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ORIGINAL ARTICLE

Professional brushing study comparing the effectiveness of sonic brush heads with manual toothbrushes: a single blinded, randomized clinical trial

Anna-Kristina Pelka · Tonia Nagler · Imke Hopp · Anselm Petschelt · Matthias Anton Pelka

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Abstract The aim of this study was to evaluate the plaque removal efficacy of four toothbrushes: the Philips Sonicare Elite with medium and mini brush heads, the Elmex Sensitive, and the American Dental Association (ADA) reference toothbrush. This study was a randomized, controlled, investigator-blinded, four-brush crossover design study, which examined plaque removal following a consecutive repeated use. All brushes were used on each participant in a randomly assigned quadrant of the mouth. A total of 90 subjects participated in the study. Prior to the experiment, they received a professional prophylaxis and were requested to refrain from toothbrushing for 48 h. Teeth were professionally brushed consecutively for 10 to 90 s per quadrant. A Turesky-modified Quigley Hein Index score was assessed at baseline and after each brushing interval by one blinded investigator. Results showed reduction of mean plaque scores for all brushes with time from 10 to 90 s. After 30 s (2-min whole mouth equivalent) of brushing, the Sonicare brushes cleaned 19, the ADA brush 16, and the Elmex Sensitive 10 of in average 28 tooth surfaces. With time, the number of additional cleaned surfaces decreased. Time is an important variable in the evaluation of plaque-removing efficacy since absolute efficacy increases with time and differs per toothbrush. No differences could be found between the two brush heads of the Sonicare.

Keywords Sonic brushes · Time efficacy · Brush head · ADA toothbrush · Professional brushing

Anna-Kristina Pelka, Tonia Nagler, and Imke Hopp contributed equally.

T. Nagler · I. Hopp · A. Petschelt · M. A. Pelka (✉)
Dental Clinic 1—Operative Dentistry and Periodontology,
University Hospital of Erlangen,
Glückstrasse 11,
91054 Erlangen, Germany
e-mail: pelka@dent.uni-erlangen.de

A.-K. Pelka
Operative Dentistry and Periodontology,
University Hospital of Munich,
Munich, Germany

Introduction

Supra- and subgingival plaque and stain removal is crucial for maintenance of gingival and periodontal health [1]. In order to improve the quality of tooth cleaning, a number of electric toothbrushes have been marketed; some manufacturers offer the powered toothbrush as a replacement for manual toothbrushes. Toothbrushing is the primary contributor to oral hygiene, and mechanical tooth cleaning remains the most reliable method of controlling supra- and subgingival bacterial plaque [2].

The efficacy of powered toothbrushes as compared to manual toothbrushes is still cause for discussion [3–5]. The powered toothbrush significantly reduces mean gingival index and probing attachment level [6]. The Cochrane systematic report found that only the rotating/oscillating powerbrush is superior to the manual toothbrush and stated that the available data for other powered toothbrushes are inconsistent [7–9]. Recently, studies have shown that the powered sonic toothbrush may also be superior to the manual toothbrush in terms of plaque removal and gingivitis [5, 10]. Due to variability in the duration of toothbrushing and other differences in study design, it is difficult to determine the relative efficacy of powered toothbrushes based on available data. Contradictory results have been reported from different research groups for the sonic toothbrush [11, 12]. In other words, the 2-min brushing is only one component of the plaque removal

capacity of a given toothbrush. van der Weijden et al. [13] showed that longer brushing can achieve cleaning results comparable with those obtained with a professional dental prophylaxis treatment. Professional polishing of teeth reduces supragingival plaque to a level approaching 0 [14].

Most patients brush their teeth regularly but do not clean the teeth long enough to prevent new plaque accumulation. In addition to an effective toothbrush, adequate brushing time to achieve optimal level of supragingival plaque control is a prophylactic treatment goal for establishing healthy teeth. The amount of time to reach an optimum level of oral hygiene will depend on the brushing method, toothbrush used, number of teeth, periodontal condition of the teeth (elongations), and manual skill.

The purpose of the present study was to investigate the time-dependent plaque score reduction efficacy of two manual and two powered sonic toothbrushes used by a professional. The null hypotheses tested in the current study were as follows:

1. All brushes show the same time-dependent plaque score reduction capacity.
2. Time interval of brushing has no influence on plaque removal efficacy.

Materials and methods

Brushes

The Sonicare Elite e9800 professional (Philips Oral Healthcare, Snoqualmie, WA) with an operating frequency of 260 Hz was used. It was equipped with the medium (A) or the mini (B) tapered brush head (Fig. 1). The easy-start feature of the brushes, designed for the first 14 days of use with reduced bristle action, was disabled.

