Received: 17 January 2019 | Revised: 26 April 2019 | Accepted: 29 April 2019

DOI: 10.1111/jcpe.13126

Journal of Clinical Periodontology WILEY

Long-term impact of powered toothbrush on oral health: 11-year cohort study

Vinay Pitchika[1] | Christiane Pink[1] | Henry Völzke[2] | Alexander Welk[1] | Thomas Kocher[1] | Birte Holtfreter[1]

[1]Department of Restorative Dentistry, Periodontology, Endodontology and Preventive and Pediatric Dentistry, University Medicine Greifswald, Greifswald, Germany

[2]Institute of Community Medicine, University Medicine Greifswald, Greifswald, Germany

Correspondence
Vinay Pitchika, Unit of Periodontology, Department of Restorative Dentistry, Periodontology, and Endodontology and Preventive and Pediatric Dentistry, University Medicine Greifswald, Fleischmannstr. 42, Greifswald 17475, Germany.
Email: pitchikav@uni-greifswald.de

Funding information
The SHIP cohort study is part of the Community Medicine Research Net (http://www.medizin.uni-greifswald.de/cm) of the University of Greifswald, Germany, which is funded by the German Federal Ministry of Education and Research (BMBF, grant no. 01ZZ96030, 01ZZ0701); the Ministry for Cultural Affairs and the Ministry for Social Affairs of the Federal State of Mecklenburg-West Pomerania (SHIP; http://www.medizin.uni-greifswald.de/cm). Vi.P was supported by funding provided by Procter and Gamble Co. towards personnel costs.

Abstract

Aims: This study aimed to assess 11-year longitudinal effects of powered toothbrush on periodontal health, caries and tooth loss in an adult population.

Materials and Methods: Participants of Study of Health in Pomerania (SHIP) cohort with dental examinations and interview data at SHIP-1, SHIP-2 or SHIP-3 examinations were included. Mixed-effects linear regression models were constructed between the exposure (manual versus powered toothbrush) and outcome variables (periodontal status using mean probing depth (PD) and mean clinical attachment loss (CAL), caries status using DMFS and DFS scores, and tooth loss), adjusting for potential baseline covariates.

Results: Final baseline (SHIP-1) study sample comprised of 2,819 participants. Powered toothbrush users increased from 18.3% (SHIP-1) to 36.9% (SHIP-3); were younger; had significantly less mean PD [β: −0.09 (95% CI: −0.16; −0.02)] and mean CAL [β: −0.19 (95% CI: −0.32; −0.07)] progressions; and had 17.7% less DMFS progression and 19.5% more teeth retained than the manual toothbrushers.

Conclusions: In the long-term, powered toothbrush seems to be effective in reducing mean PD and mean CAL progressions, besides increasing the number of teeth retained.

KEYWORDS
caries, gingivitis, oral hygiene, periodontitis, tooth loss, toothbrush

1 | INTRODUCTION

Periodontitis and caries are the most commonly occurring dental diseases worldwide (Marcenes et al., 2013) and account for about 60% of tooth loss (Glockmann, Panzner, Huhn, Sigusch, & Glockmann, 2011). The main aetiology for both diseases is accumulation of bacterial plaque on tooth surfaces (Löe, Theilade, & Jensen, 1965; Marsh & Nyvad, 2008; Newman, 1986; Theilade, Wright, Jensen, & Löe, 1966). It has been well established that the cornerstone for prevention of periodontitis and caries is through supragingival plaque control and fluoride usage, respectively. Although personal oral hygiene methods such as toothbrushing can prevent biofilm accumulation and gingivitis (Tonetti et al., 2015), it has to be noted that proper brushing skills are vital to achieve this. Effective brushing is linked to a number of influencing factors. Usually, brushing skills are acquired through parents, and it takes time to actually master them perfectly (Unkel, Fenton, Hobbs, &

Frere, 1995). If an improper technique is detected at a later point of life, it is difficult to modify it (Alcouffe, 1988). Furthermore, the fine motor skills might degrade with ageing and could impair maintaining proper oral hygiene in elderly people (Felder, Reveal, Lemon, & Brown, 1994; Hitz Lindenmüller & Lambrecht, 2011).

Powered toothbrushes (PTB) are advertised as having better biofilm removal capacity than manual toothbrushes (Verma & Bhat, 2004), which was attested by in vitro studies (Hunt, 2002; Schmidt, Zaugg, Weiger, & Walter, 2013). Under clinical settings, they were effective in removing plaque (Rosema, Slot, van Palenstein Helderman, Wiggelinkhuizen, & Van der Weijden, 2016) and tackling gingivitis (Yaacob et al., 2014). However, studies assessing the long-term effectiveness of PTBs on slowing initiation or progression of periodontitis are limited (Dentino et al., 2002; Dörfer, Staehle, & Wolff, 2016; Moritis, Jenkins, Hefti, Schmitt, & McGrady, 2008; Schmalz et al., 2017; Wilson, Levine, Dequincey, & Killoy, 1993); these studies mainly focussed on plaque, calculus or gingivitis. In addition to having employed small sample sizes (maximum of 180 subjects) and short follow-up times ranging from few weeks to a maximum of 3 years, these studies did not include tooth loss as an outcome, which is of paramount importance for patients. A recently published Cochrane review concluded "Powered toothbrushes reduce plaque and gingivitis more than manual toothbrushing in the short and long term. The clinical importance of these findings remains unclear" (Yaacob et al., 2014). Similarly, studies associating PTB usage with caries are limited (Papas et al., 2007; Willershausen & Watermann, 2001). Furthermore, prospective population-based cohort studies assessing the effectiveness of PTBs are unavailable as of now.

Therefore, in this study, we aimed to estimate the longitudinal effects of PTB usage on (a) periodontal health in terms of mean probing depths (PD) and mean clinical attachment loss (CAL), (b) coronal caries experience using decayed, missing and filled surfaces (DMFS) and decayed and filled surfaces (DFS) scores and (c) number of teeth present using 11-year data from the representative population-based cohort, Study of Health in Pomerania (SHIP).

Clinical Relevance

Scientific rationale for the study: Powered toothbrushes have been in the market for quite a long time and, their effectiveness has been shown in a number of clinical or observational studies. However, long-term effectiveness of powered toothbrushes in a population-based study has never been performed.

Principal findings: Powered toothbrush users had reduced progression of probing depths and clinical attachment loss. On the long run, this has been translated into retaining more number of teeth.

Practical implications: Powered toothbrush seems to be an effective (preventive) tool in maintaining oral hygiene. Therefore, dental practitioners might recommend its usage.

2 | MATERIAL AND METHODS

2.1 | Study population

The study sample was obtained from the ongoing prospective cohort study (SHIP), which adapted a two-stage cluster design (Keil et al., 1988). The cohort was initiated in 1997–2001 (SHIP-0) and was followed up after 5 (SHIP-1), 11 (SHIP-2) and 16 years (SHIP-3) (Völzke et al., 2011). Since information about the PTB usage was not available in SHIP-0, we considered the data from SHIP-1 as baseline examination and SHIP-2 and SHIP-3 as the 6- and 11-year follow-ups, respectively. Participants with information on exposure, outcomes and covariates within at least one examination were included in the study. The study started with a sample of 3,300 participants at baseline. The flow of study participants in the study is shown in Figure 1. The study protocol was approved a priori by the ethics committee of the University of Greifswald, and written informed consent for the interviews, clinical and dental examinations was obtained from all the participants.

