Received: 11 August 2022 | Revised: 5 December 2022 | Accepted: 21 December 2022

DOI: 10.1111/jcpe.13763

ORIGINAL ARTICLE

Journal of Clinical Periodontology WILEY

Powered tooth brushes are beneficial for long-term oral health: Results from the Study of Health in Pomerania (SHIP-TREND)

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Funding information
German Federal State of Mecklenburg-West Pomerania

Abstract

Aim: To determine the long-term effects of the use of powered tooth brush (PTB) in comparison to manual tooth brush (MTB) on periodontitis severity, coronal caries experience, and the number of missing teeth using in a population-based cohort study.

Materials and Methods: Using 7-year follow-up data of 2214 participants of the Study of Health in Pomerania (SHIP-TREND), comprehensively adjusted linear models using generalized least squares and ordinal regression models estimated the effects of PTB usage on dental outcomes in complete case and imputed data.

Results: At follow-up, PTB users had lower medians for mean probing depth (PD; 2.21 mm) and mean clinical attachment levels (1.73 mm) than MTB users (2.30 and 1.96 mm, respectively). Adjusted models revealed the beneficial effects of PTB usage on follow-up levels of plaque, bleeding on probing, mean PD, percentage of sites with PDs ≥4 mm, mean clinical attachment levels (all, interdental, and non-interdental sites, respectively), and the number of missing teeth. For the number of missing teeth, the effects were more pronounced in participants aged ≥50 years. No significant effects of PTB usage on the number of decayed or filled surfaces (all and interdental sites) were found.

Conclusions: A recommendation of PTB usage in dental practice could contribute to the long-term promotion of oral health.

KEYWORDS

caries, cohort study, number of missing teeth, periodontitis, powered tooth brush

Clinical Relevance

Scientific rationale for study: Currently, only sparse data is available on the long-term effectiveness of powered tooth brush (PTB) usage on dental outcomes in the general population.

Principal findings: Using 7-year follow-up data from a population-based cohort study, PTBs were proven to be effective in reducing periodontitis and the number of missing teeth.

Practical implications: Recommending PTBs in dental practice might have beneficial effects on oral health among the general population on a larger perspective.

1 | INTRODUCTION

Dental caries and periodontitis are the most common oral diseases (Bernabe et al., 2020) responsible for the majority of tooth extractions (Glockmann et al., 2011). In 2010, the half-mouth DMF-T (decayed, missing, filled teeth) was 8.7 in people aged 20–83 years in north-east Germany despite a marked decline in caries over the previous decade (Schmoeckel et al., 2021). Also, 33.3% and 15.7% of dentate people from north-east Germany presented with moderate and severe periodontitis, respectively (Schutzhold et al., 2015). Obviously, both coronal caries and periodontitis are still the most prevalent oral diseases in this region.

Gingivitis is characterized by reversible inflammation, but if it persists it may ultimately lead to periodontitis in susceptible subjects. Prevention of periodontitis means treating gingivitis by removing the biofilm to resolve the inflammation. In the end, periodontitis may ultimately lead to tooth loss if left untreated (Tonetti et al., 2015). Accumulation of supragingival plaque and the development of gingivitis and caries are closely related (Axelsson et al., 2004). Regular removal of biofilm at and below the gingival margin is an important part of preventing gingivitis and periodontitis. Thus, removing the supragingival plaque is an important solution in the treatment of gingival inflammation and preservation of oral health (Loe et al., 1965). In addition, frequent removal of the supragingival biofilm was found to reduce subgingival bacterial counts and favour a more beneficial composition of the subgingival plaque (Ximenez-Fyvie et al., 2000).

A necessary risk factor for periodontitis is the accumulation of biofilm at and below the gingival margin (Chapple et al., 2015). Thus, effective supragingival plaque control is essential to prevent and control periodontal disease (van der Weijden & Slot, 2011) and reduce dental decay (Walsh et al., 2010), and thereby tooth loss (Lindhe et al., 1989). In addition to mechanical plaque removal, daily application of fluoridated toothpaste is even more important in preventing caries (Griffin et al., 2007; Walsh et al., 2019). Thus, self-performed mechanical plaque control reduces supragingival plaque and therefore directly controls gingivitis, and indirectly caries, by fluoride application, if performed at least once a day (Maier et al., 2020). However, not only the interval between brushing but also the brushing technique is important for plaque control. Though it is recommended to brush teeth twice daily for at least 2 min using the modified Bass technique, these instructions are not followed by most patients (Wainwright & Sheiham, 2014).

Powered tooth brushes (PTBs) are marketed as being better at removing the biofilm than manual tooth brushes (MTBs), without requiring the user to learn better brushing skills (Verma & Bhat, 2004). They were indeed more effective in removing supragingival plaque with one-time use (Elkerbout et al., 2020). On average, clinical studies have reported a 46% reduction in plaque levels from baseline after toothbrushing (Yaacob et al., 2014; Rosema et al., 2016). A recent 8-week randomized controlled study with 110 participants showed better reduction of plaque and gingivitis at weeks 1 and 8 in PTB users (Grender et al., 2020). However, long-term studies assessing the benefit of PTB with regard to periodontal health and prevention of caries are sparse. To date, there is only one prospective cohort study using 11-year data from the Study of Health in Pomerania (SHIP; Pitchika et al., 2019), which found that PTBs, compared to MTBs, were more effective in improving and maintaining periodontal health, as measured by probing depth (PD), clinical attachment loss (CAL), and the number of missing teeth.

