.33 ± 0.24[b]*	1.43 ± 0.20[b]*	1.84 ± 0.17*	48.858 **< 0.001**	Group: 22.561 **< 0.001**
BOMP					
T0	0.75 ± 0.13	0.72 ± 0.12	0.72 ± 0.12	0.841 0.435	Time: 49.059 < **0.001** Time*group: 4.423 **0.004**
T1	0.63 ± 0.15	0.62 ± 0.10	0.69 ± 0.11	2.920 0.059	Group: 1.405 0.251
T2	0.58 ± 0.10[c]*	0.60 ± 0.12[c,d]	0.66 ± 0.10 [d]*	3.816 **0.026**	
Brushing time (T2) (minutes)	123.33 ± 9.69[e]*	117.76 ± 7.82.[e f]	114.79 ± 10.26[f]*	6.392 **0.003**	

$p < 0.05$ statistically significant differences as a result of two-way repeated measures ANOVA Greenhouse–Geisser and one-way ANOVA test written with bold. [a–f]No significant differences between two group means ($p > 0.05$). *Significant differences between two group means with Tukey HSD ($p < 0.05$)

the PTB-A group (0.58 ± 0.10) at 8 weeks ($P = 0.026$). However, there was no significant difference between the PTB-NA and MTB groups, and between the PTB-A and PTB-NA groups. BOMP scores decreased at a statistically significant level in all the groups during the study ($P < 0.001$).

At the end of the 8 weeks that it was identified that the PTB-A group (123.33 ± 9.69 s) brushed their teeth for a statistically significantly longer time than the MTB group (114.79 ± 10.26 s) ($P = 0.003$); however, PTB-A group did not significantly differ between the PTB-NA group (117.76 ± 7.82 s) (Table 2).

In all the groups, abrasion was detected in participants at a level of 65.1% at week 2 and 52.3% at week 8 (Table 3). A total of 91.1% of these abrasions were of small sizes at week 2, and this rate was 93.3% at week 8. The means of the number of sites with gingival abrasion at weeks 2 and 8 in PTB-A (0.63 and 0.44, respectively) and PTB-NA (0.97 and 0.76, respectively) were statistically lower than those in MTB (2.03 and 1.17, respectively) ($P < 0.001$ and $P = 0.005$, respectively), and no difference was observed between PTB-A and PTB-NA (Table 4). The number of gingival abrasions of small, medium, and all sizes at week 2 was found to have decreased at week 8 ($P = 0.018$, $P = 0.048$, and $P = 0.003$, respectively).

With regard to the subject-related outcomes of the three groups, the participants' responses to the questions evaluating pain/tenderness, cleaning ability, manageability, and willingness to purchase with VAS are presented in Table 5. The table shows that there is a statistically significant difference between PTB-A (8.61) and MTB (7.83) only in terms of cleaning ability ($P = 0.037$; Table 5).

Discussion

This RCT aimed to evaluate the effect of using an interactive PTB with a mobile application on dental plaque, gingivitis, and gingival abrasion over 8 weeks. In recent years, motivation-enhancing wireless technologies that modify behaviour by providing real-time feedback with both manual [19] and power toothbrushes [4, 5] have become widespread. A 2020 meta-analysis of OR PTB versus MTB or sonic PTB by Grender et al. reported that in 13 short-term (up to 3 months in duration) RCTs, the OR PTB was correlated with a greater reduction in plaque and gingivitis compared to MTB, with relative benefits of 20% and 50.3%, respectively [20]. There is a limited number of studies evaluating the plaque removal and gingivitis reduction efficacy of the interactive PTB. Erbe et al. evaluated the effect of interactive PTBs and MTBs on plaque reduction and brushing habits in adolescents [5]. The study revealed that there was a 34% decrease in plaque scores with an interactive PTB and 1.7% with an MTB at the end of 2 weeks. In a study conducted by the same group of authors on the effect on plaque reduction using an interactive PTB compared with an MTB in fixed orthodontic patients aged between 13 and 17 years, it was discovered that the intergroup differences between the baseline and second week, and between the baseline and sixth week, were

