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Have extraction patterns in German adults with severe periodontitis changed between 2000 and 2010? Results from two cohort studies

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Abstract

Aim: The aim of this study was to evaluate whether extraction thresholds in persons with severe periodontitis have changed between 2000 and 2010 and whether potential shifts have contributed to the reported decrease in tooth extractions in German adults over the last decades.

Materials and Methods: Data from two German population-based cohort studies in Northeast Germany (Studies of Health in Pomerania; SHIP-START [baseline 1997–2001; 11-year follow-up] and SHIP-TREND [baseline 2008–2012; 7-year follow-up]) were used. In SHIP-START (SHIP-TREND), 522 (478) participants with severe periodontitis according to the CDC/AAP case definition were included. Patterns of maximum probing depth (PD) and maximum clinical attachment level (CAL) for retained and extracted teeth were compared between SHIP-START and SHIP-TREND participants.

Results: No major differences in patterns of baseline maximum CAL of retained or extracted teeth were detected between SHIP-START and SHIP-TREND. Extraction thresholds were identified at the baseline at maximum CAL ≥6 and ≥9 mm. Tooth-level incidence rates for extraction for baseline maximum CAL of 6 mm were comparable between SHIP-START and SHIP-TREND (17.1 vs. 15.9 events per 1000 person-years).

Conclusions: After a decade, teeth in persons with severe periodontitis were still undergoing extraction with minor or moderate attachment loss. A change in extraction pattern did not contribute to the higher tooth retention rate.

KEYWORDS
clinical attachment level, cohort study, periodontal treatment, periodontitis, probing depth, tooth extraction

Clinical Relevance

Scientific rationale for study: We evaluated whether extraction thresholds changed over 10 years in persons with severe periodontitis.

Principal findings: Ten years later, extraction thresholds were unchanged and were identified at baseline maximum clinical attachment levels of ≥6 and ≥9 mm, independent of whether periodontal treatment (self-reported) was performed.

Practical implications: In Germany, periodontal diagnostics and therapy must be given a higher priority in general dental practices in order to achieve higher tooth retention rates.

1 | INTRODUCTION

Over the last two decades, the prevalence and severity of periodontitis has declined in Germany (Schutzhold et al., 2015). In parallel, the number of teeth has increased from 20.7 to 21.6 in dentate participants in the Studies of Health in Pomerania (SHIP) and from 12.5 to 16.1 in dentate seniors aged 65–74 years in the German Oral Health Studies (Schutzhold et al., 2015). Concomitantly, the total number of tooth extractions nation-wide has decreased from 16.2 million in 1991 to 11.9 million in 2020 (Kassenzahnärztliche Bundesvereinigung, 2021), despite increasing ageing of the German population.

What are the reasons for the decline in the number of tooth extractions? While a major contribution of increased tooth retention is indisputable due to the marked decline in caries (Schmoeckel et al., 2021), reductions in tooth loss attributable to decreasing periodontitis prevalences might provide a further explanation. In case of highly prevalent diseases such as periodontitis, two different factors may have led to a reduced disease burden (Rose, 1994): on one hand, improved personal oral hygiene measures have lowered the levels of periodontitis severity, which means there are fewer incipient cases, less progression to severe cases, and, ultimately, fewer extractions (Pitchika et al., 2021). On the other hand, the quality and quantity of periodontal treatment may have improved and led to reduced tooth loss rates due to successful periodontal interventions.

In each medical specialty, the transfer of medical advances into daily medical practice is a slow process (Lenfant, 2003; Morris et al., 2011). Using data from the two SHIP cohorts, we had the opportunity to examine whether change in periodontal training had an impact on extraction thresholds in daily dental practice. The establishment of periodontology professorships at the dental schools in Greifswald and Rostock in the 1990s boosted continuing education activities in the catchment area of SHIP for already practicing older dentists and simultaneously provided newly enrolled students with a more comprehensive periodontal education. In parallel, practicing dentists whose East German undergraduate education included little periodontal teaching went into retirement and were gradually replaced in part by newly graduated young dentists. We assumed that these two factors contributed to better knowledge of, attitudes about, and skills in periodontal treatment, retaining more teeth with advanced periodontal destruction primarily during the SHIP-TREND period (2008–2019).

According to earlier studies, general dentists in the past extracted periodontally diseased teeth showing only minor or moderate periodontal attachment loss (Klock & Haugejorden, 1993; Splieth et al., 2002; Maier et al., 2020). However, during more recent decades, it has become evident that not all persons with poor oral hygiene develop periodontitis, that periodontal progression is slow (Baelum et al., 1997; Schatzle et al., 2003; Gatke et al., 2012), and that most periodontal interventions can be performed non-surgically (Dommisch et al., 2020; Graetz et al., 2020). Today, in fact, the majority of periodontal treatments covered by statutory insurance in Germany are non-surgical (Kassenzahnärztliche Bundesvereinigung, 2021).

The above mentioned reasons support decisions to retain periodontally affected teeth instead of extracting them. Academic studies have also reported that most teeth with a "questionable" or even "hopeless" prognosis can be preserved over a long period under supportive periodontal treatment (Checchi et al., 2002; Pretzl et al., 2008; Graetz et al., 2011; Cortellini et al., 2020; Graetz et al., 2020; Rahim-Wostefeld et al., 2020). Thus, in academic settings the term "questionable" or "hopeless" prognosis had been challenged (Cortellini et al., 2020). However, in terms of the general population in which periodontal treatment is predominantly performed by general dentists, current information on attachment level thresholds at which teeth are extracted. Two hundred Italian patients with minimal dental care were followed for 8.6 years, showing the mean baseline bone loss of extracted teeth to be 31.6% and that of retained 21.4% (Al-Harthi et al., 2022). Based on data from specialized practices or university settings, a recent meta-analysis reported a wide range of baseline attachment level, ranging from 5.65 to 14.8 mm in extracted teeth (Sarafidou et al., 2022). Another recent review found that for treatment planning, an initial probing depth ≥5 mm was the factor most often considered when deciding to extract or preserve a periodontally compromised tooth (Carcamo-Espana et al., 2022). Taken together, these data point to the fact that both in periodontally untreated and treated patients, a substantial percentage of extractions was performed even with a moderate severity of periodontitis.

To clarify whether a potential change of attachment level thresholds at which periodontally diseased teeth were extracted might have contributed to the higher tooth retention rates in Germany, we compared baseline maximum probing depth (PD) and clinical attachment levels (CAL) from retained/extracted teeth of two prospective cohort studies of the SHIP project with baseline examinations conducted 10 years apart and with follow-ups. First, we associated baseline maximum values of PD and CAL with 11-year (SHIP-START) and 7-year tooth loss (SHIP-TREND). Second, we assessed patterns of baseline maximum PD and CAL in retained teeth and those extracted in the period between baseline and follow-up (incidentally extracted teeth) in participants with severe periodontitis with and without self-reported previous periodontal treatment. Our hypothesis was that teeth with greater periodontal destruction were more often retained in SHIP-TREND than in SHIP-START due to a possible shift of extraction thresholds towards higher attachment levels.

