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EPIDEMIOLOGY (M LAINE, SECTION EDITOR)

Is Periodontitis Prevalence Declining? A Review of the Current Literature

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Abstract In recent decades, a decline in caries has led to retention of more teeth in industrialised countries. However, it is unknown, if such a trend also exists for periodontitis. Thus, the aim of this article is to review the evidence for global trends in the change in the prevalence of periodontitis over the last 20 years. Because evaluations of disease trends and comparisons of those between-trend studies are complicated by several methodological aspects, we also comprehensively discuss these issues. In total, ten studies provided data on trends in periodontal diseases with varying degrees of methodological bias. All studies consistently reported declining trends of periodontal parameters. However, methodological issues partly restricted interpretability of trend studies. Nevertheless, this review supports the assumption that periodontal disease prevalence is declining, though to varying degrees, but we will probably face higher treatment demands in the future because the number of teeth within subjects as well the number of elderly subjects within populations is increasing.

Keywords Periodontitis · Tooth loss · Prevalence · Trend · Epidemiology

Introduction

The prevalence of periodontitis is high and varies markedly between but also within countries [1, 2•]. Between 5 and 25 % of the general population present with severe periodontitis, while moderate forms have been found in up to 60 % of the general population [1, 2•]. To evaluate trends over time, repeated cross-sectional studies drawn from the same catchment area are needed. In turn, such trend analyses can help to evaluate the performance of health systems at a national, state or local level to provide healthcare planners or policy makers with appropriate information for decision making. Furthermore, they may help to dissect the impact of different determinants such as healthcare, behavioural, social and economic changes in trends in population health over periods of time.

Evaluations of periodontitis trends within studies and especially comparisons across trend studies are complicated by several methodological aspects. These comprise the use of different periodontal examination protocols [3] and periodontal probes [4], missing or insufficient examiner calibration, assessment of different clinical variables, and reporting of different periodontal disease definitions or outcomes [5]. Although there is some agreement that a combination of probing pocket depth (PPD), clinical attachment loss (CAL) and bleeding on probing (BoP) should be presented to comprehensively describe current and past periodontal disease experience [5, 6], there is currently no agreement on a set of specific periodontal measures to validly assess the prevalence and extent of disease (including tooth loss and edentulism). The lack of a universally accepted case definition of chronic periodontitis [7] further complicates population comparisons or inferences regarding the true global and time variation in periodontitis prevalence.

Only few studies have monitored the trend of periodontal prevalence and severity over the last decades, with four additional epidemiologic studies being published [8–10, 11••] after the last review [2•]. For this review, five national (England, Germany, New Zealand, USA, and Greece) and five regional [Pomerania (North-East Germany), Thun (Switzerland), ´s-Hertogenbosch (The Netherlands), Jönköping (Sweden) and

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Oslo (Norway)] studies were considered. Because comparisons between trend studies are additionally limited by the selection of different age groups and by different sample populations, ranging from the general population to army recruits, we (i) present each trend study separately together with its most important limitations and (ii) summarise the evidence for a potentially declining trend in periodontal disease prevalence.

Methods

Studies were selected after an extensive search of the PubMed database. We included only epidemiologic trend studies with at least one survey within the last 20 years (1994–2014). Information on study period, number of participants, response rate, age, periodontal measures, recording protocol and the main statements of periodontitis trends were retrieved from original [8–10, 11••, 12–16] and related publications [17–20]. For PPD and CAL measures, estimates for moderate (≥3/≥4 mm) or severe (≥5/≥6 mm) disease thresholds were reported.

Susceptibility for bias was scored using four criteria: high and/or differential non-response, use and non-equalisation of different periodontal recording protocols (PRP), reporting and quality of examiner reliability [C (concordance) statistics; reporting of intra- and inter-rater kappa or ICC (intraclass correlation coefficient) depending on the scale; at least good reliability, meaning kappa [21] and ICC [22] >0.6], and quality of reporting of periodontal measures. For some studies, information was also retrieved from additional papers [UK Dental Health Survey [23, 24], DMS (German Oral Health Studies) [25], New Zealand Surveys [26], NHANES (National Health and Nutrition Examination Survey) [27–29], SHIP (Study of Health in Pomerania) [30] and the Jönköping Study [31]). Finally, overall support for a declining trend was scored based on combined information on strength and direction of any trends and rated bias susceptibility. To indicate low, moderate and strong support, the scores were assigned as +, ++ and +++, respectively.

Overview on Reported Trends in Periodontal Diseases

The Adult Dental Surveys, England

The Adult Dental Surveys were conducted in 1998 and 2009 comprising subjects aged 16–75 years and older [8, 23]. Trend analyses were restricted to England. PPD was probed at two sites of each tooth using a WHO probe; these two sites were located buccally on the upper teeth and lingually on the lower teeth [24]. PPD was categorised as <3.5/4–5.5/6–8.5/≥9 mm. In addition, tooth count data were reported for a subgroup of 27- to 70-year-olds [32].