Thus, we aimed to determine the long-term effects of PTB usage on plaque, gingival inflammation (bleeding on probing; BOP), periodontitis severity (assessed by mean PD/CAL, percentage of sites with PD ≥4 mm, Centers for Disease Control and Prevention [CDC]/American Academy of Periodontology [AAP] case definition of periodontitis), coronal caries experience (DF-S), and the number of missing teeth using 7-year follow-up data from the prospective SHIP-TREND cohort.

2 | MATERIALS AND METHODS

2.1 | Study design and sample

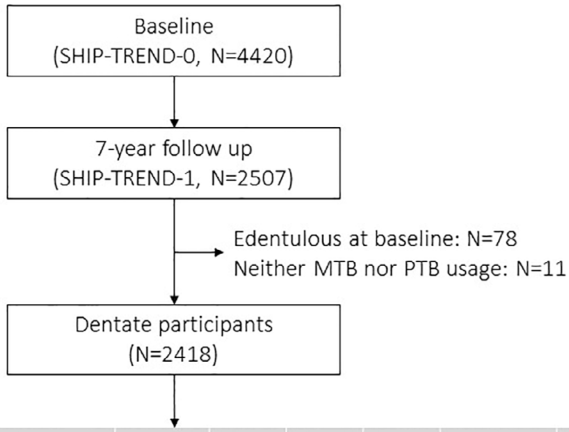
SHIP-TREND is a population-based observational study in Western Pomerania, the north-eastern region of Germany (Volzke et al., 2022). A stratified random sample of 10,000 adults aged 20–79 years was drawn from population registries. Sample selection was facilitated by the centralization of local population registries in the Federal State of Mecklenburg/West Pomerania. Stratification variables were age, sex, and city/county of residence. After exclusion of migrated ($N = 851$) and deceased ($N = 323$) persons, the net sample included 8826 persons. Because of several reasons (241 did not answer, 3367 refused participation, 549 did not keep the appointment, and 249 agreed without an appointment), 4420 subjects were finally recruited in the study (response 50.1%). Examinations were conducted during 2008–2012. After 7 years, a first follow-up study was conducted (SHIP-TREND-1, 2014–2018). Follow-up times varied between 5.0 and 10.3 years.

Of the 4420 baseline participants, 2507 had follow-up data (Figure 1). Of those, 78 edentulous participants and 11 participants using neither manual nor PTBs were excluded, leaving 2418 participants. Further exclusions were made on the basis of missing baseline or follow-up outcome values or missing baseline confounders, leaving between 2008 and 2293 subjects for analyses.

Detailed information about periodontal and caries examinations, laboratory measurements, exposure variable and covariates, and calibration data are provided in the Appendix. 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).

2.2 | Statistical analyses

Outcome variables were chosen to represent plaque removal (plaque), gingival inflammation (BOP), periodontitis (mean PD of all, interdental, or non-interdental sites; percentage of all, interdental or non-interdental sites with PD ≥4 mm; mean CAL of all, interdental or non-interdental sites; CDC/AAP case definition), coronal caries (DF-S of all, interdental, or non-interdental surfaces), and tooth loss.



	Plaque	BOP	PD	CAL	CDC/AAP	DF-S	NoMT
Baseline or follow-up outcome value missing, N	210	248	245	356	395	197	32
Resulting sample size	2208	2170	2173	2062	2023	2221	2386
Baseline confounders missing, N	95	92	92	83	77	86	172
Final sample size	2113	2078	2081	1979	1946	2135	2214

FIGURE 1 Flow-chart of the study population. AAP, American Academy of Periodontology; BOP, bleeding on probing; CAL, clinical attachment level; CDC, Centers for Disease Control and Prevention; DF-S, number of decayed or filled surfaces; MTB, manual tooth brush; N, number; NoMT, number of missing teeth; PD, probing depth; PTB, powered tooth brush

Medians with 25% and 75% quantiles for continuous variables and relative frequency distributions for categorical variables were computed.

We applied linear models using generalized least squares and ordinal logistic regression models. The latter models are recommended for skewed continuous responses (Harrell, 2015). The relevant model assumptions were tested, and the decision for linear or ordinal logistic models was made accordingly. For ordinal logistic models, various links were evaluated and the logit link was selected for all outcome variables. We estimated the effects of self-reported baseline PTB usage (ref. MTB usage), follow-up time, and their interaction on follow-up levels of outcome variables. As we aimed to estimate total effects of baseline levels of the exposure on follow-up levels of outcome variables, we did not adjust models for baseline outcome status, as the latter was assumed to be a mediator of the effect of PTB usage on follow-up outcome status (Tennant et al., 2022), assuming long-term a priori effects of PTB usage on the baseline outcome status. Confounders were chosen according to prior clinical knowledge and according to Pitchika et al. (2019). Models were adjusted for baseline levels of age, sex, school education, equivalent household income, smoking, known diabetes mellitus, HbA1c, body mass index, dental visit within the last 12 months, tooth brushing frequency, and the use of interdental cleaning aids (IDAs). Models on plaque, BOP, periodontitis variables, and the number of missing teeth were additionally adjusted for self-reported periodontal treatment within the last 5 years and physical activity. All continuous variables were modelled as restricted cubic splines with three knots to allow for non-linearity. Adjusted linear regression coefficients (beta) and odds ratios (ORs) with 95% confidence intervals (CIs) contrasting PTB users with MTB users were reported and graphically presented. Adjusted ORs were depicted for most common follow-up times of 6.8–8.1 years (corresponding to 10% and 90% quantiles). Effect modification by age and sex was tested via multiplicative interaction terms with PTB usage and, if present ($p < .10$ for interaction), stratified models were presented.