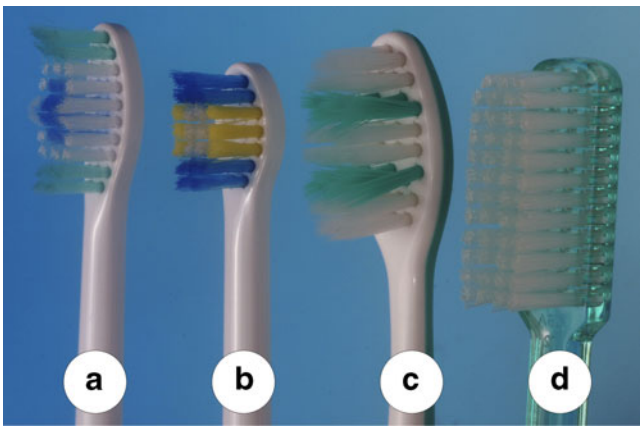

Fig. 1 Brush heads of the toothbrushes tested: **a** Sonicare Elite medium brush head. **b** Sonicare Elite mini brush head. **c** Elmex Sensitive extra soft. **d** ADA toothbrush medium

The Elmex Sensitive toothbrush extra soft (GABA, Lörrach, Germany; C; Fig. 1) is a newly developed manual toothbrush with soft bristles designed to prevent tooth hypersensitivity and recession.

The American Dental Association (ADA) 39 tuft manual toothbrush with soft texture (American Dental Association, Chicago, IL; D; Fig. 1) was used as a standard manual toothbrush. The brush head features a flat working surface.

Ethical approval

The study design was reviewed and approved by the ethics committee of the medical faculty of the University of Erlangen–Nuremberg, approval no. 3645.

Study design

Volunteers were recruited in Erlangen among students of the medical faculty. All details of the study were written in a recruitment letter to the possible participants. A convenience sample of 91 students was invited to participate in the study.

They were not admitted to the study if any of the following criteria were present: (1) less than a total of 24 evaluable teeth or less than six teeth per quadrant; (2) systemic disease affecting oral plaque accumulation or presence of gingival inflammation; (3) regular use of drugs or antibiotics; (4) orthodontic bands, other fixed appliances, or retention wires; (5) oral lesions or areas with a probing pocket depth≥5 mm; (6) an initial average Turesky-modified Quigley Hein Index (TQHI) score of <1.8 after 48 h refraining from any oral hygiene. After screening for their suitability, written consent was obtained prior to enrolment in the study. A complete medical history was obtained at screening, and subjects having any of the mentioned exclusion criteria were discontinued.

Prior to enrolment into the study, professional prophylaxis was given. The teeth were polished so that all subjects started with equally clean teeth. Before the experiment, participants refrained from brushing for 48 h.

At the second appointment, a disclosing solution (Mira-2-ton, Hager Werken, Germany) was applied to the teeth to aid in identifying plaque. TQHI plaque scores were then recorded at six sites per tooth (A.P.) [15, 16]. An overall average was then calculated. The assignment of the four brushes to a specific quadrant was randomly done using a three-sided pyramid prior to treatment (Fig. 2). Toothbrush was used as recommended by the manufacturer, and no toothpaste was used throughout the study. Next, all participants were brushed by a dentist (T.N/I.H.) in all quadrants using the randomly assigned brushes for 10, 10, 10, 15, 15, and 30 s; after each brushing period, the remaining plaque was scored by the blinded investigator

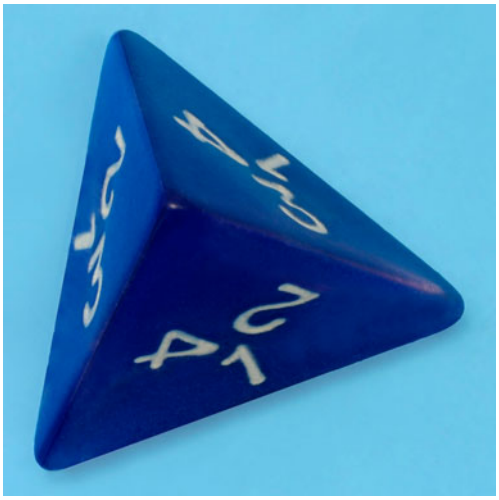

Fig. 2 Three-sided pyramid used for randomization

(A.P.). Thus, the resulting quadrant brushing endpoints were 10, 20, 30, 45, 60 and 90 s. All brushing periods were in succession in each quadrant, and all four brushes were assessed in each volunteer.

Prior to the study, the brushing dentists were trained in the correct use of each brush by carrying out five complete patient sessions with the same protocol with comparison of the brushing results between the brushers. These training sessions were in addition used to standardize and calibrate the plaque investigator. During standardization, the investigator (A.P.) judged the plaque up to three times without knowing if a brushing session was performed or not. The training was continued until an intraexaminer reliability of 0.9 (Cohens kappa of 0.9=almost perfect agreement) was reached. Each brushing dentist treated 45 participants.

This was a single-blind study design with the plaque-scoring investigator blinded to the treatment assignment. The professional brushing dentists and the study volunteers were, by necessity, unblinded. Records of earlier examinations were not available to the investigator at the time of plaque scoring.