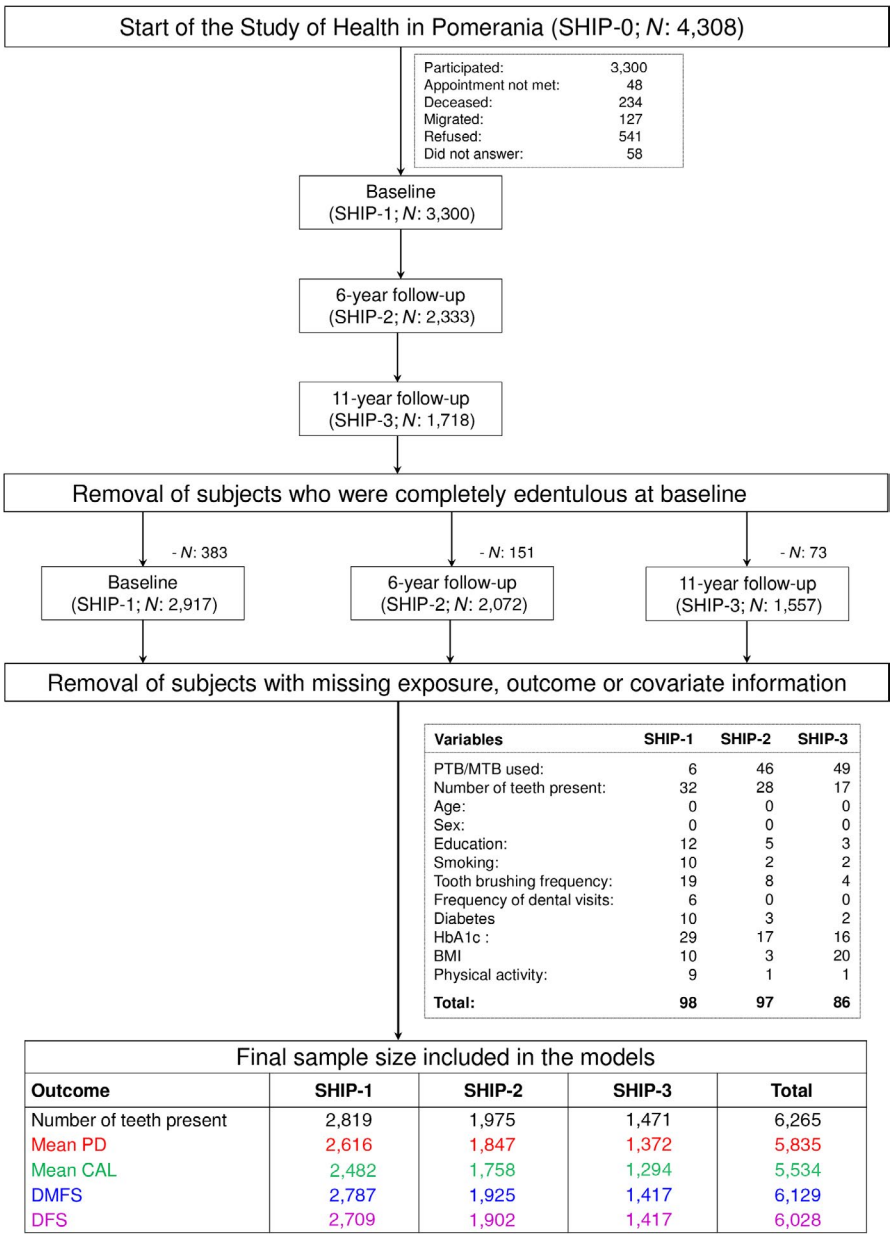
2.2 | Dental examination

Dental examinations were performed by calibrated and licensed dentists. Initial training was conducted by a periodontist (TK). The intra-rater and inter-rater reliability values are shown in Table S1. Identical recording protocols were used for all time points. From the dental examination, number of teeth present (full mouth), PD, CAL, DMFS score and DFS score were calculated. Detailed information on the dental examination can be found in the supplementary material.

2.3 | Interviews and medical examination

Trained and certified interviewers conducted computer-assisted personal interviews for participants during all the visits to collect information on the exposure and covariates. Participants were asked whether they used powered or manual toothbrush at each time point from SHIP-1 to SHIP-3. Based on the toothbrushing frequency, participants were categorised into irregular (<2 times/day) or regular brushers (≥2 times/day). Classification of covariates considered in the study (educational status at the start of study, smoking status, toothbrushing frequency, dental visit in the last 12 months, periodontal treatment in the last 5 years, diabetes, physical activity and Centers for Disease Control and Prevention/American Academy of Periodontology (CDC/AAP) case definition of periodontitis) are mentioned in Table 1. Body mass index (BMI) was calculated as weight in kg/(height in m)^2. At baseline (SHIP-1), known diabetic cases, defined as diagnosed cases according to self-reported physician's diagnosis or treatment with anti-diabetic drugs (Anatomical Therapeutic Chemical Classification System code A10), were recorded. Prevalent cases based on information from SHIP-0 were combined with incident cases between SHIP-0 and SHIP-1. Blood samples were drawn at non-fasting status to determine HbA1c levels using HPLC method (Bio-Rad Diamat, Munich, Germany).

FIGURE 1 Overview of the flow of study participants in the study



2.4 | Statistical analyses

All analyses were performed using Stata/SE 14.2 (StataCorp 2015, College Station, TX, USA). The following time-varying outcomes were considered: (a) mean PD, (b) mean CAL, (c) DMFS, (d) DFS and (e) number of teeth present. Continuous and categorical variables were compared using Student's *t* test and chi-square test, respectively. To assess the longitudinal effects of PTB usage on different outcomes, mixed-effects linear regression models over three time points were constructed for each outcome using the entire sample. The time variable was divided by 11, to obtain estimates that reflect the effect of PTB usage 11 years from baseline, which was the time span between SHIP-1 and SHIP-3. All covariates were selected a priori, based on the clinical knowledge. Models were constructed with subject ID and time as random intercept and slope, respectively, so that they took into effect the repeated measurements within subjects at different follow-ups, which denote the multiple levels. The advantage with mixed-effects modelling approach is that it requires complete datasets at each follow-up separately, but not across examinations. All models were adjusted for baseline (SHIP-1) covariates, such as age, sex, BMI, education, smoking, diabetic status, HbA1c values, frequency of toothbrushing and history of dental visit in the last 12 months. Physical activity was included as additional covariate in the number of teeth present models. Mean PD and CAL models were additionally adjusted for physical activity and history of periodontal treatments during the past 5 years; but the random slope was excluded as the models did not converge. Age was included in the model as a restricted cubic spline with three knots. The adjusted estimates (β), 95 confidence intervals (95% CI) and their corresponding *p*-values were calculated. After obtaining the adjusted estimates, percentage change for MTB and PTB users after 11 years of follow-up time was calculated using the formula $((\beta_{PTB}-\beta_{MTB})/\beta_{MTB})*100$ (United States