2 | MATERIALS AND METHODS

2.1 | Study design and sample

SHIP-START is a population-based health survey in West Pomerania, a region in the North-East of Germany (John et al., 2001).

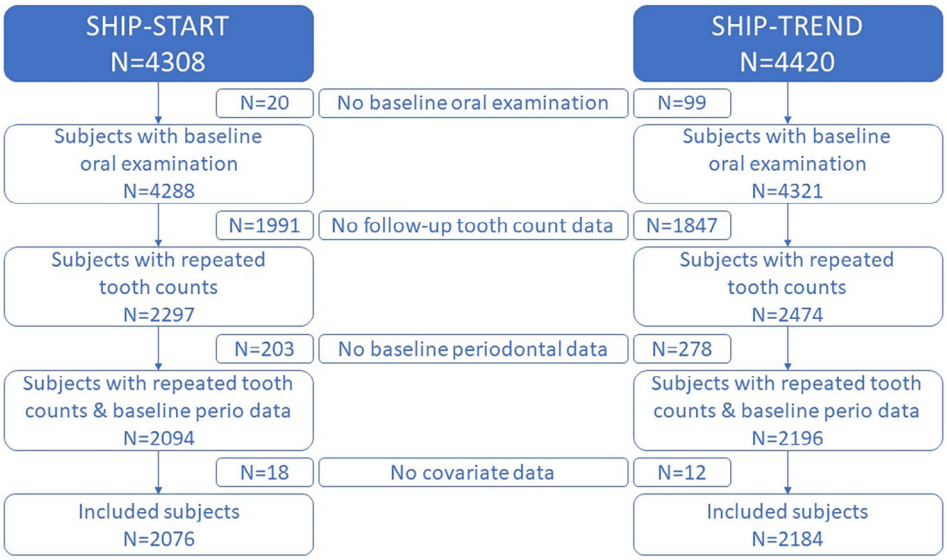

FIGURE 1 Flow-chart showing flow of subjects for SHIP-START and SHIP-TREND.

SHIP-START baseline examinations were conducted from 1997 to 2001. A two-stage cluster sampling yielded twelve 5-year strata (20–79 years) for both sexes, each including 292 subjects. Caucasian subjects with German citizenship and main residency in the area were randomly drawn, proportional to each community population size and stratified by age and sex. The net sample included 6265 eligible subjects of whom 4308 participated (response 68.8%). After 5 years (SHIP-START-1; 2002–2006; $N = 3300$) and 11 years (SHIP-START-2; 2008–2012; $N = 2333$), follow-ups were conducted. Out of 4308 baseline participants, 2076 were included in analyses (Figure 1).

SHIP-TREND is a second independent cohort selected from the same area as SHIP-START (Volzke et al., 2011). Examinations were conducted from 2008 to 2012. A stratified (age, sex and city/county of residence) random sample of 10,000 adults aged 20–79 years was drawn from population registries. The net sample included 8826 persons, of whom 4420 were finally recruited (response rate 50.1%). After 7 years, a follow-up study was conducted (SHIP-TREND-1, 2014–2018, $N = 2507$). Out of 4420 baseline participants, 2184 were included in analyses (Figure 1).

A description of the periodontal examination, covariates, laboratory measurements, and results from calibration studies evaluating intra- and inter-rater reliability are given in the on-line Supplement. Reporting was done in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.

2.2 | Statistical analyses

Descriptive analyses are presented for the total population and for participants with severe periodontitis according to the CDC/AAP case definition (Page & Eke, 2007). Mean values with standard deviations and medians with 25% and 75% quantiles are reported for continuous variables. Relative frequency distributions are presented for categorical variables.

2.3 | Subject-level analyses

We provided information on the distribution of the number of teeth at baseline and follow-up, the number of extracted teeth, annual tooth loss (calculated as the number of extracted teeth divided by follow-up time in exact years), and the number and percentage of incidentally edentulous participants. The number of extracted teeth was presented in total, according to baseline age and according to baseline levels of the CDC/AAP case definition. In addition, the number of incidentally extracted teeth was regressed on (i) age with adjustment for sex and follow-up time (logarithmized; as offset) and (ii) the CDC/AAP case definition with adjustment for age (restricted cubic splines with three knots), sex, school education, smoking status, known diabetes mellitus, HbA1c (restricted cubic splines with three knots), waist circumference (restricted cubic splines with three knots), and follow-up time (logarithms; as offset) using negative binomial regression models. For the latter model, covariates were chosen to represent the main risk factors for periodontitis and tooth loss. Incidence rate ratios (IRRs) and 95% confidence intervals (CIs) are reported.

In addition, the number of incidentally extracted teeth was regressed on the CDC/AAP case definition, with adjustment for age (linear), sex, school education, smoking status, known diabetes mellitus, HbA1c (linear), waist circumference (linear), and follow-up time (logarithms; as offset) using negative binomial regression models. These covariates were chosen to represent main risk factors for periodontitis and tooth loss. IRRs and 95% confidence intervals (CIs) are reported.

2.4 | Tooth-level analyses

For the following analyses, participants were restricted to those with severe periodontitis according to the CDC/AAP case definition. Presence of teeth was defined using clinical examination data from baseline and follow-up studies (SHIP-START-0/-1/-2, SHIP-TREND-0/-1). If in SHIP-START, information on tooth status was missing for one of