Brushing technique

Both Sonicare brushes were used as follows: prior to use, the bristles of the Sonicare Brush heads were moistened with tap water. Before the power of the toothbrush was turned on, the bristles of the brush head were placed along the vestibular gum line at a slight angle. The handle was held with a light grip, the Sonicare was turned on, and the bristles were gently moved in a slight back and forth motion so the longer bristles could reach the interproximal spaces. Only light pressure was applied, as per Sonicare user instruction. After half of the brushing interval, the brushing action was stopped, the brush was moved to the palatinal/lingual surfaces, and the brushing procedure was started again for the remaining half of the brushing interval. After each brushing interval, the toothbrush was rinsed with water and stored for further use.

The manual toothbrushes were used as follows: prior to use, the bristles of the toothbrush were moistened with water. The toothbrush was placed at a 45° angle against the vestibular gum line. The brush was gently moved in small tooth-wide circular movements with light pressure. After half of the brushing interval, the brushing action was stopped, the toothbrush was moved to the palatinal/lingual surfaces, and the brushing procedure was started again for the remaining half of the brushing interval. After each brushing interval, the toothbrush was rinsed with water and stored for further use.

Statistical analysis

All variables were summarized by descriptive statistics. Standard subject baseline characteristics (e.g., age, sex, race, and origin) were summarized for all subjects enrolled. The primary efficacy outcome variable for this study was the mean percent plaque score reduction from baseline. Means and 95% confidence intervals were calculated for the four treatment arms and for all brushing time intervals. The study was implemented as a Neyman–Pearson frequentist error-based design. The sample size was calculated assuming a difference of 6.5% for percent plaque reduction with a standard deviation of 14, a split-mouth design, and a 0.05 two-sided significance level. A sample size of 40 subjects was needed for approximately 0.8 power to detect a significant difference between two brushes. For the four treatment groups using the same assumptions, a sample size of 80 was calculated.

The primary analysis was carried out on an intent-to-treat (ITT) basis, including all randomly assigned quadrants of all subjects with a baseline and endpoint evaluation for all treatment groups. The analysis of safety included all subjects.

The analysis was carried out using percent change in mean plaque score as the response variable. The response variable was modeled in terms of a random subject effect, a section effect as well as the treatment effect of interest. The section referred to quadrant section. The primary analysis was done on an ITT basis including all subjects with baseline and postbaseline observations. Mean plaque score was treated as a continuous variable.

The analysis of the statistical models including parameter and confidence interval estimation was accomplished using a linear mixed effects model (mixed model, Bonferroni correction for multiple testing, SPSS 16.0.1). Comparisons between treatments and time intervals were performed using the appropriate F test at the 10-, 20-, 30-, 45-, 60-, and 90-s

quadrant brushing endpoints. These analyses were carried out for seven regions of the mouth: overall, anterior, posterior, vestibular/oral, interproximal, anterior interproximal, and posterior interproximal.

In addition, a secondary efficacy variable "mean number of surfaces with TQHI=0" was considered. For assessing cleaning efficacy, the per subject number of tooth surfaces that received a 0 score was determined for each test product and time interval. Then, for each time interval, the differences among brushes were examined statistically using the nonparametric Mann–Whitney *U* test. Statistical significance was set at $p<0.05$. The software package SPSS 16.0.1 (SPSS Inc., Chicago, IL) was used for statistical analyses.

Results

Results are summarized in Tables 1, 2, 3, and 4 and illustrated in Figs. 3 and 4. Ninety-one subjects signed up for the study. One subject was excluded, resulting in a sample size of 90 subjects at baseline. The sample consisted of 50 men and 40 women and had a mean age of 25.7 years (range 21–37 years), a tooth count of 27.9 (range 24–32), and a per quadrant tooth count of 6.9 (range 6–8). Differences among mean per quadrant TQHI scores at baseline were not statistically significant.

After 10 s of toothbrushing, the powered toothbrushes and the ADA manual toothbrush had reduced plaque scores by >50%, whereas the Elmex Sensitive toothbrush achieved 42%. The difference among products was statistically significant (*F* test; $p<0.001$). After 30 s, the Elmex Sensitive continued to show the smallest plaque score reduction (64%), followed by the ADA toothbrush (79%), the Sonicare with the mini brush head (84%), and the Sonicare with the medium-sized brush head (85%). After 45 s of toothbrushing, a modest increase in plaque score reduction was observed for all test products. The Sonicare products achieved 90% reduction. In comparison, plaque score reductions for the manual toothbrushes (ADA 84% and Elmex Sensitive 71%) were significantly smaller ($p<0.001$).

After another 45 s of brushing (90 s total), the two Sonicare brushes removed up to 50% of the residual plaque (absolute 5%); the manual toothbrushes removed 33% (Elmex) and 40% (ADA) of the residual plaque (absolute Elmex 10% and ADA 6%). Between the two Sonicare brushes, the medium and mini brush heads, no significant differences in plaque score reduction were found at any brushing time interval (*F* test, $p>0.05$, Table 2).