TABLE 1 Baseline characteristics (SHIP 1) for participants present in the final model

Variable	Group	Total	MTB user	PTB user	*p*-value
Sample size for SHIP 1 in model		2,819	2,304	515	–
Age (in years)	–	52.1 ± 14.4	53.4 ± 14.5	46.3 ± 12.4	**<0.001****
Sex	Male	1,353 (48.0)	1,156 (50.2)	197 (38.3)	**<0.001***
	Female	1,466 (52.0)	1,148 (49.8)	318 (61.7)	
Education	<10 years	868 (30.8)	788 (34.2)	80 (15.5)	**<0.001***
	10 years	1,408 (50.0)	1,103 (47.9)	305 (59.2)	
	>10 years	543 (19.2)	413 (17.9)	130 (25.3)	
Smoking status	Non-smoker	1,207 (42.8)	999 (43.4)	208 (40.4)	0.36*
	Former smoker	870 (30.9)	710 (30.8)	160 (31.1)	
	Occasional smoker	97 (3.4)	74 (3.2)	23 (4.4)	
	Current smoker	645 (22.9)	521 (22.6)	124 (24.1)	
Toothbrushing frequency	Irregular brushers	442 (15.7)	391 (17.0)	51 (9.9)	**<0.001***
	Regular brushers	2,377 (84.3)	1,913 (83.0)	464 (90.1)	
Dental visit in the last 12 months	No	200 (7.1)	176 (7.6)	24 (4.6)	**0.02***
	Yes	2,619 (92.9)	2,128 (92.4)	491 (95.4)	
Periodontal treatment in the last 5 years	No	2,513 (89.2)	2,076 (90.1)	437 (85.0)	**0.002***
	Yes	304 (10.8)	227 (9.9)	77 (15.0)	
Diabetes	No	2,568 (91.1)	2,090 (90.7)	478 (92.8)	0.13*
	Yes	251 (8.9)	214 (9.3)	37 (7.2)	
HbA1c (in %)	-	5.4 ± 0.8	5.4 ± 0.8	5.2 ± 0.8	**<0.001****
BMI (in kg/m^2)	-	27.8 ± 4.8	27.9 ± 4.8	27.0 ± 4.9	**<0.001****
Physical activity	<1 hr sport/week	1,784 (63.3)	1,510 (65.6)	274 (53.2)	**<0.001***
	1–2 hr sport/week	490 (17.4)	381 (16.5)	109 (21.2)	
	>2 hr sport/week	545 (19. 3)	413 (17.9)	132 (25.6)	
CDC/AAP case definition	No/mild periodontitis	1,187 (48.3)	885 (44.7)	302 (63.2)	**<0.001***
	Moderate periodontitis	877 (35.7)	740 (37.3)	137 (28.7)	
	Severe periodontitis	395 (16.0)	356 (18.0)	39 (8.1)	

Note: Data are presented as mean ± standard deviation or number (column percentages).
Abbreviations: MTB: manual toothbrush; PTB: powered toothbrush; BMI: body mass index; CDC/AAP: Centers for Disease Control and Prevention/American Academy of Periodontology.
**p*-Values were obtained using chi-square test for categorical variables. ***p*-Values were obtained using Student's t test for continuous variables.
Bold numbers indicate statistically significant effect (*p*-Value < 0.05).

Census Bureau, 2015). *p*-Values < 0.05 were considered as indicator of statistical significance.

Analyses were restricted to the following subsets: (a) regular brushers (*n* = 2,464 at SHIP-1), (b) younger subjects (25–55 years, *n* = 1,617) and (c) younger regular brushers (*n* = 1,403). After initial analyses, participants were stratified based on the CDC/AAP case definition of periodontitis to observe if the severity of periodontal disease had an influence on the association with PTB, and all models were repeated. Furthermore, sensitivity analyses were performed on the entire sample models by including subjective influence on oral hygiene, inter-dental aids usage, screening for preventive medicine and cancer or preventive dental screening (Table S5). Additionally, to avoid over-adjustment, we performed directed acyclic graphs (DAGs) for each outcome spectrum (periodontitis, caries and no. of teeth present) (Textor, Hardt, & Knüppel, 2011). DAGs for each outcome resulted in adjusting for age, sex, education, toothbrushing frequency, dental visit in the last 12 months and history of periodontal treatment within the last 5 years (Figure S1). Thereafter, models were constructed adjusting for these variables under each outcome. The recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies were applied for reporting (von Elm et al., 2014).

3 | RESULTS

3.1 | Baseline characteristics

A total of 2,819 participants with mean age of 52.1 ± 14.4 years were included in the model (Table 1). PTB users were younger (46.3 years) than the MTB users (53.4 years). PTB users fared well in education, toothbrushing frequency, dental visit in the last 12 months, diabetic

status, BMI and physical activity. PTB usage in our study had increased over time [SHIP-1: 515 (18.3%); SHIP-2: 540 (27.3%); SHIP-3: 543 (36.9%)]. Compared to MTB users, PTB users had lower mean PD, mean CAL, DMFS and DFS scores while having more teeth present (Table 2).

3.2 | Association between PTB usage and periodontal measures

After adjustment, PTB usage was significantly associated with reduced mean PD and mean CAL progression in the entire sample as well as all subsets (Table 3). "PTB usage" denotes the effect of PTB usage on dependent variable for time = 0 (baseline/SHIP-1). Time (per 11-year increase) reflects the rate of change in MTB users over 11-year follow-up (SHIP-3). Interaction denotes exposure-dependent (PTB vs. MTB) difference in the rates of change over 11-year follow-up period. For example, in the entire sample, PTB users had −0.03 mm smaller mean PD than MTB brushers at baseline. However, after 11 years, MTB users had 0.41 mm of mean PD progression, while the PTB users had 0.09 mm significantly less mean PD, that is 0.32 mm mean PD progression. This difference could also be translated as PTB users having 22% less mean PD progression over a period of 11 years (Figure 2 and Table S2). On exploring the subsets of study participants, PTB users had a significantly low mean PD progressions (estimates ranging from −0.09 to −0.11). Similarly, PTB usage was associated with low mean CAL progression in the entire sample [−0.19 (−0.32; −0.07)] as well as in all subsets (estimates ranging from −0.19 to −0.26). On stratifying the study population based on the CDC/AAP definition (Table 4 and Figure 2), PTB usage in the entire sample and regular brushers was associated with less mean PD progression among subjects with no/mild and moderate periodontitis, and less mean CAL progression in subjects with moderate periodontitis only. Subjects with severe periodontitis did not benefit from the usage of PTB.