In total, the prevalence of PPD ≥4 mm declined from 55 to 45 %, while the percentage of subjects with at least one severely diseased site (≥6 mm) increased from 6 to 9 % [8]. These trends were consistently observed within age groups. In 27- to 70-year-old subjects, the number of teeth increased from 25.0 to 26.1, with the highest increments in 49- to 59- and 60- to 70-year-old subjects (2.3 and 2.6 teeth, respectively).

Some limitations need to be considered. The validity of periodontal measurements is uncertain, because in the 1998 survey no calibration exercises were reported for PPD measurements [23]. Second, comparisons with other studies are limited because assessments of CAL and reporting extent data for PPD are missing.

The German Oral Health Studies (DMS), Germany

The DMS are national cross-sectional studies conducted in 1997 [33] and 2005 [25, 34] in 35- to 44- and 65- to 74-year-old subjects in East and West Germany. To allow proper comparisons across both studies, recording protocols were equalised afterwards [35], with reporting estimates based on six index teeth (17, 16, 11, 44, 46, 47) and two sites (midbuccal and mesiobuccal) at maximum. Measurements were recorded with a WHO periodontal probe (PCP 11.5 WHO probe).

Contradicting trends were observed regarding region and age group. In West German adults, both the prevalence and extent of moderate and severe CAL decreased, whereas in 65- to 74-year-old adults the prevalence of CAL ≥3 mm (≥5 mm) increased by about 4 % (5 %), the percentage of affected teeth did not change and prevalences of PPD ≥4 mm and ≥6 mm remained at the same level. Accordingly, the number of teeth in dentates increased by about one tooth. In East Germany, the prevalence and extent of CAL increased irrespective of the cut-off considered in both age groups. The prevalence and extent of deep PPDs (≥6 mm) was reduced slightly. The number of teeth in dentates increased significantly in both age groups (by 2 and 3.9 teeth) and the percentage of edentulous subjects aged 65–74 years decreased by about 9 %.

Since molars are over-represented among the index teeth in comparison with half-mouth protocols, the periodontitis prevalence is probably overestimated. Because recording protocols had to be equalised, the median number of periodontal measurement sites in DMS III (DMS IV) was ten (12) in adults and only six (eight) in seniors. Thus, estimates are not very robust and trend analyses are of limited power and robustness.

New Zealand Health Surveys, New Zealand

The 1988 Survey of Oral Health Outcomes (SOHO) sampled subjects aged 20–24, 35–44 and 65–74 years using a complex

survey design [36]. The 2009 survey (age 2 to ≥75 years) is a follow-up of the New Zealand Health Survey (NZHS) conducted in 2006/2007 [37] and included 3,196 subjects with a dental examination (total response 41 %). For trend analyses, age groups were equalised, covering 20–24, 35–44 and 65–74 years. In 1988, the Community Periodontal Index of Treatment Needs (CPITN) was assessed at six sites on index teeth. In 2009, PPD and gingival recession were measured at three sites (mesiobuccal, midbuccal and distolingual) on all teeth (except third molars) using a PCP2 periodontal probe. To directly compare periodontitis estimates, PPD prevalence data from 2009 were based on the same index teeth and compared with CPITN grades 3 and 4 from 1988. Information on edentulism was retrieved for 65- to 74-year-old subjects [26, 38].

Overall, the prevalence of moderate and severe PPDs decreased across all age groups. For 20- to 24-year-olds, the prevalence of CPITN grade 3 decreased by 2 %, whereas for older age groups differences were more pronounced (20 % each). For the prevalence of CPITN grade 4, changes were non-significant in all age groups. These decreasing trends were more pronounced in females than in males. Edentulism declined in 65- to 74-year-olds from 58.6 to 29.6 %.

External validity might have been affected by a non-reponse bias, which occurred especially in the 2009 NZHS. However, in the 2006/2007 NZHS, non-response was not related to the oral health variables collected [37]. Further, methodological differences in periodontal examinations might have impacted periodontal trends. Specifically, different periodontal probes were utilised and the probing scheme differed between both surveys (circumferential vs. three sites per tooth). Both aspects might have resulted in underestimated prevalences in the 2009 survey [4, 39] and, thus, overestimation of declining trends.

The National Health and Nutrition Examination Survey (NHANES), United States

Dye et al. compared the prevalence of periodontitis in the USA between 1988 and 1994 and 1999 and 2004 in adults aged 20–64 years and seniors aged ≥65 years [40]; CAL and PPD were measured. Because the recording protocol changed between the third and fourth NHANES survey, trend analyses were based on periodontal assessments at two facial sites (mesio- and mid-facial) per tooth, except third molars, in two randomly selected quadrants. A periodontal probe with 2 mm markings was used. Subjects were classified according to the Centers for Disease Control and Prevention (CDC)/American Academy of Periodontology (AAP) case definition [41].