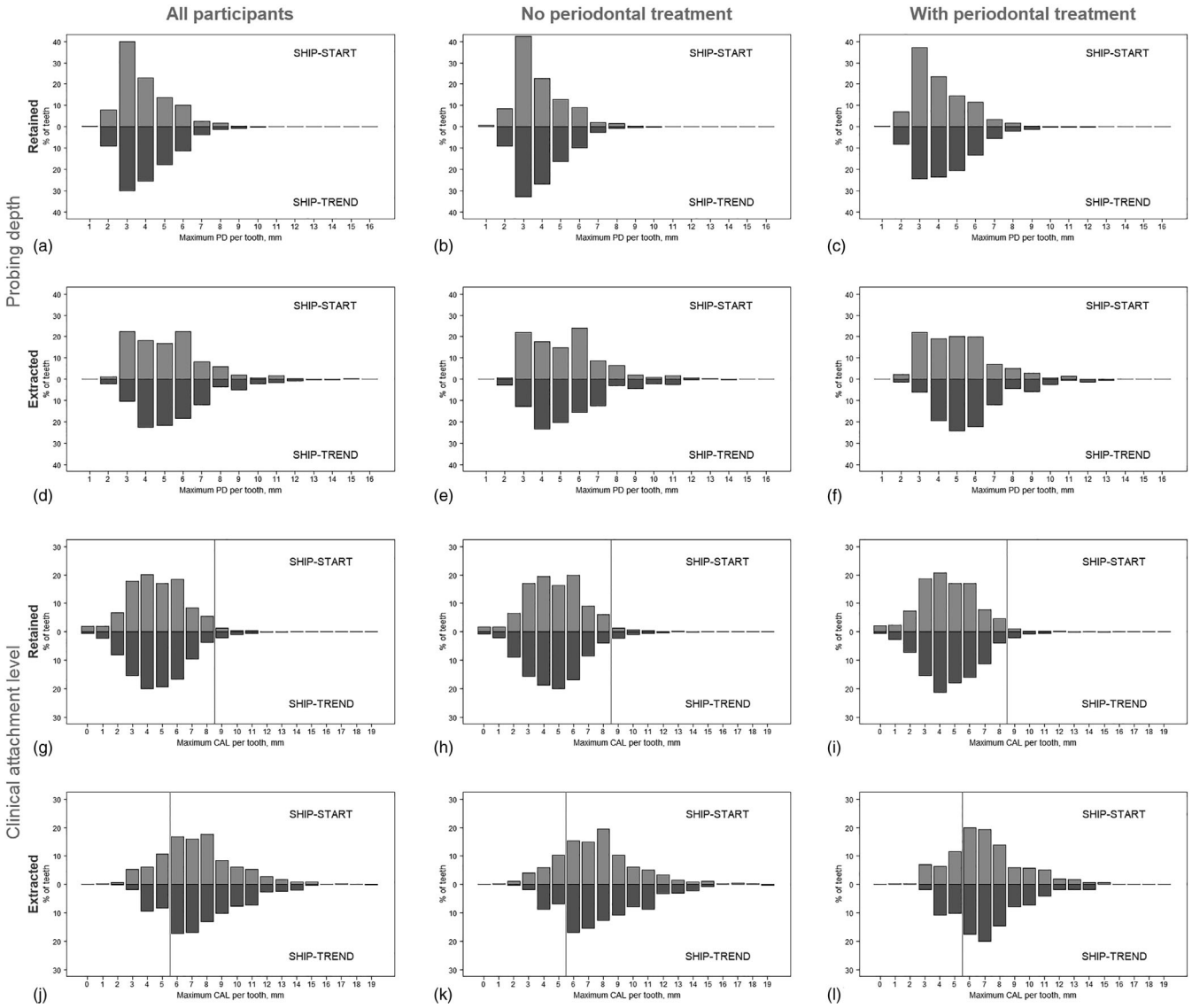

FIGURE 2 Distributions of retained and extracted teeth according to baseline maximum probing depth (PD; a–f) and baseline maximum clinical attachment level (CAL; g–l) per tooth for SHIP-START and SHIP-TREND in all participant (left), participants reporting no periodontal treatment (middle), and participants reporting periodontal treatment between baseline and follow-up (right). Derived extraction thresholds for CAL are indicated as red vertical lines.

the two follow-up examinations, information from the other two examinations was used to infer the tooth status and survival time. For calculation of incidence rates, failure times for incidentally extracted teeth were defined as follows: (i) $(\text{Date}_1 - \text{Date}_0)/2$ if extraction occurred between SHIP-START-0 and SHIP-START-1 (correspondingly for SHIP-TREND-0 and SHIP-TREND-1); (ii) $(\text{Date}_1 - \text{Date}_0) + (\text{Date}_2 - \text{Date}_1)/2$ if extraction occurred between SHIP-START-1 and SHIP-START-2.

First, extraction patterns by tooth type were evaluated, calculating incidence rates (with 95% CIs) for tooth loss for each quadrant and tooth separately and presenting them graphically (Figure S1).

Second, we graphically assessed distributions of baseline maximum PD and CAL (half-mouth data) for retained and extracted teeth and compared distributions between SHIP-START and SHIP-TREND for all participants as well as participants with and without a self-reported periodontal treatment. For exact percentages, see Tables S1 and S2. Based on these distributions, we visually determined two different baseline maximum CAL thresholds for extraction, because the extent of CAL is the decisive parameter for tooth preservation. Baseline CAL correlated better with incidental tooth loss than PD, as indicated by the higher area under the receiver operating characteristic (AUROC) values for CAL. The upper threshold was selected such that <5% of retained teeth presented with baseline CAL levels of at least that threshold (Figure 2g–i). The lower threshold was determined from the distribution of extracted teeth (Figure 2j–l). It was selected as the baseline CAL value at which the percentage of teeth presenting with that specific baseline CAL value had markedly increased. Additionally, mixed linear models were applied to test for distributional

TABLE 1 Baseline characteristics for total samples and for the subsample with severe periodontitis according to the Centers for Disease Control and Prevention (CDC)/American Academy of Periodontology (AAP) case definition for periodontitis.

	Total sample			Severe periodontitis		
	SHIP-START	SHIP-TREND	*p*-value	SHIP-START	SHIP-TREND	*p*-value
N	2076	2184	-	521	478	-
Follow-up time, years	11.1 ± 0.8	7.4 ± 0.7	.0001	11.0 ± 0.7	7.4 ± 0.6	.0001
Male sex	983 (47.4%)	1066 (48.8%)	.341	310 (59.5%)	300 (62.8%)	.291
Age, years	45.4 ± 13.3	48.5 ± 13.4	.0001	52.9 ± 10.4	56.8 ± 10.9	.0001
School education						
<10	503 (24.2%)	252 (11.5%)		206 (39.5%)	87 (18.2%)	
10	1136 (54.7%)	1222 (56.0%)		227 (43.6%)	261 (54.6%)	
>10	437 (21.1%)	710 (32.5%)	<.001	88 (16.9%)	130 (27.2%)	<.001
Smoking status						
Never smoker	804 (38.7%)	851 (39.0%)		178 (34.2%)	153 (32.0%)	
Ex-smoker	693 (33.4%)	829 (37.9%)		198 (38.0%)	212 (44.4%)	
Current smoker	579 (27.9%)	504 (23.1%)	<.001	145 (27.8%)	113 (23.6%)	.106
Known diabetes, yes	77 (3.7%)	116 (5.3%)	.012	34 (6.5%)	41 (8.6%)	.219
Haemoglobin A1c, %	5.3 ± 0.8	5.2 ± 0.7	.223	5.5 ± 0.9	5.5 ± 0.7	.167
Body mass index, kg/m^2	26.7 ± 4.5	27.4 ± 4.6	.0001	27.8 ± 4.3	28.4 ± 4.4	.0149
Waist circumference, cm	87.1 ± 13.5	88.7 ± 13.3	.0003	92.2 ± 12.9	93.8 ± 13.2	.1261
CDC/AAP case definition						
No or mild	749 (36.1%)	751 (34.4%)		-	-	
Moderate	806 (38.8%)	955 (43.7%)		-	-	
Severe	521 (25.1%)	478 (21.9%)	.003	521 (100%)	478 (100%)	-
Mean PD, mm	2.41 ± 0.65	2.50 ± 0.58	.0001	3.09 ± 0.74	3.19 ± 0.71	.0124
Mean CAL, mm	2.36 ± 1.64	2.29 ± 1.52	.3237	4.16 ± 1.60	4.16 ± 1.58	.9019
Percentage of sites with PD ≥4 mm, %	10.3 ± 14.6	12.1 ± 16.6	.0048	26.5 ± 18.5	32.5 ± 20.4	.0001
Percentage of sites with PD ≥6 mm, %	2.4 ± 7.4	1.8 ± 5.6	.0056	8.4 ± 12.1	7.7 ± 9.6	.8851
Number of teeth	22.0 ± 6.0	23.4 ± 5.2	.0001	19.1 ± 6.6	20.7 ± 6.2	.0001
Self-reported periodontal treatment[a]						
No	1415 (68.2%)	1698 (77.8%)		290 (55.7%)	295 (61.7%)	
Yes	536 (25.8%)	449 (20.6%)		212 (40.7%)	168 (35.3%)	
Missing	125 (6.0%)	37 (1.6%)	<.001	19 (3.7%)	15 (3.0%)	.007

Note: SHIP-START (11-year follow-up data) and SHIP-TREND (7-year follow-up data).