Because first, "including only participants with complete data is not only inefficient […] but may also lead to biased results when the remaining individuals without missing data are not representative of the whole original study sample" (Collins et al., 2015) and, second, as the fraction of missing values was about 50%, indicating a potential for selection bias due to attrition and thus a need for imputation (Groenwold et al., 2012), we imputed missing values using multiple imputation. We did not impute missing teeth at follow-up and baseline interview items if the participants refused examinations. We used the *aregImpute* procedure provided in the rms package to generate 50 imputed datasets. Effect estimates were pooled according to Robin's rule (White et al., 2011).

In sensitivity analyses, we additionally fitted random-effects ordered logistic, linear, and logistic models to complete case data. Baseline and follow-up values of PTB usage, outcome variables, and covariates (see above) were considered. For declaration of panel data, time was defined categorically (0/1). The respective ORs and beta coefficients (with 95% CIs) with their respective *p*-values are given in Appendix Table 3.

A two-sided $p < .05$ was considered statistically significant. All analyses were performed using Stata/SE v.17.0 (StataCorp, 2021), R 4.1.2 (R Core Team, 2021), and the rms package (Harrell, 2021).

3 | RESULTS

3.1 | Baseline and 7-year characteristics

PTB users had a more favourable covariate profile compared to MTB users; they had a lower median age (Δ5 years), more often a high

TABLE 1 Baseline characteristics (SHIP-TREND-0) for participants present in the final model for the number of missing teeth in total and stratified by tooth brush type.

	Total; $N = 2214$	MTB user; $N = 1565$	PTB user; $N = 649$	*p*-value[a]
Follow-up time, years	7.3 (7.0–7.5)	7.3 (7.0–7.5)	7.3 (7.0–7.5)	.0826
Age, years	49 (39–59)	50 (40–61)	45 (37–56)	.0001
Sex				
Female	1140 (51.5%)	791 (50.5%)	349 (53.8%)	
Male	1074 (48.5%)	774 (49.5%)	300 (46.2%)	.166
School education				
<10 years	266 (12.0%)	219 (14.0%)	47 (7.2%)	
10 years	1233 (55.7%)	881 (56.3%)	352 (54.2%)	
>10 years	715 (32.3%)	465 (29.7%)	250 (38.5%)	<.001
Household equivalent income, €[b]	1450 (1096–1803)	1450 (1025–1803)	1525 (1096–2050)	.0001
Smoking status				
Never smoker	851 (38.4%)	598 (38.2%)	253 (39.0%)	
Former smoker	859 (38.8%)	619 (39.55%)	240 (37.0%)	
Current smoker	504 (22.8%)	348 (22.2%)	156 (24.0%)	.471
Brushing ≥2 times/day, yes	1933 (87.3%)	1346 (86.0%)	587 (90.5%)	.004
Interdental cleaning aids usage, yes	644 (29.1%)	430 (27.5%)	214 (33.0%)	.010
Dental visit within the last 12 months, yes	2035 (91.9%)	1436 (91.8%)	599 (92.3%)	.672
Periodontal treatment within last 5 years, yes	453 (20.5%)	314 (20.1%)	139 (21.4%)	.472
Last time consulting a doctor (except a dentist)?				
Within the last 4 weeks	843 (38.1%)	620 (39.6%)	223 (34.4%)	
Within the last 2–12 months	1105 (49.9%)	772 (49.3%)	333 (51.3%)	
More than 1 year ago	266 (12.0%)	173 (11.1%)	93 (14.3%)	.020
Participation in an early cancer diagnosis examination, yes	1400 (63.2%)	981 (62.7%)	419 (64.6%)	.404
Known diabetes mellitus, yes	124 (5.6%)	91 (5.8%)	33 (5.1%)	
Haemoglobin A1c, %	5.2 (4.8–5.5)	5.2 (4.9–5.6)	5.1 (4.8–5.4)	.0090
Body mass index, kg/m^2	27.0 (24.2–30.1)	27.2 (24.5–30.2)	26.5 (23.8–29.6)	.0006
Physical activity, yes	1596 (72.1%)	1116 (71.3%)	480 (74.0%)	.206

Note: Data are presented as median (25%; 75% quantile) or number (percentage).
Abbreviations: MTB, manual tooth brush; PTB, powered tooth brush.
[a]Mann–Whitney *U* test or Chi squared test.
[b]Reduced sample size (2214/1565/649).

education, and a higher equivalence household income (Δ75 Euros), and they were more often regular tooth brushers and users of IDAs (Table 1). Compared to MTB users, PTB users had lower medians at baseline and follow-up for mean PD (2.39 and 2.30 mm vs. 2.29 and 2.21 mm, respectively) and mean CAL (2.00 and 1.96 mm vs. 1.67 and 1.73 mm, respectively; Table 2). Similarly, the number of missing teeth at follow-up was significantly lower in PTB users (median 3) compared to MTB users (median 5).