Table 3 The number of participants with a site of gingival abrasion at the end of 2 weeks (T1) and 8 weeks (T2). The gingival abrasion sites were determined as "small" (< 2 mm), "medium" (≥ 3 mm and ≤ 5 mm), "large" (> 5 mm), and "total" (small, medium, and large) according to the groups, and their frequencies as present (≥ 1) or none (0)

			Groups			
			PTB-A ***n = 28***	PTB-NA ***n = 29***	MTB ***n = 29***	***Total***
		Sites with gingival abrasion	*n* (% of total)	*n* (% of total)	*n* (% of total)	*n* (% of total)
T1	***Small***	***0***	16 (18.6%)	13 (15.1%)	6 (7%)	*35 (40.7%)*
		≥ 1	12 (14%)	16 (18.6%)	23 (26.8%)	*51 (59.3%)*
	Medium	***0***	26 (30.2%)	24 (27.9%)	15 (17.4%)	*65 (75.6%)*
		≥ 1	2 (2.3%)	5 (5.8%)	14 (16.3%)	*21 (24.4%)*
	Large	***0***	28 (32.6%)	28 (32.6%)	28 (32.6%)	*84 (97.7%)*
		≥ 1	0 (0%)	1 (1.2%)	1 (1.2%)	*2 (2.3%)*
	Total	***0***	15 (17.4%)	12 (14%)	3 (3.5%)	*30 (34.9%)*
		≥ 1	13 (15.2%)	17 (19.8%)	26 (30.2%)	*56 (65.1%)*
T2	***Small***	***0***	17 (19.8%)	17 (19.8%)	10 (11.6%)	*44 (51.2%)*
		≥ 1	11 (12.8%)	12 (14%)	19 (22.1%)	*52(48.8%)*
	Medium	***0***	27 (31.4%)	25 (29.1%)	23 (26.7%)	*75 (87.2%)*
		≥ 1	1 (1.2%)	4 (4.7%)	6 (7%)	*11 (12.8%)*
	Large	***0***	28(32.6%)	28(32.6%)	29 (33.7%)	*85(98.8%)*
		≥ 1	0(0%)	1(1.2%)	0(0%)	*1(1.2%)*
	Total	***0***	17 (19.8%)	16 (18.6%)	8 (9.3%)	*41 (47.7%)*
		≥ 1	11 (12.8%)	13 (15.1%)	21 (24.5%)	*45 (52.3%)*

Table 4 Comparison of the mean sites of small/medium/large and total sites of gingival abrasions with the standard deviations in three groups according to week 2 (T1) and week 8 (T2)

		Total *n* = 86 Mean ± SD	PTB-A ***n* = 28** Mean ± SD	PTB-NA ***n* = 29** Mean ± SD	MTB ***n* = 29** Mean ± SD	Chi square *P value*	Z *P value*
Small	***T1***	0.92 ± 0.93	0.56 ± 0.70[a]*	0.76 ± 0.79[a]*	1.45 ± 1.02*	13.453 **0.001**	− 2.367 **0.018**
	T2	0.64 ± 0.75	0.41 ± 0.50[d]*	0.59 ± 0.83[d e]	0.93 ± 0.80*	7.163 **0.028**	
Medium	***T1***	0.27 ± 0.50	0.07 ± 0.27[b]*	0.17 ± 0.38[b]*	0.55 ± 0.63*	14.615 **0.001**	− 1.98 **0.048**
	T2	0.14 ± 0.38	0.04 ± 0.19	0.14 ± 0.35	0.24 ± 0.51	3.826 0.148	
Large	***T1***	0.02 ± 0.15	0 ± 0.00	0.03 ± 0.19	0.03 ± 0.19	0.977 0.614	− 0.577 0.564
	T2	0.01 ± 0.11	0 ± 0.00	0.03 ± 0.19	0 ± 0.00	1.966 0.374	
Total	***T1***	1.21 ± 1.13	0.63 ± 0.74[c]*	0.97 ± 0.98[c]*	2.03 ± 1.12*	22.776 **< 0.001**	− 3.016 **0.003**
	T2	0.79 ± 0.91	0.44 ± 0.58[f]*	0.76 ± 1.06[f]*	1.17 ± 0.89*	10.47 **0.005**	