Abbreviations: CAL, clinical attachment level; PD, probing depth.

[a]Defined as self-reported periodontal treatment within the last 5 years in SHIP-START-1 or SHIP-START-2 (yes: in SHIP-START-1 or in SHIP-START-2; no: neither in SHIP-START-1 nor in SHIP-START-2) or in SHIP-TREND-1.

differences of baseline maximum PD/CAL (dependent variable) in retained or extracted teeth (separate models) between SHIP-START and SHIP-TREND (fixed effect: study, differentiating between SHIP-START and SHIP-TREND; random effect for clustering of teeth within subjects). No other covariates were adjusted for. Respective *p*-values are reported.

Third, percentages of extracted teeth (no. extracted/[no. extracted + no. retained]) were calculated for varying levels of maximum PD/CAL and compared between SHIP-START and SHIP-TREND for all participants and stratified for participants without self-reported periodontal treatment and with self-reported periodontal treatment. Fourth, we estimated the AUROC to assess the ability of baseline maximum PD/CAL to differentiate with regard to prospective tooth loss, that is, tooth preservation versus extraction. AUROCs are presented together with their corresponding 95% CIs. Teeth were restricted to those with at least one baseline PD and at least one baseline CAL measurement, to ensure comparability of AUROC values. Finally, to account for the different follow-up times of SHIP-START and SHIP-TREND, we also calculated incidence rates by baseline maximum PD/CAL per tooth (in 1000 person-years). In sensitivity analyses, tooth-level analyses were repeated excluding carious or filled teeth (baseline status, see Data S1).

All analyses were conducted with complete case data. Missing values were not imputed. Two-sided *p*-values <.05 were

TABLE 2 Tooth count and tooth loss information (from baseline to follow-up; full-mouth excluding third molars) in total and by age as well as by the Centers for Disease Control and Prevention (CDC)/American Academy of Periodontology (AAP) case definition for periodontitis for SHIP-START (11-year follow-up data) and SHIP-TREND (7-year follow-up data).

		Number of teeth		Number of extracted teeth				Incidence rate for edentulism, 1000 person-years	
	N	At baseline	At follow-up	Between baseline and follow-up	IRR (95% CI)[a]	Annual tooth loss, teeth/year	Number of incidentally edentulous subjects	Between baseline and follow-up	IRR (95% CI)**
SHIP-START									
Total	2076	22.0 ± 6.0 24 (20; 26)	20.3 ± 7.4 23 (17; 26)	1.7 ± 2.9 1 (0; 2)	-	0.15 ± 0.26 0.08 (0; 0.19)	50	2.19 (1.66; 2.89)	-
By age, years									
20–39	783	25.3 ± 3.3 26 (24; 28)	24.6 ± 4.1 26 (23; 27)	0.7 ± 1.8 0 (0; 1)	1.00 (ref.)[a]	0.06 ± 0.16 0 (0; 0.09)	2	0.23 (0.06; 0.90)	1.00 (ref.)[a]
40–59	968	21.1 ± 5.6 22 (19; 25)	19.0 ± 7.2 21 (15; 25)	2.1 ± 3.2 1 (0; 3)	2.98 (2.55; 3.48)	0.19 ± 0.29 0.09 (0; 0.28)	27	2.57 (1.76; 3.74)	11.09 (2.64; 46.62)
60–81	325	16.6 ± 7.3 18 (11; 23)	13.9 ± 8.2 15 (7; 21)	2.7 ± 3.2 2 (0; 4)	3.74 (3.06; 4.57)	0.25 ± 0.29 0.18 (0; 0.37)	21	6.12 (3.99; 9.38)	25.06 (5.87; 106.95)
By CDC/AAP case definition									
No or mild	749	23.8 ± 5.2 25 (22; 27)	23.2 ± 5.7 25 (22; 27)	0.6 ± 1.2 0 (0; 1)	1.00 (ref.)[b]	0.05 ± 0.10 0 (0; 0.09)	8	0.96 (0.48; 1.92)	1.00 (ref.)[b]
Moderate	806	22.2 ± 5.5 24 (20; 26)	20.8 ± 6.5 23 (18; 26)	1.4 ± 2.2 1 (0; 2)	1.77 (1.51; 2.09)	0.12 ± 0.20 0.08 (0; 0.19)	12	1.35 (0.77; 2.38)	0.66 (0.26; 1.66)
Severe	521	19.1 ± 6.6 21 (14; 24)	15.3 ± 8.4 17 (8; 22)	3.8 ± 4.2 2 (1; 6)	4.09 (3.42; 4.89)	0.34 ± 0.38 0.19 (0.09; 0.48)	30	5.37 (3.76; 7.68)	1.68 (0.73; 3.89)
SHIP-TREND									
Total	2184	23.4 ± 5.2 25 (21; 27)	22.3 ± 6.3 24 (20; 27)	1.0 ± 2.2 0 (0; 1)	-	0.14 ± 0.29 0 (0; 0.14)	19	1.18 (0.76; 1.86)	-
By age, years									
20–39	600	26.6 ± 2.1 27 (26; 28)	26.3 ± 2.6 27 (25; 28)	0.33 ± 1.01 0 (0; 0)	1.00 (ref.)[a]	0.04 ± 0.13 0 (0; 0)	1	0.23 (0.03; 1.60)	1.00 (ref.)[a]
40–59	1080	23.2 ± 4.7 24 (22; 26)	22.1 ± 5.8 24 (20; 26)	1.08 ± 2.27 0 (0; 1)	3.29 (2.64; 4.11)	0.15 ± 0.30 0 (0; 0.14)	6	0.76 (0.34; 1.69)	3.34 (0.40; 27.75)
60–81	504	19.8 ± 6.2 21 (16; 25)	18.0 ± 7.3 20 (13; 24)	1.77 ± 2.72 1 (0; 2)	5.40 (4.23; 6.90)	0.24 ± 0.37 0.13 (0; 0.29)	12	3.27 (1.86; 5.76)	14.00 (1.82; 107.72)
By CDC/AAP case definition									
No or mild	751	25.0 ± 4.2 26 (24; 28)	24.7 ± 4.6 26 (23; 28)	0.4 ± 1.0 0 (0; 0)	1.00 (ref.)[b]	0.05 ± 0.13 0 (0; 0)	2	0.36 (0.09; 1.45)	1.00 (ref.)[b]
Moderate	955	23.4 ± 4.7 25 (21; 27)	22.6 ± 5.5 24 (20; 27)	0.8 ± 1.6 0 (0; 1)	1.31 (1.07; 1.60)	0.11 ± 0.22 0 (0; 0.14)	4	0.57 (0.21; 1.52)	0.67 (0.12; 3.85)