3.2 | Modelling beneficial effects of self-reported PTB usage

We evaluated linear and ordinal logistic models to estimate effects of self-reported baseline PTB usage and follow-up time on follow-up dental status (Figure 2 and Appendix Table 1). Adjusted ORs or beta coefficients indicated relevant benefits of PTB usage compared to MTB usage on all periodontal variables (Figure 2a–f, g–k), except for the percentage of interdental sites with PD ≥4 mm and the CDC/AAP case definition (Figure 2g,l). An OR of less than 1 indicates a lower odds of higher outcome values for PTB than for MTB, which confers a beneficial effect of PTB versus MTB. ORs contrasting PTB users with MTB users ranged between 0.66 and 0.76 for plaque, between 0.65 and 0.82 for BOP, between 0.67 and 0.87 for mean PD, between 0.70 and 0.86 for mean interdental PD, between 0.67 and 0.90 for mean non-interdental PD, between 0.61 and 0.85 for mean CAL, between 0.58 and 0.92 for mean interdental CAL, and between 0.64 and 0.77 for mean non-interdental CAL depending on the follow-up time. For the number of missing teeth (Figure 2p), ORs were between 0.54 and 0.69 for follow-up times of 6.8–7.7 years (restricting ORs to significant ones). No beneficial effects of PTB usage were found for all three DF-S variables (Figure 2m–o).

TABLE 2 Baseline (SHIP-TREND-0) and 7-year-follow-up (SHIP-TREND-1) dental data in total and stratified by baseline tooth brush usage.

		Total		MTB user		PTB user		
		N	*N* (%) or Median (Q25; Q75)	*N*	*N* (%) or Median (Q25; Q75)	*N*	*N* (%) or Median (Q25; Q75)	*p*-value[a]
Plaque, %	Baseline	2113	8.3 (0; 29.2)	1481	12.5 (0; 33.3)	632	5.0 (0; 18.8)	.0001
	Follow-up		16.7 (5.0; 37.5)		20.8 (8.3; 40.0)		12.5 (4.2; 9.2)	.0001
BOP, %	Baseline	2078	16.7 (4.2; 33.3)	1453	16.7 (5.0; 37.5)	625	12.5 (4.2; 25.0)	.0001
	Follow-up		12.5 (4.2; 25.0)		15.0 (5.0; 29.2)		12.5 (4.2; 20.8)	.0001
Mean PD, mm	Baseline	2081	2.36 (2.13; 2.71)	1455	2.39 (2.15; 2.75)	626	2.29 (2.06; 2.57)	.0001
	Follow-up		2.27 (2.07; 2.58)		2.30 (2.10; 2.61)		2.21 (2.02; 2.46)	.0001
Mean interdental PD, mm	Baseline	2081	2.72 (2.43; 3.15)	1455	2.75 (2.46; 3.21)	626	2.64 (2.38; 3.00)	.0001
	Follow-up		2.58 (2.32; 2.95)		2.62 (2.35; 3.00)		2.50 (2.29; 2.83)	.0001
Mean non-interdental PD, mm	Baseline	2081	2.00 (1.79; 2.29)	1455	2.04 (1.79; 2.36)	626	1.95 (1.73; 2.15)	.0001
	Follow-up		1.96 (1.79; 2.20)		2.00 (1.79; 2.25)		1.92 (1.73; 2.11)	.0001
Percentage of sites with PD ≥4 mm, %	Baseline	2081	5.4 (0; 16.7)	1455	2.8 (0; 18.8)	626	3.6 (0; 12.5)	.0001
	Follow-up		4.2 (0; 13.5)		4.5 (0; 15.6)		3.6 (0; 9.6)	.0001
Percentage of interdental sites with PD ≥4 mm, %	Baseline	2081	8.3 (0; 27.8)	1455	10.0 (0; 30.0)	626	4.5 (0; 20.8)	.0001
	Follow-up		7.1 (0; 21.4)		7.7 (0; 25.0)		4.4 (0; 16.7)	.0013
Percentage of non-interdental sites with PD ≥4 mm, %	Baseline	2081	0 (0; 5)	1455	0 (0; 7.1)	626	0 (0; 3.8)	.0001
	Follow-up		0 (0; 5)		0 (0; 7.1)		0 (0; 3.8)	.0001
Mean CAL, mm	Baseline	1979	1.88 (1.20; 2.86)	1363	2.00 (1.23; 3.03)	616	1.67 (1.14; 2.56)	.0001
	Follow-up		1.88 (1.43; 2.71)		1.96 (1.47; 2.92)		1.73 (1.34; 2.33)	.0001
Mean interdental CAL, mm	Baseline	1978	1.98 (1.18; 3.05)	1362	2.07 (1.21; 3.22)	616	1.79 (1.14; 2.75)	.0001
	Follow-up		1.92 (1.50; 2.75)		2.00 (1.54; 3.00)		1.73 (1.38; 2.35)	.0001
Mean non-interdental CAL, mm	Baseline	1978	1.81 (1.15; 2.75)	1362	1.93 (1.19; 2.92)	616	1.61 (1.08; 2.46)	.0001
	Follow-up		1.86 (1.33; 2.69)		1.96 (1.36; 2.91)		1.71 (1.26; 2.35)	.0001
CDC/AAP case definition		1946		1333		613		
No/mild periodontitis	Baseline		1020 (52.4%)		662 (49.7%)		358 (58.4%)	
Moderate periodontitis	Baseline		654 (33.6%)		469 (35.2%)		185 (30.2%)	
Severe periodontitis	Baseline		272 (14.0%)		202 (15.1%)		70 (11.4%)	.001
No/mild periodontitis	Follow-up		1129 (58.0%)		747 (56.0%)		382 (62.3%)	
Moderate periodontitis	Follow-up		627 (32.2%)		448 (33.6%)		179 (29.2%)	
Severe periodontitis	Follow-up		190 (9.8%)		138 (10.4%)		52 (8.5%)	.032
DF-S	Baseline	2135	17 (10; 25)	1496	17 (10; 25)	639	17 (10; 25)	.3151
	Follow-up		18 (10; 26)		17.5 (10; 26)		19 (10; 26)	.0980
Interdental DF-S	Baseline	2135	8 (4; 11)	1496	8 (4; 11)	639	8 (4; 12)	.7642
	Follow-up		8 (4; 12)		8 (4; 11)		8 (4; 12)	.2449
Non-interdental DF-S	Baseline	2135	10 (6; 14)	1496	10 (6; 13)	639	10 (6; 14)	.0939
	Follow-up		10 (6; 14)		10 (6; 14)		11 (6; 14)	.0450
Number of missing teeth	Baseline	2214	3 (1; 7)	1565	4 (1; 9)	649	2 (1; 5)	.0001
	Follow-up		4 (1; 9)		5 (2; 10)		3 (1; 6)	.0001