For all four toothbrushes, there was a significant overall improvement in mean TQHI scores, as the brushing time increased from 10 to 90 s per quadrant (*F* test, $p<0.001$, Fig. 3). Table 3 shows the mean TQHI score reductions in different locations. At all brushing time intervals, significant differences in plaque score reductions between anterior and posterior teeth and between vestibular/lingual and interproximal sites (*F* test, $p<0.05$) could be observed for all toothbrushes investigated.

Regarding the time-dependent efficacy of plaque removal, it was shown that with time, the TQHI 0 score (=number of clean surfaces) increased differently for the brushes tested. The number of additional cleaned tooth surfaces (=efficacy) decreased significantly with time for all brushes tested.

A time-dependent distribution of the number of surfaces that received a TQHI score of 0 is presented in Fig. 4. After 10 s of toothbrushing, the Sonicare and ADA toothbrushes received 0 scores on 8 and 7 of a possible 28 surfaces, respectively. Only four surfaces, on average, received 0 scores when the Elmex Sensitive toothbrush was used. Sixteen completely clean surfaces were achieved after using the Sonicare, ADA, and Elmex Sensitive products for 20, 30, and 90 s, respectively.

Twenty-two sites of in average 27.9 judged tooth surfaces were cleaned by both Sonicare toothbrushes after 45 s of brushing in contrast to the ADA toothbrush with in average 18.5 clean surfaces and the Elmex Sensitive brush with 12 clean surfaces.

After 90 s of brushing, the Sonicare brushes cleaned with 24.5 surfaces significantly more than the ADA toothbrush with 22 ($p=0.03$) and the Elmex Sensitive with 16 ($p=0.01$) tooth surfaces.

At baseline, the most frequently assigned TQHI score in the posterior proximal region was a "2" (Table 4). With increasing brushing time, a shift to lower TQHI scores (1, 0) was evident. The transition to lower scores occurred faster for the Sonicare and ADA products than for the Elmex Sensitive.

Table 1 Nonadjusted mean baseline TQHI and SD per quadrant

	N	Mean	SD
Quadrant 1	90	2.65	0.50
Quadrant 2	90	2.51	0.50
Quadrant 3	90	2.65	0.62
Quadrant 4	90	2.61	0.60

Discussion

The main null hypothesis that all brushes show the same time-dependent plaque removal capacity was rejected. Our results showed significant differences between the Elmex Sensitive toothbrush and the powered toothbrushes at all brushing times. From 20- to 90-s brushing, the powered

Table 2 Estimated TQHI means, standard error, and 95% confidence interval

Time	Brush	*N*	Mean	Standard error	95% Confidence interval	
					Lower bound	Upper bound
BL	Sonicare medium	90	2.61	0.00	2.61	2.61
	Sonicare mini	90	2.61	0.00	2.61	2.61
	Elmex Sensitive	90	2.61	0.00	2.61	2.61
	ADA brush	90	2.61	0.00	2.61	2.61
10 s	Sonicare medium	90	1.19[a]	0.13	1.17	1.19
	Sonicare mini	90	1.16[a]	0.13	1.16	1.16
	Elmex Sensitive	90	1.68	0.13	1.68	1.69
	ADA brush	90	1.21[a]	0.13	1.22	1.22
20 s	Sonicare medium	90	0.64[a]	0.06	0.50	0.79
	Sonicare mini	90	0.64[a]	0.06	0.49	0.79
	Elmex Sensitive	90	1.24	0.06	1.09	1.40
	ADA brush	90	0.77[b]	0.06	0.61	0.94
30 s	Sonicare medium	90	0.42[a]	0.08	0.07	0.76
	Sonicare mini	90	0.39[a]	0.08	0.05	0.74
	Elmex Sensitive	90	0.95	0.08	0.60	1.31
	ADA brush	90	0.56[b]	0.08	0.21	0.92
45 s	Sonicare medium	90	0.35[a]	0.09	0.28	0.46
	Sonicare mini	90	0.26[a]	0.14	0.26	0.26
	Elmex Sensitive	90	0.77	0.14	0.77	0.77
	ADA brush	90	0.42[b]	0.14	0.42	0.42
60 s	Sonicare medium	90	0.20[a]	0.03	0.14	0.26
	Sonicare mini	90	0.18[a]	0.03	0.13	0.24
	Elmex Sensitive	90	0.64	0.03	0.59	0.70
	ADA brush	90	0.32[a]	0.03	0.26	0.38
90 s	Sonicare medium	90	0.15[a]	0.21	0	0.56
	Sonicare mini	90	0.13[a]	0.21	0	0.54
	Elmex Sensitive	90	0.52	0.21	0.11	0.93
	ADA brush	90	0.25[b]	0.21	0	0.66

Letters (a, b) note significant differences between brushes within the same time interval (F test, $p<0.05$)

Between time intervals, a significant difference could be found for all brushes tested (F test, $p<0.01$)

Sonicare brushes reduced the plaque score better than both manual toothbrushes.