TABLE 2 (Continued)

	N	Number of teeth		Number of extracted teeth		Annual tooth loss, teeth/year	Number of incidentally edentulous subjects	Incidence rate for edentulism, 1000 person-years	
		At baseline	At follow-up	Between baseline and follow-up	IRR (95% CI)[a]			Between baseline and follow-up	IRR (95% CI)**
Severe	478	20.7 ± 6.2 22 (17; 26)	18.2 ± 7.8 20 (13; 25)	2.6 ± 3.5 1 (0; 4)	3.52 (2.81; 4.39)	0.34 ± 0.46 0.14 (0; 0.52)	13	3.71 (2.15; 6.39)	2.63 (0.53; 13.05)

Note: Data are presented as Mean ± SD and median (Q25%; Q75%) or numbers (percentages).
Abbreviations: CI, confidence interval; IRR, incidence rate ratio; N, number; Q25%, 25% quantile; Q75%, 75% quantile; SD, standard deviation.
[a]Adjusted for sex and follow-up time (logarithmised; as offset).
[b]Adjusted for age (restricted cubic splines with three knots), sex, school education, smoking status, known diabetes mellitus, HbA1c (restricted cubic splines with three knots), waist circumference (restricted cubic splines with three knots), and follow-up time (logarithmised; as offset).
**$p < 0.01$.

considered statistically significant. All analyses were performed using Stata/SE Version 17.0 (StataCorp, 2021) and R 4.0.3 (R Core Team, 2021).

3 | RESULTS

3.1 | Subject-level analyses

In SHIP-START and SHIP-TREND, 521 (25.1%) and 478 (21.9%) participants had severe periodontitis, respectively (Table 1). Participants with severe periodontitis differed by age (3.9 years) and follow-up time (11.0 and 7.4 years). For baseline mean CAL, no differences were detected between SHIP-TREND and SHIP-START participants, but SHIP-TREND participants had 1.6 more teeth than SHIP-START participants. Periodontal treatment between baseline and follow-up was reported in 40.7% and 35.3% of SHIP-START and SHIP-TREND participants with severe periodontitis, respectively.

In SHIP-START, the average annual tooth loss was 0.15 (SD 0.26) (Table 2). Compared to participants with no/mild periodontitis, incidence rates for tooth loss were 1.77-fold higher (95% CI: 1.51–2.09) in participants with moderate periodontitis and 4.09-fold higher (95% CI: 3.42–4.89) in participants with severe periodontitis. In SHIP-TREND, the average annual tooth loss was 0.14 (SD 0.29). IRRs for tooth loss were 1.31 (95% CI: 1.07–1.60) and 3.52 (95% CI: 2.81–4.39) in SHIP-TREND participants with moderate and severe periodontitis, respectively, and were thus lower than in SHIP-START.

In the following, we will focus on tooth loss (presumably) attributable to periodontitis. In subsequent analyses, participants were restricted to those with severe periodontitis and the analysis was changed to tooth level.

3.2 | Extraction thresholds based on tooth-level analyses

We evaluated whether distributions of baseline maximum PD/CAL of retained or extracted teeth had changed between SHIP-START and SHIP-TREND (Figure 2). Although distributions of baseline maximum PD differed significantly between the two studies for retained ($p = .001$; Figure 2a) and extracted ($p = .005$; Figure 2d) teeth due to the large sample size, only a slight right shift of the distribution (i.e., shift to higher baseline maximum PD levels) in SHIP-TREND was observed. Changes were slightly more pronounced in participants reporting periodontal treatment ($p = .010$ and $p < .001$, respectively) compared to participants reporting no periodontal treatment ($p = .037$ and $p = .174$, respectively). In contrast to baseline maximum PD levels, distributions of baseline maximum CAL did not differ significantly between the two studies for retained ($p = .154$; Figure 2g) or extracted ($p = .096$; Figure 2j) teeth, either statistically or visually. Only in participants reporting periodontal treatment did the maximum CAL of extracted teeth improve significantly between SHIP-START and SHIP-TREND