Note: Data are presented as median (25%; 75% quantile) or number (percentage).
Abbreviations: AAP, American Academy of Periodontology; BOP, bleeding on probing; CAL, clinical attachment level; CDC, Centers for Disease Control and Prevention; DF-S, number of decayed or filled surfaces; MTB, manual tooth brush; PD, probing pocket depth; PTB, powered tooth brush.
[a]Mann–Whitney *U* test or Chi squared test.

Age significantly modified the effects of PTB usage on the number of missing teeth (Appendix Figure 1). In subjects aged ≥50 years, effects were more pronounced than in subjects age <50 years, with odds ratios around 0.4 across all follow-up times (adjusted ORs were depicted for follow-up times of 6.8–8.1 years).

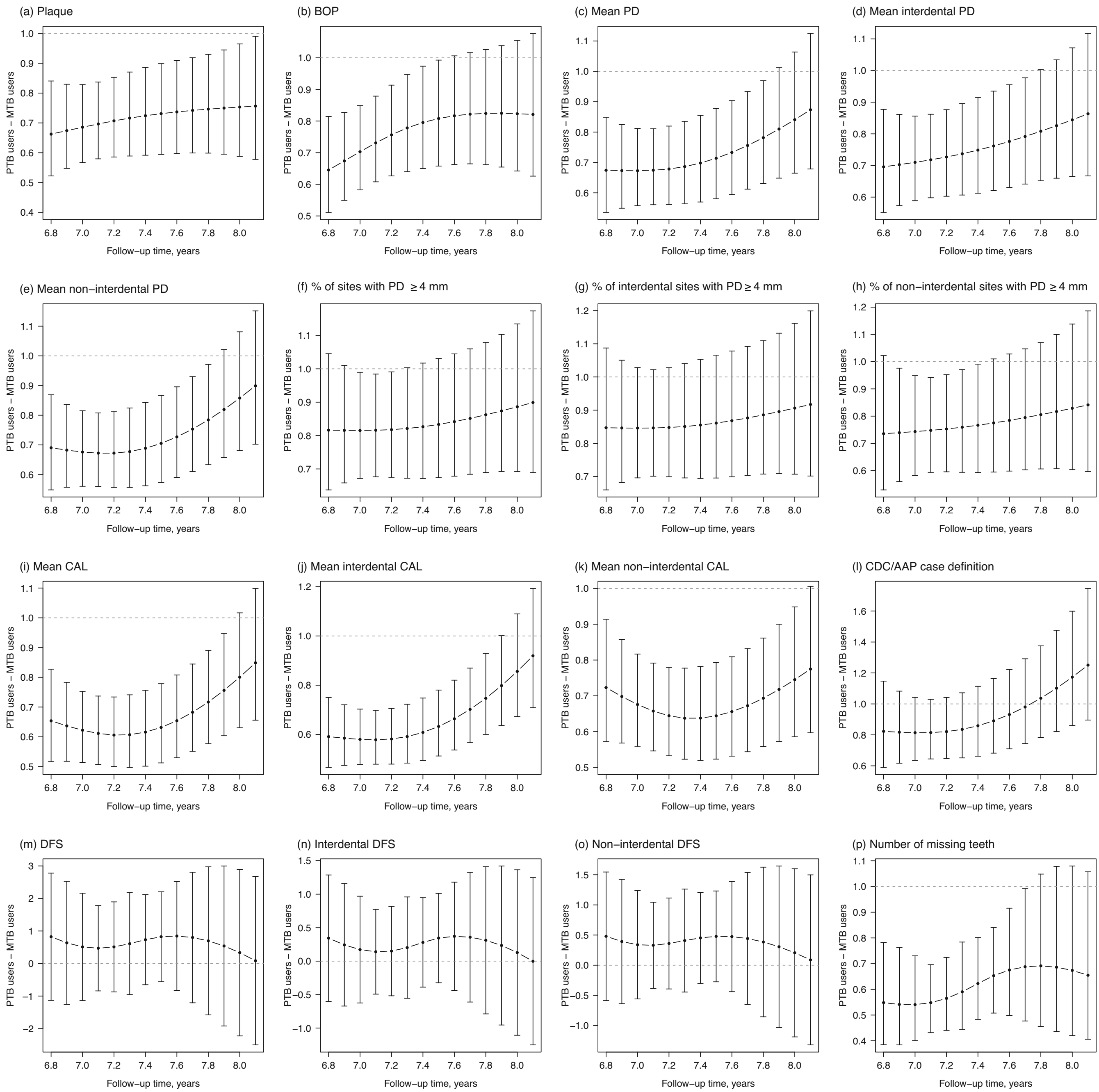


FIGURE 2 Adjusted odds ratios from ordinal logistic models (a–l, p; with logit link) and adjusted beta coefficients from linear models using generalized least squares (m–o) contrasting powered tooth brush (PTB) users with manual tooth brush (MTB) users. Contrast estimates and 95% confidence intervals are given. The null effect is indicated by the horizontal dashed line (no difference between PTB and MTB users). Estimates are tabulated in Appendix Table 1. AAP, American Academy of Periodontology; BOP, bleeding on probing; CAL, clinical attachment level; CDC, Centers for Disease Control and Prevention; DF-S, number of decayed or filled surfaces; MTB, manual tooth brush; PD, probing depth; PTB, powered tooth brush

3.3 | Analyses of imputed datasets

Using imputed data (Appendix Figure 2 and Appendix Table 2) effect estimates contrasting PTB and MTB users were slightly reduced, but still significant, confirming the beneficial effects of PTB usage compared to MTB usage. For all three DF-S variables, the results remained insignificant. For the number of missing teeth, ORs ranged between 0.63 and 0.69, depending on the follow-up time.

3.3.1 | Results from random-effects models

In sensitivity analyses, random-effects models (see Appendix Table 3) yielded confirmatory results. PTB usage was associated with lower odds of higher outcome values compared to MTB usage for all outcome variables, except for DF-S variables. For example, ORs were 0.61 for plaque (95% CI: 0.52–0.71), 0.78 for BOP (95% CI: 0.68–0.90), and 0.68 for mean PD (95% CI: 0.58–0.80).

Logarithmized mean CAL was −0.039 mm lower for PTB users compared to MTB users.

4 | DISCUSSION

Using 7-year follow-up data from SHIP-TREND, we estimated total effects of baseline self-reported PTB usage on dental outcomes at follow-up. Compared to MTBs, PTBs were beneficial for plaque, BOP, mean PD (all, interdental, and non-interdental sites), percentage of sites with PD ≥4 mm (all and non-interdental sites), and mean CAL (all, interdental, and non-interdental sites). In addition, PTB users had fewer missing teeth at follow-up compared to MTB users, with more pronounced effects seen in ≥50-year-old subjects. However, there was no beneficial effect in terms of caries experience. Using imputed data, effect estimates were slightly diminished, but still confirmative. Finally, the beneficial effects of PTB usage were confirmed in random-effects regression models.