3.3 | Association between PTB usage and caries

With respect to caries, PTB users had lower DMFS and DFS scores throughout the study period (Table 2). On further exploring the data after adjustment (Table 3), PTB users in the entire sample and in the regular brushers' subset had 1.32 surfaces (half-mouth) less DMFS progression, corresponding to 17.7% significantly less DMFS progression than the MTB users; but this association was not present among other subsets of participants. PTB usage had no influence on the DFS scores (Table 3), even after stratifying the subjects based on CDC/AAP definition (Table S3).

3.4 | Association between PTB usage and number of teeth present

PTB users also had significantly less number of teeth lost over 11-year follow-up, indirectly leading to more number of teeth present (Table 2). After adjustment, reduction in the number of teeth present was about

TABLE 2 Distribution of dental variables in participants included in the models, stratified by examination time points

		Mean ± SD			
Outcome	**Examination (*N*)**	**Total**	**MTB user**	**PTB user**	***p*-Value[a]**
Mean PD	SHIP-1 (2,616)	2.31 ± 0.71	2.34 ± 0.76	2.13 ± 0.57	**<0.001**
	SHIP-2 (1,847)	2.64 ± 0.58	2.69 ± 0:60	2.52 ± 0:51	**<0.001**
	SHIP-3 (1,372)	2.49 ± 0.59	2.55 ± 0.65	2.38 ± 0.45	**<0.001**
Mean CAL	SHIP-1 (2,482)	2.23 ± 1.72	2.38 ± 1.78	1.62 ± 1.31	**<0.001**
	SHIP-2 (1,758)	2.85 ± 1.53	3.02 ± 1.62	2.44 ± 1.20	**<0.001**
	SHIP-3 (1,294)	2.54 ± 1.45	2.76 ± 1.59	2.21 ± 1.13	**<0.001**
DMFS	SHIP-1 (2,787)	33.1 ± 16.4	34.1 ± 16.7	28.6 ± 14.3	**<0.001**
	SHIP-2 (1,925)	34.6 ± 15.8	36.0 ± 16.2	30.8 ± 14.0	**<0.001**
	SHIP-3 (1,417)	36.0 ± 15.8	38.1 ± 16.4	32.6 ± 14.3	**<0.001**
DFS	SHIP-1 (2,709)	32.5 ± 16.2	33.4 ± 16.5	28.6 ± 14.3	**<0.001**
	SHIP-2 (1,902)	34.3 ± 15.7	35.8 ± 16.2	30.7 ± 14.0	**<0.001**
	SHIP-3 (1,417)	36.0 ± 15.8	38.1 ± 16.4	32.6 ± 14.3	**<0.001**
No. of teeth present	SHIP-1 (2,819)	19.9 ± 7.5	19.2 ± 7.8	23.1 ± 5.0	**<0.001**
	SHIP-2 (1,975)	20.0 ± 7.6	18.9 ± 8.1	22.9 ± 4.9	**<0.001**
	SHIP-3 (1,471)	20.1 ± 7.6	18.5 ± 8.4	22.8 ± 5.0	**<0.001**

Note: Data are presented as mean ± standard deviation.
Abbreviations: MTB: manual toothbrush; PTB: powered toothbrush; PD: probing depth, CAL: clinical attachment loss, DMFS: decayed, missing, filled surfaces; DFS: decayed, filled surfaces.
[a]*p*-Values were obtained using Student's t test.
Bold numbers indicate statistically significant differences ($p < 0.05$). Mean values do not allow directly comparing the time course of the variables, since the three follow-ups are not identical in terms of included SHIP participants.

TABLE 3 Results from mixed-effects linear models evaluating the effects of powered toothbrush usage on rates of change in oral health parameters

		β (95% CI)			
Outcome	**Variable**	**Entire sample**	**Regular brushers**	**Younger subjects**	**Younger regular brushers**
Mean PD[a]	PTB usage	−0.03 (−0.08; 0.03)	−0.03 (−0.09; 0.03)	−0.02 (−0.09; 0.04)	−0.02 (−0.08; 0.05)
	Time (per 11-year increase)	0.41 (0.38; 0.45)	0.42 (0.38; 0.46)	0.42 (0.38; 0.47)	0.43 (0.39; 0.48)
	Interaction	**−0.09 (−0.16; −0.02)**	**−0.10 (−0.17; −0.02)**	**−0.09 (−0.17; −0.01)**	**−0.11 (−0.19; −0.02)**
Mean CAL[a]	PTB usage	0.00 (−0.11; 0.11)	−0.01 (−0.13; 0.10)	0.02 (−0.10; 0.14)	0.03 (−0.10; 0.15)
	Time (per 11-year increase)	0.93 (0.86; 0.99)	0.93 (0.85; 1.00)	0.99 (0.91; 1.07)	1.00 (0.92; 1.09)
	Interaction	**−0.19 (−0.32; −0.07)**	**−0.19 (−0.33; −0.06)**	**−0.23 (−0.38; −0.09)**	**−0.26 (−0.41; −0.11)**
DMFS[b]	PTB usage	0.06 (−0.67; 0.79)	0.07 (−0.69; 0.83)	0.11 (−0.69; 0.92)	0.26 (−0.59; 1.12)
	Time (per 11-year increase)	7.43 (6.97; 7.89)	7.51 (7.01; 8.01)	6.84 (6.26; 7.42)	6.93 (6.30; 7.56)
	Interaction	**−1.32 (−2.18; −0.45)**	**−1.32 (−2.23; −0.41)**	−0.73 (−1.71; 0.25)	−0.78 (−1.82; 0.25)
DFS[b]	PTB usage	0.41 (−0.01; 0.82)	0.37 (−0.06; 0.80)	0.35 (−0.14; 0.85)	0.36 (−0.16; 0.87)
	Time (per 11-year increase)	3.68 (3.41; 3.94)	3.60 (3.32; 3.87)	3.78 (3.44; 4.13)	3.71 (3.34; 4.08)
	Interaction	−0.40 (−0.89; 0.10)	−0.25 (−0.76; 0.26)	−0.40 (−0.99; 0.20)	−0.29 (−0.90; 0.33)
No. of teeth present[b]	PTB usage	−0.03 (−0.24; 0.18)	−0.03 (−0.25; 0.19)	−0.00 (−0.21; 0.21)	−0.05 (−0.27;0.17)
	Time (per 11-year increase)	−1.86 (−2.01; −1.72)	−1.88 (−2.03; −1.72)	−1.38 (−1.56; −1.21)	−1.39 (−1.58; −1.20)
	Interaction	**0.36 (0.11; 0.62)**	**0.39 (0.12; 0.66)**	0.01 (−0.25; 0.27)	0.04 (−0.23; 0.31)

Note: All models were adjusted for baseline covariates, such as, age, sex, education, smoking, BMI, diabetic status, HbA1c values, toothbrushing frequency and dental visits in the last 12 months. Subject ID and time were constructed as random intercept and slope, respectively. Number of teeth present models were additionally adjusted for physical activity. Mean PD and mean CAL models were additionally adjusted for physical activity and periodontal treatment within the last 5 years.