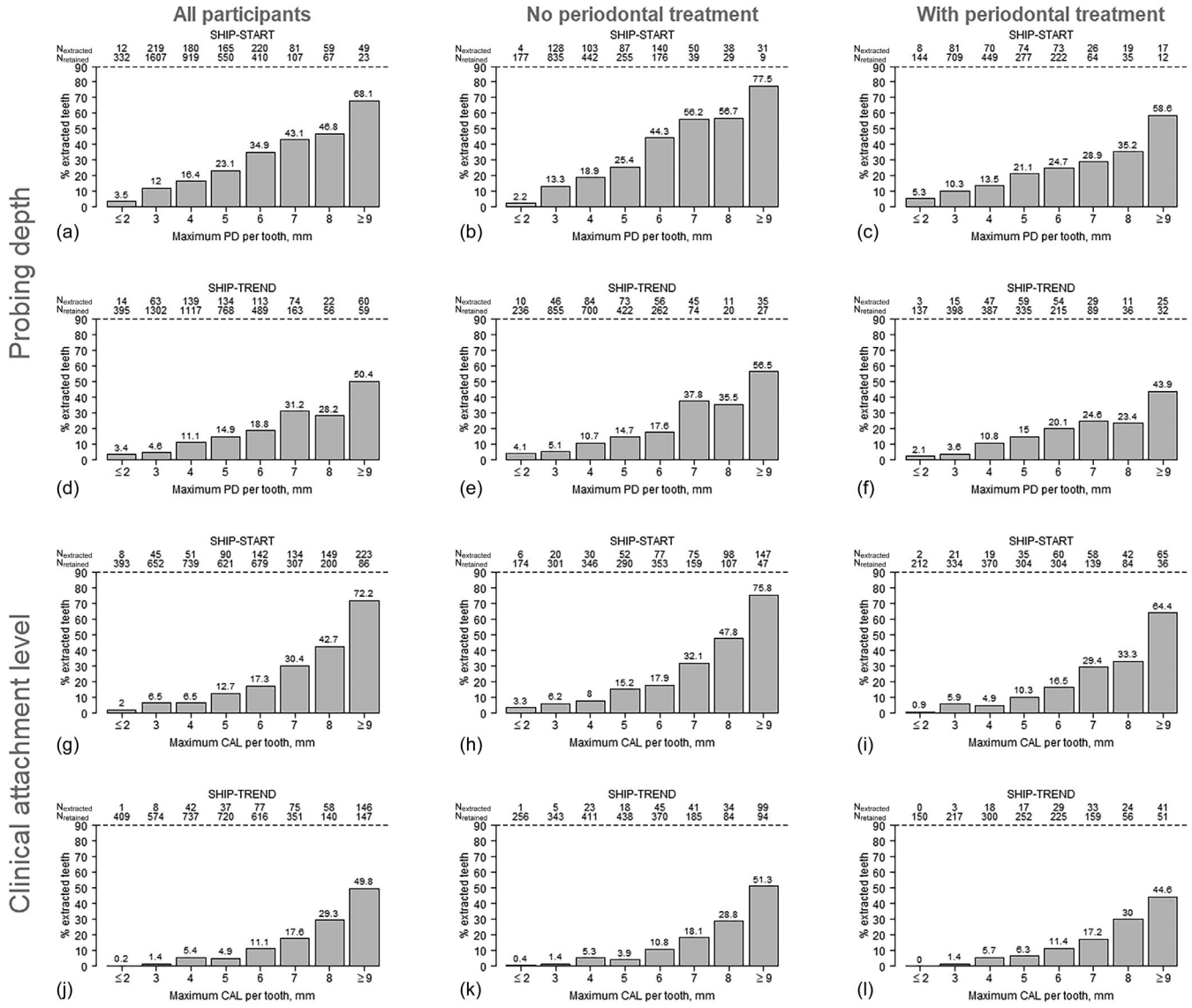

FIGURE 3 Distributions of percentages of extracted teeth by maximum probing depth (PD; a–f) and maximum clinical attachment level (CAL; g–l) per tooth at baseline for SHIP-START (above) and SHIP-TREND (below) for all participants (left), participants with no self-reported periodontal treatment between baseline and last follow-up (middle), and participants with self-reported periodontal treatment between baseline and last follow-up (right). Derived extraction thresholds are indicated as red vertical lines. As SHIP-START (mean: 11.1 years) has a longer follow-up time than SHIP-TREND (mean: 7.4 years), SHIP-START participants naturally had higher percentages of extracted teeth.

($p < .001$); however, visually, only a minor shift of the distribution was found. For the remaining comparisons in periodontally treated ($p = .730$ for retained teeth) and untreated participants ($p = .740$ and $p = .189$ for retained and extracted teeth, respectively), no differences were detected.

Figure 3 shows the percentages of extracted teeth in relation to maximum baseline PD/CAL per tooth for both studies. In SHIP-START, percentages of tooth extractions increased steadily with increasing baseline CAL categories: for CALs of 3–5 mm by 0%–5% in all, by 2%–7% in periodontally untreated, and by 5%–6% in treated participants. However, the percentages of extracted teeth increased markedly (13.1%) between baseline maximum CALs of 6 and 7 mm and between baseline maximum CALs of 8 and ≥9 mm (29.5%) in the total sample, with similar results in untreated and treated participants (Figure 3g–i). The upper baseline CAL threshold (≥9 mm) was replicated in SHIP-TREND (Figure 3j–l), but to a lesser extent (15–22% difference), whereas the lower CAL threshold (≥6 mm) was blurred (6%–7%). Finally, in both studies, the percentages of extracted teeth in relation to baseline maximum CAL improved in treated compared to untreated participants, albeit less pronounced in SHIP-TREND.

These results were underlined by AUROC estimates (Table 3). In SHIP-START/TREND, differentiation with regard to tooth loss was better for baseline maximum CAL (AUROC = 0.792/0.809) than for baseline maximum PD (AUROC = 0.695/0.723). Results were consistent for subgroups defined by self-reported periodontal treatment.

TABLE 3 Areas under the receiver operating characteristic curve (AUROC) with 95% confidence intervals for baseline maximum probing depths and maximum clinical attachment levels (maximum per tooth) on 11-year (SHIP-START) and 7-year tooth loss (SHIP-TREND) in total and by self-reported periodontal treatment.

	SHIP-START	SHIP-TREND
Total subsample		
N teeth	4519	4138
N retained	3677	3694
N extracted	842	444
AUROC (95% CI)		
Maximum PD	0.695 (0.675–0.714)	0.723 (0.698–0.747)
Maximum CAL	0.792 (0.775–0.809)	0.809 (0.788–0.830)
Reporting NO periodontal treatment between baseline and follow-up		
N teeth	2282	2447
N retained	1777	2181
N extracted	505	266
AUROC (95% CI)		
Maximum PD	0.724 (0.700–0.749)	0.719 (0.686–0.752)
Maximum CAL	0.796 (0.774–0.819)	0.822 (0.796–0.849)
Reporting periodontal treatment between baseline and follow-up		
N teeth	2085	1575
N retained	1783	1410
N extracted	302	165
AUROC (95% CI)		
Maximum PD	0.660 (0.627–0.693)	0.736 (0.700–0.772)
Maximum CAL	0.782 (0.753–0.810)	0.786 (0.751–0.821)

Note: Only participants with severe periodontitis according to Centers for Disease Control and Prevention (CDC)/American Academy of periodontology (AAP) case definition were included. Teeth were restricted to those with at least one probing depth and at least one clinical attachment level measurement.
Abbreviations: AUROC, area under the receiver operating characteristic; CAL, clinical attachment level; CI, confidence interval; *N*, number of teeth; PD, probing depth.

3.3 | Rates of incident tooth loss

To account for different follow-up times of SHIP-START and SHIP-TREND, we also calculated incidence rates by baseline maximum PD/CAL per tooth (Figure 4). Incidence rates by baseline maximum PD (Figure 4a–c) and baseline maximum CAL (Figure 4d–f) between SHIP-START and SHIP-TREND showed nearly consistent patterns across the two studies. Lower and upper maximum CAL thresholds, as described in Figure 3, were clearly detected in both studies, both in the total sample and in the subgroups.

3.4 | Sensitivity analyses

Sensitivity analyses were performed, excluding filled and carious teeth (Figure S3). Basically, the results remained consistent. Distributions of maximum PD/CAL in retained and extracted teeth did not differ significantly between SHIP-START and SHIP-TREND ($p > .05$) (Table S3).

4 | DISCUSSION

Ten years after conducting SHIP-START, periodontitis severity by CDC/AAP case definition was still associated with markedly increased risk for incident tooth loss. Overall, annual tooth loss rates remained unchanged between SHIP-START (0.15 ± 0.26) and SHIP-TREND (0.14 ± 0.29), while minor decreases were observed only in 40- to 59-year-olds (0.19 ± 0.29–0.15 ± 0.30). At the tooth level, no major differences in distributions of baseline maximum PD and CAL in extracted teeth were identified while comparing SHIP-START with SHIP-TREND. This apparent similarity of the baseline maximum CAL distribution in both cohorts indicates that dentists reached similar decisions to extract or retain teeth and that treatment planning had not changed. Irrespective of how data were visualized (Figures 2–4), the upper CAL extraction threshold was clearly evident for both cohorts: in SHIP-START and SHIP-TREND, 72.2% and 49.8% of teeth with baseline maximum CAL ≥9 mm were extracted during follow-up, respectively (Figure 3). In SHIP-TREND, the lower extraction threshold at baseline CAL (≥6 mm) was clearly noticeable because of the steep increase (about 13%) between baseline CALs of 5 and 6 mm (Figure 2j), whereas in SHIP-START this was less clear. It is our opinion that extracting teeth with an attachment loss of 5–7 mm is premature, because the annual changes in mean CAL are very low in these populations, equaling just 0.62 mm over 10 years. Even without periodontal treatment, it would probably have been possible to retain these teeth for a longer period. Nevertheless, it should be borne in mind that we assumed that the extractions were due to periodontitis; we did not know the real reasons for tooth extractions.