In line with our results, the beneficial effects of PTB usage on supragingival plaque control and gingivitis have been proven in many short-term studies. Compared to manual tooth brushing, powered tooth brushing showed better supragingival plaque removal after 1 min (Williams et al., 2004), 1 week (Ikawa et al., 2021), or 4 months (Bilen et al., 2021). A randomized controlled trial reported improved plaque removal and reduction in gingivitis for PTB users after 4 and 12 weeks compared to MTB users (Gallob et al., 2015). Another group reported more plaque reduction in the lingual sites with PTB and that PTB users brushed longer than MTB counterparts (Schmidt et al., 2019). A series of in vitro studies showed that biofilm in interdental spaces could be removed with PTB without direct mechanical contact depending on the amplitude of the bristles (Schmidt et al., 2017). PTB use without direct mechanical contact changed the viscoelastic properties of the biofilm and increased the penetration of anti-microbials (He et al., 2014). In a small clinical trial, a synergistic action of PTB brushing and anti-bacterial tooth paste was demonstrated with small clinical effects (Jongsma et al., 2015). Perhaps, these small clinically non=significant differences may, over time, differentially impact periodontal health. In contrast, a recent cross-sectional study found no significant difference in plaque removal and gingivitis reduction between PTB and MTB users, who were not instructed in brushing techniques; according to the authors, both groups did not achieve satisfactory oral cleanliness (Petker et al., 2019), as they both neglected lingual surfaces and gingival margins (Petker-Jung et al., 2022). Thus, in addition to recommending the use of PTBs, dentists should also give oral hygiene instructions.

Long-term clinical and observational studies investigating periodontitis measures such as PD, CAL or tooth loss are rare. In 2016, a randomized controlled trial over 3 years did not show any significant advantage of PTB over MTB for PD and CAL progression in patients with pre-existing recessions (Dorfer et al., 2016). However, a large-scale observational study showed that PTBs were better than MTBs at impeding the progression of periodontitis over 11 years of follow-up and resulted in about 20% less tooth loss in PTB users (Pitchika et al., 2019). In a repeated cross-sectional study, increasing PTB usage significantly contributed to decreasing levels of mean PD in adults over 9 years (Pitchika et al., 2021). Also, the number of teeth increased by 0.77 (1.66) in adults (seniors), of which 0.04 (0.25) was explained by increasing PTB usage. Reduced periodontal progression translates into the tangible effect of reduced tooth loss. This conclusion is supported by our observation that self-reported PTB usage had an effect on periodontal conditions of younger subjects, which translated into less tooth loss in older subjects. Our observation that self-reported PTB usage had a favourable impact on periodontal conditions at follow-up is also supported by a 6-month longitudinal study, which reported that improved supragingival plaque control resulted in less periopathogenic subgingival plaque in subjects with moderate periodontitis (Haffajee et al., 2001). Thus, improved supragingival plaque control, as observed in this study, may also reduce periodontal progression, even in the long-term.