PTB usage: Effects of powered toothbrush usage on dependent variable for time = 0 (baseline/SHIP-1). Time (per 11-year increase): Rate of change for manual toothbrush user over 11-year follow-up period. Interaction: Exposure-dependent (PTB versus MTB) difference in the rates of change over 11-year follow-up period.

Abbreviations: β: beta coefficient; 95% CI: 95% confidence interval; PD: probing depth; CAL: clinical attachment loss; DMFS: decayed, missing, filled surfaces; DFS: decayed, filled surfaces.

[a]Models were performed without the inclusion of random slope.

[b]Models were performed with the inclusion of time per 11-year increase as a random slope.

Bold numbers indicate statistically significant effect (p-Value < 0.05).

20% lesser in PTB users, that is PTB users retained on average 0.36 teeth more than their counterparts. Regularly brushing PTB users retained 0.39 teeth more. On analysing the strata of study sample based on CDC/AAP definition categories, PTB users in the entire sample with no/mild periodontitis had 0.19 more teeth retained (Table S4).

4 | DISCUSSION

This study assessed the longitudinal association of PTB usage on periodontitis, caries and number of teeth present from a prospective population-based cohort. Our main findings suggest that PTB usage over a period of 11 years had an effect in reducing the progression of mean PD and mean CAL in the study participants. This protective effect translated into more retained teeth in the whole cohort over the 11-year study period. However, PTB usage did not influence caries (DFS) progression. These data circumvent the critique of the latest Cochrane review on this subject: *Empirical data on thresholds for clinically important differences in plaque and gingivitis levels would help to determine whether oral hygiene aids provide important health benefits* (Yaacob et al., 2014). Published short-term studies on PTB usage showed better plaque control and reduced gingivitis, but the present longitudinal study showed for the first time that these effects are likely to get translated into reduced progression of PD and CAL. Also, more retained teeth speak in favour of a clear tangible health benefit of PTB.

The main strength of the present study is that prospective data from a population-based cohort with a follow-up time of 11 years have been analysed. Our study had the benefit of extensive dental data in terms of surface-level periodontal measures and caries data. We identified and adjusted for commonly observed covariates such as age, sex, BMI, education, smoking, diabetic status, HbA1c values, toothbrushing frequency and history of dental visits, in addition to periodontal treatment history and physical activity in some models. Our study also had its share of limitations. It might be argued that PTB users were younger in age, with better education, and oral health awareness, in addition to having better physical activity. However, the associations observed in this study were not lost even after adjusting for all the relevant factors, although residual confounding cannot be excluded. Furthermore, when the entire sample models were additionally adjusted for subjective influence on oral hygiene, inter-dental

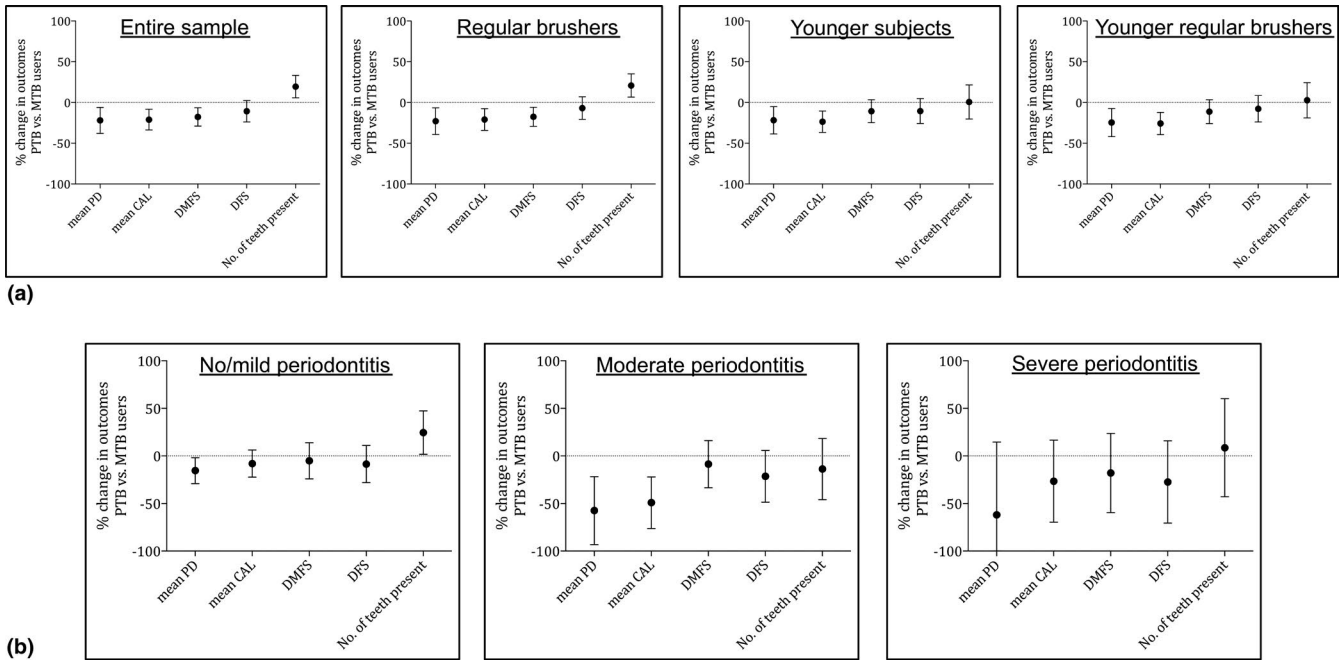


FIGURE 2 Percentage differences between the rates of change for powered toothbrush users in comparison with manual toothbrush users. (a) Percentage change for powdered toothbrush users in entire sample and different subsets (regular brushers, younger subjects and younger regular brushers) analysed. (b) Percentage change for powdered toothbrush users in entire sample stratified based on the CDC/AAP definition of periodontitis (No/mild, moderate and severe)

aids usage, screening for preventive medicine and cancer or preventive dental screening, none of these variables failed to elicit significant effect on the estimates. To avoid over-adjustment, based on the information from DAGs, models were adjusted only for age, sex, education, toothbrushing frequency, dental visits in the last 12 months and history of periodontal treatment within the last 5 years. This conservative approach did not alter any of our results (Table S6).

Periodontal and caries examinations were recorded using half-mouth basis, which might not reflect the absolute values, although it has less bias in comparison with full-mouth method (Tran et al., 2016). Furthermore, caries was recorded only on cavitation level. Leaving out non-cavitated caries lesions would have under-represented the caries burden in this study. Information on PTB usage was obtained only through a simple question with binomial answer possibility. In addition to usage of PTB in combination with MTB, differentiation between different types of PTB, that is oscillatory vs. vibratory, battery-powered vs. electric, sonic vs. ultra-sonic, was not measured, especially when there were studies reporting differences among them (Deacon et al., 2010; Rosema et al., 2016). However, the differences between the different types of PTB are not well studied, and more focus in this direction is needed. Because it is not plausible to perform a long-term randomized controlled trial to test the effectiveness of PTBs over MTBs, evidence from well-designed population-based cohorts/practice-based research is relevant for the dental community.