The second null hypothesis that the time interval of brushing had no influence on the plaque removal could be rejected for all toothbrushes tested, with the recognition that brushing times greater than 60 s had limited additional cleaning effects with exception for the Elmex Sensitive manual toothbrush.

This study was carried out to investigate the influence of brushing time on plaque score reduction for different types of manual and powered toothbrushes. The design consisted of 48 h of plaque accumulation after which the participants were professionally brushed. This design facilitated the exclusion of patient related factors such as brushing technique, dexterity, motivation, or handedness.

The study design also eliminated the Hawthorne and Novelty effect that can appear when study participants use new oral hygiene devices at home [17, 18]. The Hawthorne effect is a form of reactivity whereby subjects improve an aspect of their behavior being experimentally measured simply in response to the fact that they are being studied, not in response to any particular experimental manipulation [19, 20]. Due to the professional brushing design in this study, these effects could be excluded. This contributed to a high external validity of the present study results.

The study was conducted as a single-blind, split-mouth, professional brushing study. The professional brushing design had two disadvantages. First, professional brushing does not simulate results seen with self-brushing. Second, the dentists, who were assigned to brushing the subjects' teeth, were aware of the product they used and of the amount of residual plaque. This may have influenced the results because the dentists could focus their brushing on the removal of the disclosed plaque. However, due to calibration, the dentists focused primarily on the correct brushing time and brushing technique with each brush tested. It is therefore unlikely that bias was introduced by the dentists who were assigned to toothbrushing.

Table 3 Adjusted TQHI score reductions (in percentages with 95% confidence interval) for different locations: anterior=front teeth, posterior=posterior teeth, interproximal=all interproximal sites, vest./oral=all vestibular and oral sites, anterior interproximal=all anterior interproximal sites, and posterior interproximal=all posterior interproximal sites

Brush	Time	*N*	Anterior		Posterior		Interproximal		Vest./oral		Anterior interproximal		Posterior Interproximal	
			Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI
Sonicare medium	10 s	90	61.74	4.10	52.91[a]	3.35	53.48[a]	3.15	65.55[b]	3.64	58.56	3.90	49.08[a]	3.42
	20 s	90	80.18	3.16	73.25[a]	3.12	74.04[a]	2.76	82.12[b]	2.63	77.83	3.27	70.82[a]	3.32
	30 s	90	87.52	2.47	83.07	2.75	83.27	2.33	89.24[b]	1.97	85.64	2.70	81.46[a]	2.93
	45 s	90	91.74	1.97	88.77	2.15	88.69	1.81	93.23[b]	1.54	89.99	2.19	87.77	2.33
	60 s	90	94.01	1.74	92.17	1.68	91.87	1.47	95.62[b]	1.13	92.76	1.93	91.23	1.92
	90 s	90	95.77	1.50	94.30	1.46	94.15	1.25	96.75	0.99	94.91	1.69	93.65	1.67
Sonicare mini	10 s	90	60.57	3.72	51.34[a]	3.58	51.84[a]	3.26	63.20[b]	3.56	57.14	3.81	47.76[a]	3.57
	20 s	90	79.27	2.92	71.91[a]	3.31	72.20[a]	2.93	81.65[b]	2.80	76.80	3.21	68.73[a]	3.41
	30 s	90	87.41	2.34	82.69	2.65	82.39	2.50	90.02[b]	2.15	85.17	2.65	80.37[a]	2.87
	45 s	90	92.12[b]	1.94	88.28	2.12	88.35	2.03	93.60[b]	1.61	90.74	2.07	86.59	2.34
	60 s	90	94.29	1.69	91.53	1.63	91.62	1.61	95.24[b]	1.35	93.33	1.76	90.39	1.79
	90 s	90	96.26	1.16	93.77	1.27	94.01	1.16	96.79	1.03	95.68	1.25	92.79	1.45
Elmex Sensitive	10 s	90	42.62[b]	3.79	29.59[a]	2.86	31.08[a]	2.88	46.86[b]	3.71	37.81	3.36	24.99[a]	3.04
	20 s	90	60.14[b]	3.69	46.57[a]	3.15	48.05[a]	3.07	64.48[b]	3.45	55.83	3.54	41.11[a]	3.37
	30 s	90	70.86[b]	3.24	58.26[a]	3.18	59.57[a]	2.99	74.47[b]	3.08	67.10	3.38	53.09[a]	3.50
	45 s	90	77.31[b]	2.91	65.62[a]	3.16	66.82[a]	2.89	80.64[b]	2.65	73.92	3.18	60.82[a]	3.55
	60 s	90	81.63[b]	2.67	70.89[a]	3.01	72.19[a]	2.77	84.30[b]	2.34	78.82	3.00	66.63[a]	3.40
	90 s	90	85.17[b]	2.31	76.29[a]	2.79	77.22	2.55	87.63[b]	1.99	82.97	2.60	72.40[a]	3.30
ADA brush	10 s	90	57.01[b]	3.77	50.48[a]	3.60	48.37[a]	3.33	66.13[b]	3.75	52.59	3.64	44.65[a]	3.75
	20 s	90	74.23[b]	3.42	67.31[a]	3.32	66.28[a]	3.23	81.49[b]	3.03	70.69	3.37	62.30[a]	3.73
	30 s	90	81.56	3.10	76.31	3.00	75.50[a]	2.88	87.67[b]	2.51	78.97	3.00	72.21[a]	3.38
	45 s	90	86.69[b]	2.66	82.11	2.69	81.53[a]	2.53	91.09[b]	2.13	84.63	2.63	78.95[a]	3.07
	60 s	90	89.85	2.34	86.41	2.37	85.92	2.21	93.24[b]	1.82	88.38	2.19	83.94[a]	2.76
	90 s	90	92.24	2.08	89.43	2.04	89.02	1.95	95.02[b]	1.53	91.15	1.85	87.36[a]	2.44