$p < 0.05$ statistically significant differences as a result of Kruskal–Wallis and Wilcoxon test written in bold. [a–f]No significant differences between two group means with Mann–Whitney *U* test ($p > 0.05$). *Significant differences between two group means with Mann–Whitney *U* test ($p < 0.05$)

Table 5 The presented subject-reported outcomes in mean ± standard deviation of the survey were analysed at the end of the study, based on the VAS from 0 to 10

				Groups			
				PTB-A ***n* = 28**	PTB-NA ***n* = 29**	MTB ***n* = 29**	*P value*
Subject-reported outcomes	Questions	***From* (0)**	***To* (10)**	Mean ± SD	Mean ± SD	Mean ± SD	
Pain/tenderness	How was the pain/tenderness after tooth brushing?	No pain/tenderness	Worst pain	0.39 ± 0.79	0.72 ± 1.16	0.55 ± 1.06	0.610
Cleaning ability	How was the cleaning ability?	Very unpleasant	Very pleasant	8.61 ± 1.13[a]*	8.28 ± 1.10.[a b]	7.83 ± 0.97[b]*	**0.037**
Manageability	What do you think about the ease of use?	Very difficult	Very easy	8.36 ± 9.95	8.86 ± 1.03	8.62 ± 1.02	0.187
Willingness to purchase	What do you think about purchasing this toothbrush?	Very unwilling	Very willing	8.93 ± 0.9	8.9 ± 0.98	8.48 ± 0.95	0.171

$p < 0.05$ statistically significant differences as a result of Kruskal–Wallis test written in bold. [a–b]No significant differences between two group means with Mann–Whitney *U* test ($p > 0.05$). *Significant differences between two group means with Mann–Whitney *U* test ($p < 0.05$)

much smaller, in favour of the interactive PTB [4]. In this study, use of interactive PTBs at the 2nd and 8th weeks did not make a difference to plaque scores, whereas the highest plaque score was observed with MTB use. Accordingly, the interactive PTB was more effectively controlled plaque than the MTB, regardless of visual motivation, based on the data obtained from the position detection feature. This might be due to voluntary participants' interest in having a new experience (use of PTB) — the "novelty effect" [21]. The effect of using an interactive OR PTB with app on oral hygiene as compared to an OR PTB with a different pulse rate was explored in a recently published study by Deleuse et al. [22]. The study revealed that the effect of app use on plaque removal was not observed until the 6th week, whereas the plaque score decreased more at the 12th week. This finding was associated with the fact that the novelty effect of app use decreased markedly after the 6th week, allowing the true effectiveness of the app to come to the fore [22].

Likewise, Erbe et al. indicated that the plaque removal effect of the interactive PTB increased more than that of MTB after 6 weeks of use since the performance gap between the groups increased over time [4]. In this study, plaque control of using a PTB-A or PTB-NA increased more than that of an MTB at the 8th week compared to the 2nd week; this might be due to progress in plaque control made during regular tooth-brushing during the 6-week period between two visits.