Although the effectiveness of PTB on periodontitis has been well documented in the literature (Forrest & Miller, 2004; de Jager, Rmaile, Darch, & Bikker, 2017; Yaacob et al., 2014), the evidence arriving from long-term studies is limited (Ainamo, Xie, Ainamo, & Kallio, 1997; Dentino et al., 2002; Dörfer, Joerss, & Wolff, 2009; Dörfer et al., 2016). In a 12-month longitudinal study, Ainamo et al. (1997) found PTBs to be effective in controlling gingivitis in terms of reducing bleeding on probing, but they were not significantly better in removing plaque. Dörfer et al. (2016) performed a randomized study with the longest follow-up time of 3 years, in which they did not find any significant differences in PD and CAL progression between PTB and MTB users with pre-existing recessions >2 mm. However, as shown in a recent meta-analysis (Yaacob et al., 2014), the use of a PTB results in less supragingival plaque, which in consequence prevents or decreases the magnitude of gingivitis. An improved oral hygiene has an effect on preventing the transition from gingivitis to periodontitis rather than the progression of periodontitis (Hellström, Ramberg, Krok, & Lindhe, 1996; Ramseier et al., 2017; Schätzle et al., 2004). In line with this observation, we could see that PTB had a distinct effect in reducing the PD and CAL progression in subjects affected with no/mild or moderate periodontitis, whereas the subjects with severe periodontitis did not benefit from the better oral hygiene through PTB usage (Hellström et al., 1996). Although the magnitude of change in PD and CAL among subjects with severe periodontitis was in line with the moderate periodontitis subjects, the effects were not significant, presumably due to the reduced sample size. Furthermore, it could be observed that the mean age of the PTB users was significantly lower than the MTB users. In addition to oral hygiene, progression of the periodontal disease in elderly people is influenced by many other factors (Lamster, 2016), which might not be counteracted by toothbrushing alone. Ramseier et al. (2017) concluded from the 40-year results of the Sri Lanka study that gingivitis control in young subjects is essential in preventing progression of

TABLE 4 Results from mixed-effects linear models evaluating the effects of powered toothbrush usage on rates of change in periodontitis models stratified by CDC/AAP definition

		β (95% CI)			
Outcome	**Variable**	**Entire sample**	**Regular brushers**	**Younger subjects**	**Younger regular brushers**
CDC/AAP definition = no/mild periodontitis					
Mean PD[a]	PTB usage	−0.00 (−0.05; 0.04)	0.01 (−0.04; 0.06)	0.01 (−0.11; 0.13)	0.03 (−0.09; 0.16)
	Time (per 11-year increase)	0.42 (0.38; 0.45)	0.43 (0.39; 0.47)	0.37 (0.30; 0.45)	0.40 (0.32; 0.48)
	Interaction	**−0.06 (−0.13; −0.00)**	**−0.08 (−0.14; −0.01)**	−0.05 (−0.22; 0.12)	−0.08 (−0.26; 0.10)
Mean CAL[a]	PTB usage	−0.02 (−0.11; 0.07)	0.01 (−0.09; 0.10)	0.06 (−0.21; 0.33)	0.10 (−0.19; 0.39)
	Time (per 11-year increase)	0.82 (0.75; 0.89)	0.83 (0.75; 0.91)	0.67 (0.50; 0.83)	0.73 (0.55; 0.92)
	Interaction	−0.07 (−0.19; 0.06)	−0.09 (−0.22; 0.04)	−0.09 (−0.47; 0.29)	−0.15 (−0.55; 0.25)
CDC/AAP definition = moderate periodontitis					
Mean PD[a]	PTB usage	0.04 (−0.04; 0.13)	0.05 (−0.04; 0.14)	−0.04 (−0.17, 0.09)	−0.05 (−0.18; 0.09)
	Time (per 11-year increase)	0.27 (0.22; 0.33)	0.28 (−0.22; 0.34)	0.29 (0.21; 0.36)	0.28 (0.20; 0.37)
	Interaction	**−0.16 (−0.27; −0.05)**	**−0.17 (−0.29; −0.05)**	−0.04 (−0.21; 0.13)	−0.05 (−0.23; 0.13)
Mean CAL[a]	PTB usage	0.04 (−0.12; 0.21)	0.03 (−0.14; 0.20)	0.00 (−0.25; 0.25)	−0.04 (−0.30; 0.22)
	Time (per 11-year increase)	0.64 (0.55; 0.74)	0.65 (0.55; 0.76)	0.63 (0.50; 0.76)	0.61 (0.47; 0.75)
	Interaction	**−0.32 (0.51; −0.12)**	**−0.33 (−0.54; −0.13)**	−0.17 (−0.46; 0.12)	−0.17 (−0.48; 0.14)
CDC/AAP definition = severe periodontitis					
Mean PD[a]	PTB usage	−0.00 (−0.23; 0.23)	−0.03 (−0.28; 0.22)	0.10 (−0.24; 0.45)	−0.01 (−0.38; 0.36)
	Time (per 11-year increase)	0.36 (0.23, 0.49)	0.36 (0.22; 0.51)	0.41 (0.24; 0.58)	0.40 (0.22; 0.59)
	Interaction	−0.22 (−0.52; 0.08)	−0.19 (−0.52; 0.13)	−0.45 (−0.93; 0.03)	−0.31 (−0.81; 0.19)
Mean CAL[a]	PTB usage	−0.09 (−0.50; 0.32)	−0.06 (−0.48; 0.37)	−0.21 (−0.85; 0.43)	−0.27 (−0.92; 0.37)
	Time (per 11-year increase)	1.13 (0.92; 1.35)	1.12 (0.89; 1.35)	1.09 (0.80; 1.38)	1.06 (0.76; 1.35)
	Interaction	−0.30 (−0.81; 0.21)	−0.35 (−0.88; 0.18)	−0.65 (−1.50; 0.20)	−0.59 (−1.40; 0.22)

Note: All models were adjusted for baseline covariates, such as, age, sex, education, smoking, BMI, diabetic status, HbA1c values, toothbrushing frequency, dental visit in the last 12 months, physical activity and history of periodontal treatment in the last 5 years. Subject ID was constructed as random intercept.

Abbreviations: β: beta coefficient; 95% CI: 95% confidence interval. CDC/AAP: Centers for Disease Control and Prevention/American Academy of Periodontology. PD: probing depth; CAL: clinical attachment loss; DMFS: decayed, missing, filled surfaces; DFS: decayed, filled surfaces. PTB usage: Effects of powered toothbrush usage on dependent variable for time = 0 (baseline/SHIP-1). Time (per 11-year increase): Rate of change for manual toothbrush user over 11-year follow-up period. Interaction: Exposure-dependent (PTB versus MTB) difference in the rates of change over 11-year follow-up period.

[a]Models were performed without the inclusion of random slope.

Bold numbers indicate statistically significant effect (p-Value < 0.05).

periodontitis, further loss of attachment and ultimately tooth loss. Our data may be interpreted that subjects using a PTB experience less attachment loss, which after 11-year follow-up resulted on average 0.36 more teeth than the MTB users. Furthermore, subjects with no/mild periodontitis had 0.19 more teeth retained than their MTB counterparts.