Letters (a: lower than overall, b: higher than overall) mark significant differences within the same time interval (F test, $p<0.05$)

We used the disclosing solution only once, but prior experiments could show that the disclosing solution we used was able to completely penetrate the dental plaque at baseline. This solution had a dark blue contrast color, and this might be the reason for the good plaque removal capacity of most of the brushes tested.

The results indicated a strong link between brushing time and cleaning efficacy. The relationship was obvious for all test products; however, differences existed between powered and manual toothbrushes. For example, using the manual toothbrushes for 2 min (i.e., 30 s per quadrant) did not sufficiently reduce plaque scores on proximal surfaces of posterior teeth. This observation is in agreement with previous reports [21, 22].

It should be emphasized that the test group consisted of young students. In this age group, the interproximal areas have abundant gingival papillae and are relatively easy to clean. The major problems in plaque removal seem to be these interproximal spaces. Therefore, in a toothbrush comparison study, the plaque index used should adequately record plaque in the interproximal area. The Turesky-modified Quigley and Hein Index used in the present study is well suited for recording interproximal plaque due to its site-related plaque scoring.

Several important aspects concerning the time dependence of plaque removal can be found in the published literature. van der Weijden et al. [22] reported a similar experiment showing that time-related plaque removal differed significantly between manual toothbrushes and powered toothbrushes. They recommended 2 min of brushing as a suitable time interval for dental health education of children. The present study confirmed differences in the efficacy of manual versus powered toothbrushes. It also emphasized that a 2-min brushing period is insufficient to remove plaque completely. In particular, using the Elmex Sensitive manual toothbrush resulted in

Table 4 Mean number of sites per quadrant for the different TQHI scores in the posterior proximal region (maximum number of sites=20 with wisdom teeth)

Time	Brush	*N*	TQHI=0 Mean	TQHI=1 Mean	TQHI=2 Mean	TQHI=3 Mean	TQHI=4 Mean	TQHI=5 Mean
BL	Sonicare medium	90	0.66	0.96	7.82	3.08	2.28	1.28
	Sonicare mini	90	0.44	1.00	7.02	3.34	2.66	1.56
	Elmex Sensitive	90	0.52	0.78	7.92	2.96	2.08	1.68
	ADA brush	90	0.54	0.86	7.56	3.42	2.16	1.32
10 s	Sonicare medium	90	4.82	3.46	6.14	0.94	0.48	0.26
	Sonicare mini	90	4.44	3.64	5.64	1.12	0.78	0.42
	Elmex Sensitive	90	2.08*	2.14*	7.92*	1.98*	1.08*	0.74*
	ADA brush	90	4.10	3.44	6.38	1.00	0.54	0.38
20 s	Sonicare medium	90	8.58	3.26	3.52	0.52	0.18	0.04
	Sonicare mini	90	7.86	3.84	3.32	0.46	0.38	0.16
	Elmex Sensitive	90	3.56*	3.22	6.72*	1.42*	0.66*	0.36*
	ADA brush	90	6.88*	3.30	4.78*	0.48	0.26	0.14
30 s	Sonicare medium	90	10.98	2.52	2.20	0.28	0.12	0.00
	Sonicare mini	90	10.44	3.06	1.98	0.32	0.18	0.08
	Elmex Sensitive	90	5.04*	3.72*	5.62*	1.00*	0.32	0.24*
	ADA brush	90	8.78*	3.06	3.40*	0.40	0.14	0.06
45 s	Sonicare medium	90	12.56	1.86	1.42	0.22	0.04	0.00
	Sonicare mini	90	11.96	2.44	1.26	0.26	0.08	0.02
	Elmex Sensitive	90	6.44*	3.50*	4.92*	0.72*	0.18	0.18*
	ADA brush	90	10.16	2.88*	2.40*	0.28	0.08	0.04
60 s	Sonicare medium	90	13.38	1.54	1.08	0.06	0.04	0.00
	Sonicare mini	90	13.06	1.88	0.82	0.24	0.04	0.00
	Elmex Sensitive	90	7.38*	3.66*	4.08*	0.54*	0.16	0.12*
	ADA brush	90	11.4	2.30*	1.92*	0.18	0.04	0.02
90 s	Sonicare medium	90	14.12	1.10	0.84	0.04	0.00	0.00
	Sonicare mini	90	13.80	1.40	0.62	0.22	0.02	0.00
	Elmex Sensitive	90	8.44*	3.60*	3.40*	0.34*	0.12*	0.04*
	ADA brush	90	12.26*	1.92*	1.54*	0.10	0.04	0.00