Periodontally affected teeth are classified as questionable when they exhibit a radiological bone loss (BL) between 50% and 75% and as hopeless if BL exceeds 75% (Checchi et al., 2002). To translate CAL measurements into percentages of BL, a mean root length of 13.6–15.2 mm for premolars and 13.0–14.5 mm for molars (Schumacher, 1997) was assumed. Thus, a BL of 50% (75%) corresponds to approximately 6.5 mm (11.4 mm) CAL. This BL range well matches the lower and upper attachment level thresholds for extracted teeth as found in our analyses. The upper threshold corresponds to Checci's classification as hopeless teeth. To treat and to retain teeth with such severe periodontal destruction requires profound periodontal knowledge, and thus this threshold can be accepted for extraction in general practice without objections. The lower threshold with ≥6 mm baseline CAL, however, which encompasses about 80% of extracted teeth, does not justify unreflected tooth extractions for periodontal reasons. Preserving a tooth within this CAL range should be within the competence of general dentists (Maier et al., 2020).

Our major finding, namely that the decision to extract based on a low CAL, was in accordance with previous studies (Klock &

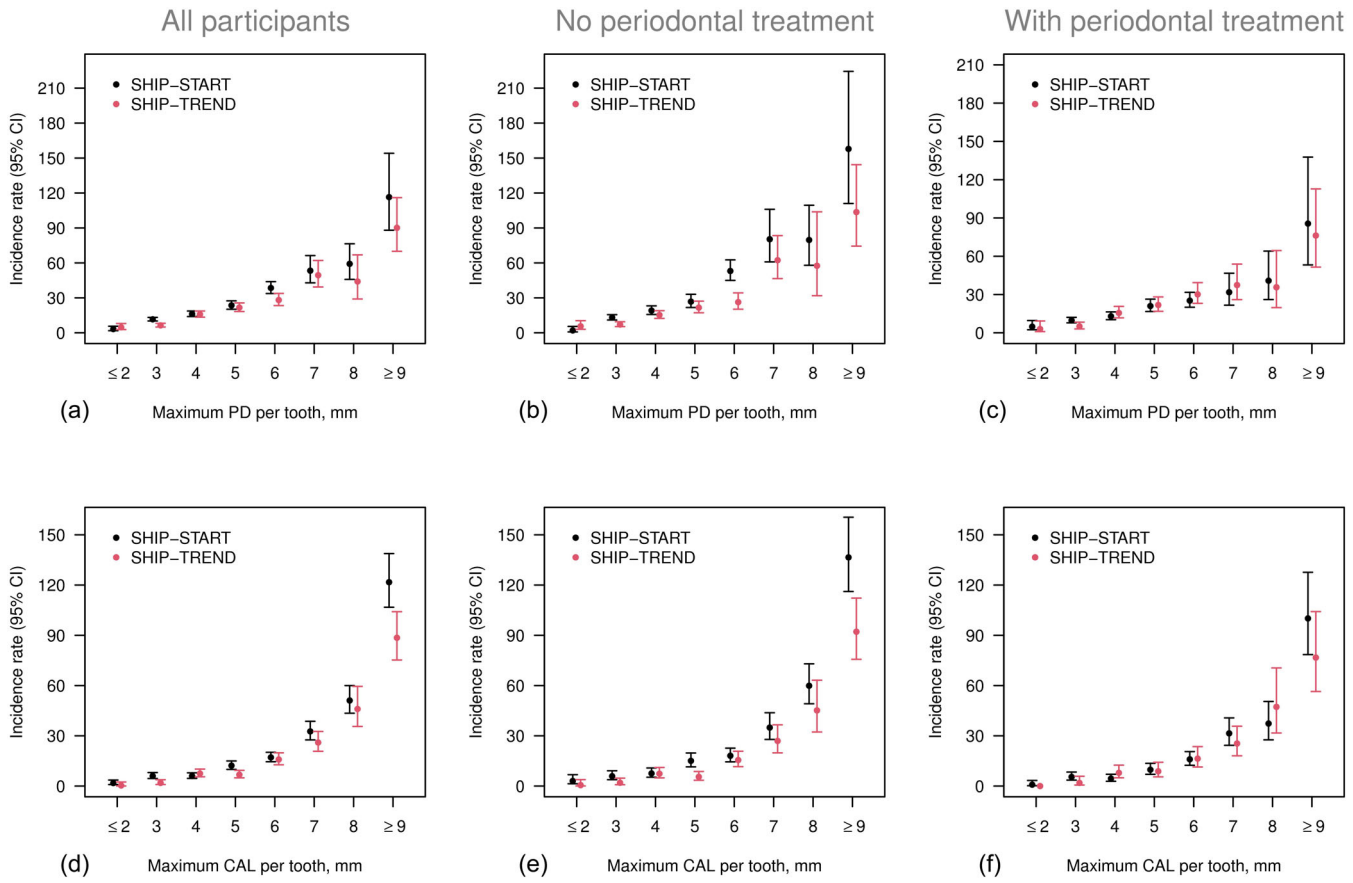

FIGURE 4 Incidence rates (in 1000 person-years; with 95% confidence intervals) by maximum probing depth (PD; a–c) and maximum clinical attachment level (CAL; d–f) per tooth at baseline for SHIP-START (black) and SHIP-TREND (red) for all participants (left), participants with no self-reported periodontal treatment between baseline and last follow-up (middle), and participants with self-reported periodontal treatment between baseline and last follow-up (right).

Haugejorden, 1993; Splieth et al., 2002; Maier et al., 2020), which investigated the residual periodontal ligament of extracted teeth in general practice. Klock and Haugejorden (1993) reported a mean residual attachment loss between 11% and 50% loss for 50% and between 51% and 76% loss for 40% of teeth extracted due to periodontitis. In a similar study, Splieth et al. (2002) found that most extractions were performed on teeth with around 30% residual periodontal attachment loss, and only about one-third of teeth were extracted with attachment levels between 50% and 69%.

CAL distributions can be compared between cohorts and within cohorts, contrasting periodontally treated to untreated participants. Self-reported periodontal treatment did not result in a different pattern of retained and extracted teeth between SHIP-START and SHIP-TREND (Figure 2g). This would have been expected if the mindset for periodontal treatment decision making had changed between SHIP-START and SHIP-TREND. However, the academic discussion of the last 20 years, namely that periodontally questionable teeth can be retained, has not reached general dentists and has not influenced their decision making. Our expectation was that periodontal treatment would have led to more retention of teeth with baseline CAL ≥6 mm in the medium and long term. Obviously, self-reported periodontal treatment did not result in a shift of the lower CAL threshold towards a higher threshold. This observation agrees with a recent publication from our group, in which no beneficial impact of periodontal treatment was found on annual tooth loss in the SHIP-TREND cohort and in a registry-based cohort (Kocher et al., 2022).