Although various studies have investigated the relationship between PTB usage and supragingival plaque control (Elkerbout et al., 2020), only a few have studied its effects on caries experience. Our results are in line with those of a recent meta-analysis, which did not show a benefit of PTB on the caries experience in mentally impaired children (Zhou et al., 2019). Also, in patients with drug-associated xerostomia, MTB and PTB users did not differ with regard to coronal caries progression; however, a benefit was found for root caries (Papas et al., 2007). Previously, our group evaluated to what extent changes in the use of PTB and IDAs explained changes in caries-free surfaces over the course of 17 years in adults and seniors (Pitchika et al., 2021). Among seniors, PTB and IDA usage explained a significant amount of change in caries-free surfaces (1.72 and 5.80, respectively, out of 8.44 total change explained). In a 11-year cohort study, PTB usage did not convene any beneficial effect on caries experience (Pitchika et al., 2019). To conclude, current evidence suggests that for coronal caries prevention the use of a fluoridated toothpaste is of utmost importance and that the mechanical aspect of self-performed oral hygiene is of minor importance (Hujoel et al., 2018).

In Germany, the number of PTB users has steadily increased over the past 20 years (Pitchika et al., 2019), which has likely led to fewer oral health problems in both younger and older generations (Pitchika et al., 2021). Considering current evidence stemming from clinical (Schmalz et al., 2017) and observational studies (Pitchika et al., 2019; Pitchika et al., 2021), it is coherent to recommend PTBs in dental practices as a preventive measure to reduce periodontal disease progression and tooth loss in the long term.

To identify major and minor confounders of the association between PTB usage and dental outcomes, we applied stepwise confounder adjustment (model 1: age and sex; model 2: model 1 plus education; model 3: model 2 plus remaining covariates) and evaluated changes in effects estimates for PTB usage. Age and sex were major confounders of the associations between PTB usage and all oral health variables. This is explained by pronounced differences in PTB usage with regard to age (see Appendix Table 3) in combination with the strong age dependence of all outcome variables (Schutzhold et al., 2015; Natto et al., 2018; Schmoeckel et al., 2021). With the exception of the youngest age group (probably due to limited financial resources), PTB usage declined with increasing age and was highest in 30–39-year-olds (38.1% vs. 12.8% in 70–81-year-olds). For plaque, school education was also identified as a major confounder. This is in agreement with previous studies, in which the socio-economic position was associated with higher plaque levels (Zini et al., 2011) and a higher risk of periodontitis (Borrell et al., 2006), which is one of the consequences of insufficient plaque control. Potential pathways comprehend insufficient oral hygiene procedures, irregular dental visits, and triggering of various risk factors related to socio-economic position (e.g., smoking), which in turn affect plaque control (Zini et al., 2011). The remaining confounders did not affect effect estimates and were therefore considered to be minor confounders.

Between SHIP-TREND baseline and follow-up examinations, periodontal disease levels had consistently improved. Loss to follow-up occurs in all longitudinal studies and is influenced by a number of factors including social status, general health, and age. Loss to follow-up introduces a selection bias, as the more diseased subjects drop out more frequently, and therefore the surviving participants are probably generally and also periodontally healthier. Also, in repeatedly participating subjects, periodontally diseased teeth are more frequently extracted. Thus, overall, we observe a survival of the fitter subjects and the fitter teeth. In addition, it has been reported in many observational studies that participants with periodontitis have a remarkable remission rate in deep sites (Mlachkova & Popova, 2014). In addition, subjects who participate in health surveys are likely to be very health conscious, as reflected in their high rates of doctor consultations and early cancer screenings (see Table 1), and may be highly motivated to improve their oral health habits. Similar observations can be made with control groups of randomized clinical trials studying the effect of scaling versus no treatment (Saffi et al., 2018; Kaushal et al., 2019). Here, patients improved their oral hygiene even though they were not motivated or instructed. Consistent with our data, the periodontal status also improved in a 3-year follow-up study (Desvarieux et al., 2013). To counter the problem of selection bias due to attrition (Collins et al., 2015), missing data were multiply imputed (Groenwold et al., 2012). Using imputed data, effect estimates were slightly diminished (see Figures 2 and Appendix Table 2) but still confirmative. Especially for longer follow-up times, effects were less pronounced using imputed data. This might be explained as follows. First, changes in tooth brush usage (i.e., from PTB to MTB, and from MTB to PTB and back) are more probable with longer follow-up times, resulting in classification bias and shifts of effect estimates towards the null. Second, compared to responders with no missing data included in complete case analyses, non-responders may have a less favourable risk factor profile at baseline, overriding the effects of PTB usage on oral health outcomes in the analysis of imputed data.