To our knowledge, the number of studies assessing the relationship between caries and PTB is rare. In an interventional study among drug-induced xerostomia patients (N = 80) with a follow-up time of 1 year, Papas et al. (2007) recorded a significant reduction of root caries among PTB users. Willershausen and Watermann (2001) performed an interventional study (N = 40) with a 3-year follow-up on elementary school children, but did not observe any benefit of PTB on caries prevalence. A systematic review conducted on seven studies assessing influence of oral hygiene in the absence of fluoride on dental caries concluded "Personal oral hygiene in the absence of fluorides has failed to show a benefit in terms of reducing the incidence of dental caries" (Hujoel, Hujoel, & Kotsakis, 2018). In line with this argumentation, lack of association between PTB usage and DFS seems plausible. However, PTB usage was associated with less DMFS progression, and this was due to the influence from the M-component, which is a predominant feature in the elderly population.

There has been a significant association of PTB usage with more number of teeth retained in the entire sample and in the regular brushers' subset. Based on this, it is evident that the PTB usage on the long run helps in preventing tooth loss and maintaining the number of teeth in the oral cavity. From this study, it could be seen that the

PTB usage may have a long-term protective effect on the oral health in general. It could also be seen that there has been a gradual increase in the usage of PTB over time. The reasons for this might be increased advertisements and dentist recommendations. German Oral Health Study showed that recently there has been an increase in the usage of inter-dental cleaning aids (Jordan & Micheelis, 2016). This, in addition to increased PTB usage as observed in the SHIP cohort, reflects the increased awareness of German population towards oral hygiene.

5 | CONCLUSION

From the results in this study, it could be seen that the PTB usage has a long-term protective effect on the oral health in terms of reduced probing depths, clinical attachments and number of teeth lost. Based on this, it seems that the PTB usage in the long run helps in maintaining the number of teeth in the oral cavity and reducing the progression of periodontal disease burden.

ACKNOWLEDGEMENTS

The authors thank the study participants and all contributions to the SHIP data collection by dental and medical examiners, technicians, interviewers and assistants.

CONFLICTS OF INTERESTS

Prof. Dr. Thomas Kocher had received grants from Procter and Gamble Co. to pay the salary for a scientist for 6 months, which did not have any influence on the study design, data analysis and interpretation of the results. The authors declare no potential conflicts of interest with respect to the authorship and publication of this article, and this includes financial interests.

ORCID

Vinay Pitchika https://orcid.org/0000-0001-6947-2602
Christiane Pink https://orcid.org/0000-0001-5950-2716

REFERENCES

Ainamo, J., Xie, Q., Ainamo, A., & Kallio, P. (1997). Assessment of the effect of an oscillating/rotating electric toothbrush on oral health. A 12-month longitudinal study. *Journal of Clinical Periodontology*, *24*, 28–33. https://doi.org/10.1111/j.1600-051X.1997.tb01180.x

Alcouffe, F. (1988). Improvement of oral hygiene habits: A psychological approach. 2-year data. *Journal of Clinical Periodontology*, *15*, 617–620. https://doi.org/10.1111/j.1600-051X.1988.tb02261.x

Deacon, S. A., Glenny, A. M., Deery, C., Robinson, P. G., Heanue, M., Walmsley, A. D., & Shaw, W. C. (2010). Different powered toothbrushes for plaque control and gingival health. *The Cochrane Database of Systematic Reviews*, (12), Cd004971.https://doi.org/10.1002/14651858.CD004971.pub2

Dentino, A. R., Derderian, G., Wolf, M., Cugini, M., Johnson, R., Van Swol, R. L., … Warren, P. (2002). Six-month comparison of powered versus manual toothbrushing for safety and efficacy in the absence of professional instruction in mechanical plaque control. *Journal of Periodontology*, *73*, 770–778. https://doi.org/10.1902/jop.2002.73.7.770

Dörfer, C. E., Joerss, D., & Wolff, D. (2009). A prospective clinical study to evaluate the effect of manual and power toothbrushes on pre-existing gingival recessions. *The Journal of Contemporary Dental Practice*, *10*, 1–8.

Dörfer, C. E., Staehle, H. J., & Wolff, D. (2016). Three-year randomized study of manual and power toothbrush effects on pre-existing gingival recession. *Journal of Clinical Periodontology*, *43*, 512–519. https://doi.org/10.1111/jcpe.12518

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2014). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for reporting observational studies. *International Journal of Surgery*, *12*, 1495–1499. https://doi.org/10.1016/j.ijsu.2014.07.013

Felder, R., Reveal, M., Lemon, S., & Brown, C. (1994). Testing toothbrushing ability of elderly patients. *Special Care in Dentistry*, *14*, 153–157. https://doi.org/10.1111/j.1754-4505.1994.tb01123.x

Forrest, J. L., & Miller, S. A. (2004). Manual versus powered toothbrushes: A summary of the Cochrane Oral Health Group's Systematic Review. Part II.. *Journal of Dental Hygiene*, *78*, 349–354.

Glockmann, E., Panzner, K., Huhn, P., Sigusch, B., & Glockmann, K. (2011). Ursachen des Zahnverlustes in Deutschland–Dokumentation einer bundesweiten Erhebung (2007)[Reasons for tooth loss in Germany-Documentation of a nationwide survey (2007)]. IDZ-Information, Institute of German dentists (IDZ), Editor.

Hellström, M.-K., Ramberg, P., Krok, L., & Lindhe, J. (1996). The effect of supragingival plaque control on the subgibgival microflora in human periodontitis. *Journal of Clinical Periodontology*, *23*, 934–940. https://doi.org/10.1111/j.1600-051X.1996.tb00514.x

Hitz Lindenmüller, I., & Lambrecht, J. T. (2011). Oral care. *Current Problems in Dermatology*, *40*, 107–115. https://doi.org/10.1159/000321060

Hujoel, P. P., Hujoel, M. L. A., & Kotsakis, G. A. (2018). Personal oral hygiene and dental caries: A systematic review of randomised controlled trials. *Gerodontology*, *35*, 282–289. https://doi.org/10.1111/ger.12331

Hunt, S. A. (2002). The relative cleaning effectiveness of manual and powered toothbrushes. *The Journal of Clinical Dentistry*, *13*, 211–214.

de Jager, M., Rmaile, A., Darch, O., & Bikker, J. W. (2017). The effectiveness of manual versus high-frequency, high-amplitude sonic powered toothbrushes for oral health: A meta-analysis. *The Journal of Clinical Dentistry*, *28*, A13–A28.

Jordan, A. R., & Micheelis, W. (2016). Fünfte Deutsche Mundgesundheitsstudie (DMS V). In I. D. Z. Zahnärzte (Eds.), *IDZ-Materialienreihe*, *Bd. 35* (pp. 617). Köln, Germany: Deutscher Zahnärzte Verlag DÄV.