The decision whether or not to extract seemed to be made on the basis of CAL, as AUROCs were higher for baseline CAL than for baseline PD. In German dental practices, attachment levels are usually not measured, although radiographs are mandatory according to the insurance regulations. Based on radiographs, dentists assess residual bone level and decide whether or not to extract teeth. For this reason, we considered only baseline maximum CAL and not baseline maximum PD levels in our discussion.

The main question is why extraction thresholds have not changed. In Germany, until now periodontal diagnostics (25%) and periodontal treatment (1.8%) have rarely been performed by dentists (Rädel et al., 2017), despite a high prevalence of moderate and severe periodontitis (55.9%) in the country (Schutzhold et al., 2015). This concurs with the finding that only 25.8% and 20.6% of SHIP-START and SHIP-TREND participants reported having periodontal treatment between the baseline and follow-up examination. The increased

attendance of continuing education courses (Bloom, 2005) or the establishment of professorships in periodontology in the catchment area of the SHIP studies did not improve the periodontal situation in terms of public health. Thus, we can conclude that the improved tooth retention rates in SHIP-START versus SHIP-TREND (22.0 ± 6.0 vs. 23.4 ± 5.2) were not related to improvement in periodontal treatment frequency and protocols but to a decreased caries burden (Schmoeckel et al., 2021). To better understand the consequences of these findings and assess their implication for dental public health, similar studies should be performed in different countries. To reduce the national burden of periodontitis, the Joint Federal Committee consisting of representatives of the statutory health insurances and care providers introduced a new directive in July 2021 (Gemeinsamer Bundesausschuss, 2021). It is intended to provide a higher quality of periodontal therapy. It will be interesting to see whether more money spent for periodontal treatment will translate into retention of more teeth with moderate and severe periodontal destruction. In parallel, a reform of the dental undergraduate curriculum in Germany is under process, which gives more weight to dental prophylaxis and periodontal treatment. Students educated under the reformed curriculum may start their professional life with a different mindset and may endeavour to retain more teeth.

A strength of the present study is the reporting of tooth loss patterns in relation to the baseline periodontal status from two large-scale cohort studies of the same region. To perform sufficiently powered studies on incident tooth loss, which is an event that rarely occurs, large-scale cohort studies such as SHIP are needed. Additionally, the fact that long-term data from observational studies on tooth extractions in relation to previous periodontal status have rarely been reported raises the value of data from the SHIP project. Furthermore, as tooth loss is the most important patient-relevant factor when periodontal therapy is performed (Institut für Qualität und Wirtschaftlichkeit im Gesundheitswesen (IQWiG), 2017), it is important to identify factors related to incident tooth loss in the general population.

Some limitations of this study should be noted. First, SHIP-TREND participants were on average 3–4 years older than SHIP-START participants, had higher baseline mean PD levels but similar baseline mean CALs, and a lower proportion of severe disease, limiting comparisons between both studies. Obviously, despite the markedly lower total response rates in SHIP-TREND (50.1%) than in SHIP-START (68.8%), participation rates were higher among the older subjects of SHIP-TREND.

Second, attrition is a common problem in all longitudinal cohort studies, resulting in the survival of the fittest teeth and the fittest participants. The impact of attrition on associations between baseline periodontal status and tooth loss during follow-up is unclear. Third, despite similar distributions from our sensitivity analyses, in which we excluded filled and carious teeth to rule out extractions due to caries or endodontic problems and concentrated on extracted sound teeth, the real reasons for tooth extractions remain unknown. In both cohorts, other factors besides periodontal problems may have influenced the decision to extract. From a clinical perspective, we can state with a high degree of certainty that teeth with a baseline maximum CAL of <4 or <5 mm were not extracted for periodontal reasons. Fourth, baseline levels of maximum PD and CAL were associated with (clinically assessed) tooth loss recorded at follow-up, neglecting potential deterioration of the periodontal status over time. Also, the exact time of tooth extraction was unknown. However, this is also a limitation of many previously conducted clinical retrospective studies (Checchi et al., 2002; Matuliene et al., 2008; Graetz et al., 2015; Dannewitz et al., 2016; Graetz et al., 2020). Fifth, the information about whether or not periodontal treatment was performed was based on self-reporting. According to Deinzer et al. (2009), the German population has pronounced periodontitis-related knowledge deficits. Consequently, several subjects may have falsely stated that they received periodontal therapy when it was only a professional dental cleaning. This could have led to an erroneously high number of participants self-reporting periodontal treatment (SHIP-START: 25.8%, SHIP-TREND: 20.6%), whereas according to the National Association of Statutory Dental Health Insurance (Kassenzahnärztliche Bundesvereinigung, 2021) only 4.7% of dental bills were issued for periodontal treatment. Sixth, periodontal recordings were made according to the half-mouth method on four sites. Thus, baseline maximum CALs at the tooth level were probably underestimated and associations of baseline maximum CAL with thresholds levels might have been underestimated, but to a minor extent. Regarding potential biasing effects of the PD and CAL half-mouth assessment on associations with tooth extraction rates, it can be assumed that extraction patterns on the left and right side are similar (see Figure S1). Thus, associations between baseline maximum PD/CAL and tooth loss are probably less biased. Seventh, our results are based on the data from participants in Western Pomerania, which is one of least affluent counties in Germany. Therefore, the results may not be representative for the whole of Germany.

5 | CONCLUSION

In 2010, 10 years after conducting SHIP-START, teeth in persons with severe periodontitis were still extracted at comparably low thresholds of baseline CAL. Although SHIP-TREND participants with severe periodontitis had on average 1.6 teeth more than their counterparts in SHIP-START, extraction patterns remained unchanged. Probably, decline in caries rather than not changes in extraction patterns of periodontally diseased teeth contributed to the higher tooth retention rate.

AUTHOR CONTRIBUTIONS

Joey Rug, Thomas Kocher, and Birte Holtfreter substantially contributed to the conception or design of the work. Birte Holtfreter, Thomas Kocher, and Henry Völzke contributed to the acquisition, analysis, or interpretation of data. Joey Rug, Birte Holtfreter, and Thomas Kocher drafted the work. Henry Völzke critically revised the work for important intellectual content. All authors approved the final version of the manuscript and are accountable for all aspects of the work.

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CONFLICT OF INTEREST

There are no conflicts of interest associated with this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

All SHIP studies were positively evaluated by the ethics committee of the University of Greifswald (SHIP-START-0: issued on 31 July 1995; SHIP-START-1: III UV 73/01 issued on 12 December 2001; SHIP-START-2: BB 39/08 issued on 19 June 2008; SHIP-TREND-0: BB 39/08a issued on 3 September 2009; SHIP-TREND-1: BB 174/15, issued on 12 December 2015). 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.

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