Studies on the effectiveness of toothbrushes have mostly been conducted with individuals who have gingivitis, a reversible plaque-related disease that has gingival bleeding as the most significant symptom. In studies exploring the correlation between BOP and gingival histopathology, inflammatory cell infiltrate density has been found to be significantly higher in areas of gingival bleeding compared to areas without bleeding, while inflammation can be observed in the gingival connective tissue [23]. The presence or absence of bleeding on probing gives a positive predictive value of 6% and a negative predictive value of 98% for the progression of periodontal disease [24]. Absence of bleeding on probing is considered the most decisive indicator of periodontal health. This study aimed to compare gingival bleeding, which is a clinical sign of gingival inflammation, with a quantitative value obtained with BOMP, an index used to determine periodontal health and gingivitis [14]. Since the new classification had not been published at the time the study was taking place, the inclusion criterion was the finding of at least 40% bleeding, similar to the study conducted by Salzer et al. in 2016. Using the new classification released at the 2017 World Workshop, at least 30% of bleeding on probing (BOP) and a probing depth of 3 mm or less are defined as gingivitis [25]. The bleeding scores determined with BOMP in this study are compatible with the BOP percentage for gingivitis, which is valid in the new classification. Bilen et al. [6] compared the effectiveness interactive PTBs and MTBs on plaque, gingivitis, and bleeding in orthodontic patients at the 2nd and 8th weeks, and in the 4th month. In this study, the bleeding scores were observed to be lower in interactive PTBs than in MTBs in the 4th month only. Similarly, in the present study, there was no difference regarding gingival bleeding among the three toothbrushes at the 2nd week. However, a statistically lower BOMP score was observed in the interactive PTB as compared to the MTB at the 8th week. It should be noted that the expectation of a decrease in bleeding is not the primary concern of this study. In the present study, a decrease in gingival bleeding cannot be anticipated, since 8 weeks of brushing cannot eliminate gingivitis without phase I treatment. However, a significant decrease in the bleeding scores of individuals with gingivitis was identified as a result of 8-week regular use of an interactive PTB.

While brush users and dental professionals focus on removing plaque from hard tissue surfaces and reducing gingivitis using tooth-brushes, several studies have shown that these brushes can also have an effect on soft tissues [23, 26–28]. Gingival abrasion is a superficial gingival lesion extending to the submucosa, which removes the superficial keratinized epithelial layer of the gingival tissue and exposes the connective tissue. The effects of factors such as pressure, time, and bristle type on gingival abrasion or erosion in MTBs and PTBs have been investigated in various studies [23, 26–31]. Possible causes of non-inflammatory gingival recession are thought to play a role in tooth malposition and local anatomy [32] or incorrect and hard brushing [33, 34]. Superficial gingival abrasions might be expected to heal naturally, but it is unclear to what extent the toothbrush causes gingival erosion associated with gingival recession, manifested by exposure of the root surface apical to the enamel-cementum junction [3, 35].

Since gingival abrasion is not a common finding, it is quite challenging to score [36]. The study by Danser et al. [10] scored gingival abrasion based on categories for the first time as small, medium, and large. In a study by Van der Weijden et al. [11], the plaque removal effect and possible gingival abrasion of various PTBs were evaluated, and it was revealed that PTBs mostly cause minor abrasions (mid-buccal) and a decrease in the number of abrasions over time. Consistent with the present study, Danser et al. [10] encountered minor gingival abrasions with use of both MTBs and PTBs [10]. Rosema et al. [3], a 3-month study, reported that gingival abrasion may occur less due to the gentle brushing resulting from the learning effect, they also commented that the old brush may have an effect as there may be reduced bristle stiffness [3]. Meanwhile, in a recent study, the bristle stiffness of PTBs was found to have decreased significantly after 2 months usage [37].

In a study conducted with 219 patients, it was observed as a result of the 5-week evaluation of PTBs that medium-sized abrasions could develop [38]. In a 5-year follow-up study, it was found that use of a PTB might result in soft-tissue trauma or have a more abrasive effect compared to use of an MTB, and the authors stated that this might carry a risk of gingival recession due to chronic trauma [39]. However, in recent clinical studies, an excellent safety profile has been reported for OR PTB [3, 40]. In the present study, both of the PTBs, regardless of app usage, have a rotation-speed reduction feature that stops the vibration of the brush and can reduce gingival abrasion. It was observed, however, that minor abrasions occurred in all groups, using interactive PTBs. Although it was not statistically significant, mostly small or medium-sized abrasions occurred and were fewer than those resulting from use of MTBs. This may be due to the position detection feature, one of the leading features of triple force control; by following a certain brushing sequence, unnecessary brushing of the same area and thus gingival trauma is prevented. Although there are varied

opinions about the effect of pressure control on gingival abrasion [36], PTBs have pressure control feature (stopping the pulsation and decreasing its speed). In MTB use, the criss-cross bristle configuration of the brush may cause higher gingival abrasion while increasing its plaque reduction effectiveness. This may also explain the high incidence and number of abrasions resulting from the use of MTBs. However, the presence of gingival abrasions, even small numbers, observed with the use of interactive PTBs, suggests that researchers should focus on this issue.