Significant differences within the same time interval are marked with an asterisk (*Mann–Whitney *U* test, $p<0.05$)

incomplete plaque removal on the hard-to-reach proximal surfaces of posterior teeth.

The results for the power-driven Sonicare toothbrushes in the present study (85% reduction) were comparable with those found by van der Weijden et al. [22] for the Braun Plak Control (85%) and the Interplaque (83%) power toothbrushes after the 2-min whole mouth brushing time. The values for the manual toothbrushes in the present study and in the study of van der Weijden et al. ranged between 66% and 79%. The reason for this wide variation could be the different sizes of the brush heads, the stiffness of the bristles themselves, and the different number of bristles within the toothbrushes tested. In addition, the manual mode of action may be less standardized than that of power-driven toothbrushes. As concluded by van der Weijden et al. [22], all brushes can reach the same stage of cleanliness if enough time is given.

In another time-dependent study, van der Weijden et al. [13] showed clearly that an extension of brushing time up to 10 min can achieve nearly complete plaque removal and produces results comparable to a professional cleaning session carried out by a dental hygienist.

The question that remains after this study is: Which level of plaque removal should be clinically reached within one session of oral hygiene? Looking at the literature, there are no recommendations with a clear scientific background such as prevention of caries and gingivitis. Is 80% plaque removal enough or is it better to remove 100% of plaque especially in the posterior proximal areas? With increasing brushing time, the risk for adverse effects such as recessions and dentin sensitivity may increase.

The link between bristle stiffness, gingival trauma, and plaque removal efficacy was investigated recently [23–25]. It was shown that soft brushes produce less gingival abrasion but are less effective in plaque removal.

Our results showed that with exception of the Elmex Sensitive toothbrush, all brushes were able to clean 80% of all tooth surfaces to a TQHI value of 0 after 45-s brushing per quadrant (equivalent to 3 min for the whole mouth; Table 4). The remaining 20% of surfaces with plaque was

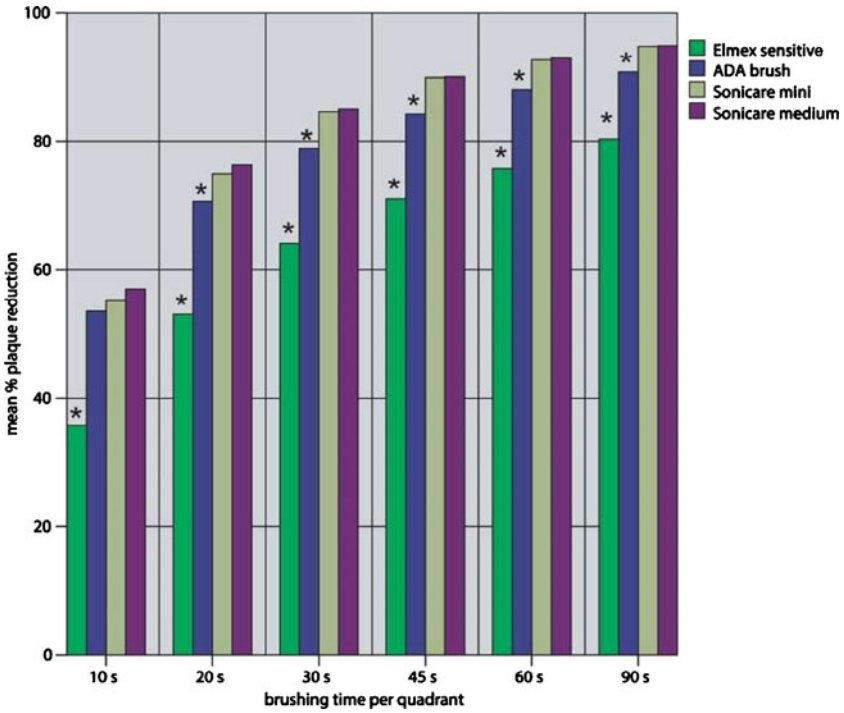

Fig. 3 Bar diagram of the adjusted mean overall plaque score reductions (in percentages) for the different brushes and brushing intervals. *Asterisks* mark significant differences between the toothbrushes within the time intervals (n=90, F test, p<0.05)

mainly localized on the proximal tooth sites. An inordinate amount of time was required to clean these surfaces to a 0-plaque level.