This study has strengths and limitations. A strength of our study is the prospective study design and the long median observation period of 7 years. We examined a large set of oral health outcomes, comprising gingival inflammation, periodontitis, caries, and their sequalae, namely tooth loss. Second, regression models were carefully chosen, including comprehensive adjustment for various confounders, thereby minimizing the chance for residual confounding. We used restricted cubic splines to allow for non-linear relationships. In main analyses, we did not adjust for baseline values of the outcome because PTB usage might have already affected baseline levels of the outcome and might thus be a mediator (Tennant et al., 2022). Effect estimates (ORs and betas) contrasting PTB and MTB users were graphically presented, facilitating interpretation of results. We additionally fitted random-effects models, considering time-variant levels of PTB usage, outcome variables, and covariates, giving confirmative results. However, as (i) follow-up time could not be modelled flexibly and (ii) the assumption that "time-invariant attributes of individuals are the result of random variation that is not correlated with other explanatory variables" (Listl et al., 2016) is usually not met, random-effects models were reported as sensitivity analyses and should be interpreted with care.

The study also has some limitations. First, PTB users had a more favourable health profile at baseline, rendering residual confounding probable despite comprehensive adjustment. Second, no distinction was made between different types of electric toothbrushes, although there have been studies showing performance differences between the various types (sonic, oscillating-rotating, battery powered). In a meta-analysis of 28 publications, the oscillating-rotating toothbrush was superior to the sonic toothbrush with respect to supragingival plaque control and gingivitis (Thomassen et al., 2022). Furthermore, in a video-controlled explorative clinical trial, no significant difference in plaque removal between manual and sonic toothbrushes could be demonstrated (Schlueter et al., 2021). Third, we considered only baseline levels of PTB usage (exposure) in main regression models, thereby ignoring potential shifts in PTB usage between baseline and follow-up. Indeed, 22.9% of MTB users became PTB users, while 19.4% of PTB users became MTB users between baseline and follow-up (Appendix Table 4). This methodological bias might have resulted in attenuated effect estimates as estimated by main models. However, random-effects models were generally confirmative, giving ORs of 0.6–0.8 for varying outcome variables, thus confirming the conclusions of the main models. Fourth, while tooth brushing frequency was generally adjusted for in regression models (86.0% and 90.5% of MTB and PTB users, respectively, brushed their teeth ≥2 times daily; see Table 1), tooth brushing frequency was not separately quantified in participants using both manual and PTBs. In participants reporting only MTB usage, 86.0% brushed their teeth ≥2 times daily. The corresponding percentages for participants reporting both MTB and PTB usage ($N = 153$; 23.6% of total PTB users in analysis) or only PTB usage ($N = 496$; 76.4% of total PTB users in analysis) were 88.7 and 96.1, respectively. Thus, there was little variation in tooth brushing frequencies in all subgroups. Lastly, periodontitis and caries measurements were only assessed on a half-mouth basis on four sites per tooth. Thus, the analysed outcome variables may not reflect the true situation and may underestimate disease severity. For measurements such as mean PD/CAL, the level of bias associated with half-mouth partial recordings is nevertheless small (Kingman et al., 2008). In general, there is a shift in effect estimates towards the null effect (Akinkugbe et al., 2015).

5 | CONCLUSION

Using prospective SHIP-TREND data, we found beneficial effects of self-reported PTB usage at baseline on gingival inflammation, periodontitis severity, and tooth loss at the 7-year follow-up. In contrast to short-term studies, which only investigated surrogate endpoints (plaque, gingivitis), we were additionally able to show age-dependent effects for the hard end-point tooth loss. Thus, PTB usage might have a positive impact on oral health in the general population. If in future randomized clinical trials, the beneficial effects of PTB usage on various short- and long-term end-points were confirmed, evidence on the beneficial effects of PTB usage as compared to MTB usage might be strengthened. This would, in turn, support a future recommendation of PTBs in dental practice.

AUTHOR CONTRIBUTIONS

Thomas Kocher and Birte Holtfreter substantially contributed to the conception or design of the study. Pauline Sager, Thomas Kocher, Vinay Pitchika, Stefanie Samietz, Henry Völzke, Clemens Walter, and Birte Holtfreter contributed to the acquisition, analysis, or interpretation of data. Pauline Sager, Birte Holtfreter, and Thomas Kocher drafted the manuscript. Vinay Pitchika, Stefanie Samietz, Henry Völzke, and Clemens Walter revised the manuscript critically for important intellectual content. All authors approved the final version of the manuscript and are accountable for all aspects of the work.

ACKNOWLEDGEMENT

Open Access funding enabled and organized by Projekt DEAL.

FUNDING INFORMATION

SHIP is part of the Community Medicine Research Network of the University Medicine Greifswald, which is supported by the German Federal State of Mecklenburg-West Pomerania.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from Forschungsverbund Community Medicine. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from https://fvcm.med.uni-greifswald.de/dd_service/data_use_intro.php with the permission of Forschungsverbund Community Medicine.

ETHICS STATEMENT

SHIP-TREND was positively evaluated by the ethics committee of the University of Greifswald (SHIP-TREND-0: BB 39/08a; SHIP-TREND-1: BB 174/15). All participants were informed about the study protocol and signed the informed consent and the privacy statement.

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SUPPORTING INFORMATION

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

How to cite this article: Sager, P., Kocher, T., Pitchika, V., Samietz, S., Völzke, H., Walter, C., & Holtfreter, B. (2023). Powered tooth brushes are beneficial for long-term oral health: Results from the Study of Health in Pomerania (SHIP-TREND). *Journal of Clinical Periodontology*, *50*(5), 548–558. https://doi.org/10.1111/jcpe.13763