Regarding the evaluation of the effectiveness of toothbrushes, there are cross-over designed studies that include different study groups in which the same individuals use different types of toothbrushes alternately or parallel-designed studies including groups in which different individuals use the same type of brush throughout the study [9, 41]. This present study was parallel designed, based on the fact that a habit might not be changed despite the time left between brush alternations in cross-over studies. Additionally, in studies examining the effects of various bristles, PTBs, or abrasives in toothpastes on gingival abrasion, the results of single tooth brushing or long-term monitoring have been evaluated [13, 42, 43]. Pizzo et al. [44] monitored the Oral B Professional Care 8500 PTB for 30-days and found that there was no difference in abrasions with single use, but that abrasion might be observed in the mid-gingival and approximal regions in the long term (30 days). Consequently, in this study, an evaluation following use of the brushes for 8 weeks was preferred to determine the differences that may occur in the formation of gingival abrasion.

Toothbrush selection is primarily based on personal preference and professional recommendations. In order to include information about personal preferences in the study, individual-oriented results including pain/tenderness, cleaning ability, ease of use, and willingness to purchase the toothbrush were evaluated using a survey. Accordingly, interactive PTBs were revealed to be more satisfactory than MTBs in terms of cleaning ability. This may be because interactive PTBs are more efficient at plaque removal than MTBs, as has been determined clinically, and enables the monitoring of brushing via the application. Although the participants found the cleaning capacity better in PTBs, there was no concomitant willingness to buy a PTB. This may be due to complexity of preparation of the application or financial reasons [45]. The similar results in terms of pain and sensitivity were attributed to the fact that the participants already brushed their teeth regularly and could tolerate the pain since they were young.

According to the brushing time records obtained only at the end of the study — the first of the limitations of our research — and using different evaluation methods, an increase of 8.54 s using an interactive PTB compared with an MTB did not clearly reveal the contribution of app use to time spent brushing. We predicted we would not be able to provide precise information about the consistency of the time records due to home brushing. Another potential limitation of our research was that our study group consisted of dental students. Even if the time spent brushing difference was significantly more than with the MTB group, the fact that it was not different from the PTB group without time reminders can be attributed to the session length for both the PTB-NA group and the MTB group, due to the Hawthorne effect [46]. Although homogeneity might be a benefit of using a group of dental student, ensuring reliability and standardization of the results among the groups, such as dexterity, motivation and brushing frequency, and the willingness to use digital tools [47], it makes interpretation difficult due to the difficulties of generalization. However, better and time-appropriate brushing can be achieved with the contribution of app, seen in PTB-A. In the study by Erbe et al. [5], an increase of 34 s was achieved with the use of an interactive PTB with mobile app compared to the use of an MTB. In this study, the authors attributed the possible increase in brushing time using an interactive PTB over an MTB to the presence of personalized reminders designed to enable the interactive PTB to brush for 2 min.

Although the presence of the app in the interactive PTB did not present any difference in the results of this 8-week study, studies are still needed to evaluate the long-term effects of application use in the general population, including those in which the effect of interactive PTBs on brushing usage times can be evaluated with a video camera tracking system.

Conclusion

In conclusion, the results of the current study have shown that there is no evidence that the use of the app in interactive PTBs, whose effectiveness was tested on a group of dental students with gingivitis, would provide an extra benefit in terms of plaque control and gingival inflammation. Although interactive PTBs have better results than MTBs with regard to plaque, gingivitis, and abrasion reduction, PTBs may create a few small abrasions. The authors concluded that brushing might be made safer by adding software to prevent gingival abrasion, regardless of the individual factor, to the applications focused on plaque removal in interactive PTBs.

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Declarations

Ethics approval This article reports a study that involved human participants. All the procedures performed in the study involving human

participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Ethics Committee approval was received for this study from the Ethics Committee of Gazi University, Ankara, Turkey (approval number: 2017/146).

Informed consent Informed consent was obtained from each individual participant involved in the study.

Conflict of interest The authors declare no competing interests.

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