Considering these results, which brushing time should be recommended? The benefit of several short brushing sessions (<1 min) is the frequent delivery of fluoride to the tooth surfaces. A benefit of fewer but longer (>2 min) brushing sessions might be the thorough removal of plaque even in the posterior interproximal areas [26, 27]. The

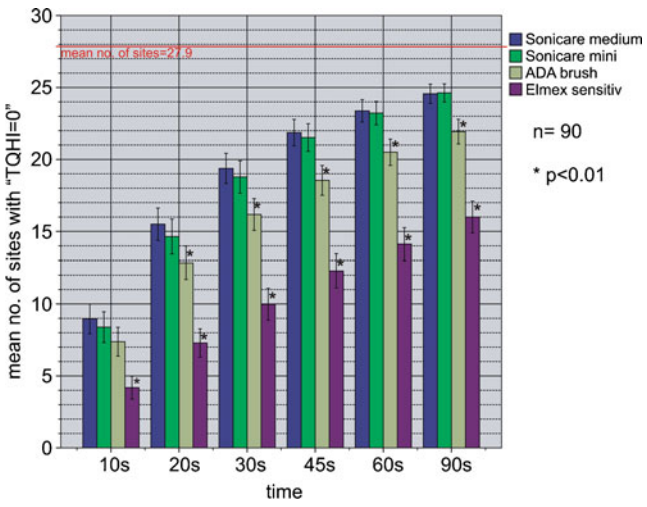

Fig. 4 Bar diagrams of the mean time-dependent TQHI 0 scores [no.] for the different brushes and brushing times (n=90). The lower efficacy of the Elmex Sensitive toothbrush is clearly visible. Over time, the number of additionally cleaned surfaces decreased for all brushes. The *red line* indicates the mean number of surfaces judged

results of this study do not clarify which length of time is clinically preferable. Patient-related risks such as caries, gingivitis, periodontitis, and life conditions may require individual oral hygiene demands. Brushing times longer than 3 min may increase the risk for gingival recessions and cervical abrasions.

The role of dental biofilm accumulation in the initiation, progression, and control of caries is well established [28] and demonstrates that evaluation of oral hygiene habits alone may be of limited value. Moreover, reports of toothbrushing habits are subject to response bias [29] and give no indication of the effectiveness of biofilm removal [30]. Santos et al. [31] showed that the frequency of toothbrushing had no influence on the amount of biofilm persisting on tooth surfaces in children. Considering these data and the current results, it can be concluded that frequent toothbrushing for short times (<1 min) may be less effective in biofilm removal than a single brushing session of more than 2 min. The plaque-removing efficacy after 40 s of brushing (10 s per quadrant) was around 50% for the toothbrushes tested. After 40 s, most plaque was removed on buccal and lingual sites, whereas on proximal surfaces, substantial residual plaque was detected.

The subjects in the present study started with an oral prophylaxis session and abstained then from oral hygiene for 48 h prior to the experimental appointment. Typically, 24 h (range 12–48 h) of oral hygiene abstinence are used to test the efficacy of toothbrushes [32–35]. After 48 h of plaque accumulation, a solid plaque layer can develop with a thickness of about 30–50 μm [36–38]. This might be a

reason for the worse results of the Elmex Sensitive toothbrush with very soft bristles.

Whether a dynamic sonic action as described by Parini et al. [39] could support the plaque (or biofilm) removal of the two Sonicare brushes was not an objective of the present study, but the professional brushing required an opened mouth during brushing. Therefore, this effect could be excluded as a reason for the good performance of these two power brushes.

Various studies have reported the average time spent on toothbrushing to be between 50 s and 70 s [40–45]. Nakashima et al. [46] found a significant correlation between advanced state of periodontal disease and a decrease in daily toothbrushing time. The average brushing time in this study of about 1 min corresponds to 15 s of quadrant brushing. In the current study, after 20 s of brushing, the Sonicare was able to clean 15 of the 28 tooth surfaces, the ADA brush could clean 13, and the Elmex Sensitive only seven under optimal study conditions with professionally applied brushing.

Comparing the two brush heads of the Sonicare, it was surprising that they did not show any differences in plaque removal despite the fact that the mini brush head was only two thirds in size of the medium brush head. The equation: brush size per brushing area=efficacy, which should be much better for the medium brush head, does not seem correct in this setting. Results showed no differences between the two brush heads even in the posterior interproximal areas.

The results of this study indicate that both Sonicare brushes and the ADA toothbrush removed significantly more plaque than the Elmex Sensitive manual toothbrush. Furthermore, we found statistically significant differences between the powered Sonicare brushes and the ADA toothbrush. Due to the low absolute differences in plaque score reduction (5–7%), this difference should have no clinical relevance. Individual brushing time should be more considered in the oral hygiene demands than the choice of toothbrush.

Conflict of interest The authors declare that there are no conflicts of interest in this study.

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