Keil, U., Stieber, J., Döring, A., Chambless, L., Härtel, U., Filipiak, B., … Gostomzyk, J. G. (1988). The cardiovascular risk factor profile in the study area Augsburg. Results from the first MONICA survey 1984/85. *Acta medica Scandinavica. Supplementum*, *728*, 119–128. https://doi.org/10.1111/j.0954-6820.1988.tb05563.x

Lamster, I. B. (2016). Geriatric periodontology: How the need to care for the aging population can influence the future of the dental profession. *Periodontology 2000*, *72*, 7–12. https://doi.org/10.1111/prd.12157

Löe, H., Theilade, E., & Jensen, S. B. (1965). Experimental gingivitis in man. *Journal of Periodontology*, *36*, 177–187. https://doi.org/10.1902/jop.1965.36.3.177

Marcenes, W., Kassebaum, N. J., Bernabé, E., Flaxman, A., Naghavi, M., Lopez, A., & Murray, C. J. (2013). Global burden of oral conditions in 1990–2010: A systematic analysis. *Journal of Dental Research*, *92*, 592–597. https://doi.org/10.1177/0022034513490168

Marsh, P. D., & Nyvad, B. (2008). The oral microflora and biofilms on teeth. In O. Fejerskov & E. A. M. Kidd (Eds.), *Dental caries* (2 edn, pp. 163–187). Oxford, UK: Blackwell Publishing Ltd.

Moritis, K., Jenkins, W., Hefti, A., Schmitt, P., & McGrady, M. (2008). A randomized, parallel design study to evaluate the effects of a Sonicare and a manual toothbrush on plaque and gingivitis. *The Journal of Clinical Dentistry*, *19*, 64–68.

Newman, H. N. (1986). The relation between plaque and dental caries. *Journal of the Royal Society of Medicine*, *79*, 1–5.

Papas, A. S., Singh, M., Harrington, D., Ortblad, K., de Jager, M., & Nunn, M. (2007). Reduction in caries rate among patients with xerostomia using a power toothbrush. *Special Care in Dentistry*, *27*, 46–51. https://doi.org/10.1111/j.1754-4505.2007.tb00327.x

Ramseier, C. A., Anerud, A., Dulac, M., Lulic, M., Cullinan, M. P., Seymour, G. J., … Lang, N. P. (2017). Natural history of periodontitis: Disease progression and tooth loss over 40 years. *Journal of Clinical Periodontology*, *44*, 1182–1191. https://doi.org/10.1111/jcpe.12782

Rosema, N., Slot, D. E., van Palenstein Helderman, W. H., Wiggelinkhuizen, L., & Van der Weijden, G. A. (2016). The efficacy of powered toothbrushes following a brushing exercise: A systematic review. *International Journal of Dental Hygiene*, *14*, 29–41. https://doi.org/10.1111/idh.12115

Schätzle, M., Löe, H., Lang, N. P., Bürgin, W., Ånerud, Å., & Boysen, H. (2004). The clinical course of chronic periodontitis. *Journal of Clinical Periodontology*, *31*, 1122–1127. https://doi.org/10.1111/j.1600-051X.2004.00634.x

Schmalz, G., Müller, M., Schmickler, J., Rinke, S., Haak, R., Mausberg, R. F., & Ziebolz, D. (2017). Influence of manual and power toothbrushes on clinical and microbiological findings in initial treatment of periodontitis – A randomized clinical study. *American Journal of Dentistry*, *30*, 40–46.

Schmidt, J. C., Zaugg, C., Weiger, R., & Walter, C. (2013). Brushing without brushing?–a review of the efficacy of powered toothbrushes in noncontact biofilm removal. *Clinical Oral Investigations*, *17*, 687–709. https://doi.org/10.1007/s00784-012-0836-8

Textor, J., Hardt, J., & Knüppel, S. (2011). DAGitty: A graphical tool for analyzing causal diagrams. *Epidemiology*, *22*, 745. https://doi.org/10.1097/EDE.0b013e318225c2be

Theilade, E., Wright, W. H., Jensen, S. B., & Löe, H. (1966). Experimental gingivitis in man. II. A longitudinal clinical and bacteriological investigation. *Journal of Periodontal Research*, *1*, 1–13. https://doi.org/10.1111/j.1600-0765.1966.tb01842.x

Tonetti, M. S., Eickholz, P., Loos, B. G., Papapanou, P., van der Velden, U., Armitage, G., … Suvan, J. E. (2015). Principles in prevention of periodontal diseases: Consensus report of group 1 of the 11th European Workshop on Periodontology on effective prevention of periodontal and peri-implant diseases. *Journal of Clinical Periodontology*, *42*(Suppl 16), S5–S11. https://doi.org/10.1111/jcpe.12368

Tran, D. T., Gay, I. C., Du, X. L., Fu, Y., Bebermeyer, R. D., Neumann, A. S., … Walji, M. F. (2016). Partial-mouth periodontal examination protocol for estimating periodontitis extent and severity in a US population. *Clinical and Experimental Dental Research*, *2*, 73–79. https://doi.org/10.1002/cre2.24

United States Census Bureau (2015). American Community Survey (ACS): Code lists, definitions and accuracy. Retrieved from https://www2.census.gov/programs-surveys/acs/tech_docs/accuracy/percchg.pdf

Unkel, J. H., Fenton, S. J., Hobbs, G. Jr, & Frere, C. L. (1995). Toothbrushing ability is related to age in children. *ASDC Journal of Dentistry for Children*, *62*, 346–348.

Verma, S., & Bhat, K. M. (2004). Acceptability of powered toothbrushes for elderly individuals. *Journal of Public Health Dentistry*, *64*, 115–117. https://doi.org/10.1111/j.1752-7325.2004.tb02738.x

Völzke, H., Alte, D., Schmidt, C. O., Radke, D., Lorbeer, R., Friedrich, N., … Hoffmann, W. (2011). Cohort profile: The study of health in Pomerania. *International Journal of Epidemiology*, *40*, 294–307. https://doi.org/10.1093/ije/dyp394

Willershausen, B., & Watermann, L. (2001). Longitudinal study to assess the effectivity of electric and manual toothbrushes for children. *European Journal of Medical Research*, *6*, 39–45.

Wilson, S., Levine, D., Dequincey, G., & Killoy, W. J. (1993). Effects of two toothbrushes on plaque, gingivitis, gingival abrasion, and recession: A 1-year longitudinal study. *Compendium (Newtown, Pa.). Supplement*, (16), S569–S579; quiz S612–4.

Yaacob, M., Worthington, H. V., Deacon, S. A., Deery, C., Walmsley, A. D., Robinson, P. G., & Glenny, A. M. (2014). Powered versus manual toothbrushing for oral health. *The Cochrane Database of Systematic Reviews*, (6), CD002281. https://doi.org/10.1002/14651858.CD002281.pub3

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Pitchika V, Pink C, Völzke H, Welk A, Kocher T, Holtfreter B. Long-term impact of powered toothbrush on oral health: 11-year cohort study. *J Clin Periodontol*. 2019;46:713–722. https://doi.org/10.1111/jcpe.13126