In general, marked improvements were seen in periodontal health and tooth retention. Prevalences of PPD declined in all age groups and were most pronounced for ≥3 mm cut-offs. For example, in 20- to 34-year-olds, prevalence of PPD ≥3 mm declined from 66.9 to 28.8 %. Mean PPD decreased in all adult and senior age groups by values ranging between 0.38 and 0.49 mm. Also, mean CAL declined in all adult and senior age groups by values up to 0.50 mm (50–64 and 65–74 years). Likewise, the prevalence of moderate or severe periodontitis (CDC/AAP definition) in adults and seniors significantly declined by 4.5 and 9.4 % between 1988 and 1994 and 1999 and 2004, respectively. Edentulism has declined and the number of teeth in dentates has increased by on average one tooth in all age groups.

The Pathfinder Survey, Greece

In 1985 and 2005, two nationally representative stratified cluster samples of 35- to 44-year-olds (N=741 and 1,182, respectively) were selected according to World Health Organization (WHO) guidelines for national pathfinder surveys. In the 2005 survey, four new areas were additionally included. The Community Periodontal Index (CPI) was assessed according to WHO recommendations at index teeth using the WHO CPITN periodontal probe [42].

Comparisons of CPI indices indicated that severe periodontal diseases may be declining in Greece. In total, the percentage of subjects presenting with CPI grades 3 and 4 decreased markedly. The percentage of subjects with grade 4 declined from 14.3 to 3.3 %; for grade 3 a decline from 25.9 to 24.2 % was observed. Similar trends were observed in urban and rural areas. It may be emphasised that in rural areas CPI grade 4 declined by 19.6 to 4.3 %, while the percentage of CPI grade 3 increased by 4.5 to 34.4 %.

Some aspects limiting interpretation of the Greek studies include the restricted comparability of the regions due to additional consideration of four further areas in the second survey, the sampling of only 35- to 44-year-old subjects, no reporting of calibration results for both surveys and the use of the CPI in connection with the WHO probe. Overall, the authors provided a restricted view on periodontal disease trends and did not report any data on extent measures.

Study of Health in Pomerania (SHIP-0 and SHIP-Trend), Pomerania/Germany

The trend of prevalence and extent of periodontitis was compared in two independent population-based regional studies (SHIP-0 and SHIP-Trend) in West Pomerania (North-East Germany), which were conducted in 1997–2001 [43] and 2008–2012 [44], i.e. 11 years apart, covering the age range of 20–83 years. Participation rates were 68.8 % in SHIP and 50.1 % in SHIP-Trend. Periodontal measurements comprised CAL and PPD at four sites per tooth, half-mouth recording, using two different periodontal probes (PCP11 and PCP15, respectively).

In general, the prevalence and severity of CAL decreased for all severity cut-offs. While PPD prevalence remained unchanged for moderate cut-offs, it decreased for ≥6 mm estimates. Specifically, the prevalence of CAL ≥3 mm decreased significantly from 89.7 to 85.1 % and the mean percentage of affected teeth was reduced from 62.8 to 55.9 % ($p<0.05$). In line with this, the percentage of edentulous subjects halved in elder subjects and the number of teeth in dentates increased significantly in all age groups.

Some aspects, which limit generalisability, should be considered. In the second survey, the low participation rate might have led to a non-response bias. This might have led to lower prevalences of periodontitis, assuming that responders had a more favourable periodontal risk factor profile and were thus periodontally healthier. A second issue concerns the change of periodontal probe, because of which estimates of prevalence and severity of PPD ≥3 mm have been biased towards higher values in SHIP-0 [4] as opposed to SHIP-Trend. Lastly, estimates were generally, though equally, underestimated in SHIP because of the half-mouth recording at four sites only.

Survey of Young Army Recruits, Thun/Switzerland

Periodontal conditions were reported in a total of 620 18- to 24-year-old male Swiss army recruits at the army base of Thun, Switzerland [13]. Study participants were examined during three surveys conducted in 1985, 1996 and 2006. Probing depths were assessed at six sites on all teeth with a Michigan M1 periodontal probe.

Periodontal health improved significantly in Swiss army recruits between 1985 and 1996, but did not change considerably in the last 10 years. Accordingly, the prevalence of PPD ≥5 mm stagnated at a low level after having improved between 1985 and 1996 (from 15.0 to 4.5 %). Likewise, the mean PPD did not change between 1996 and 2006.

Critical issues regarding this study are severe selection bias related to the non-random selection of only male army recruits from one army base, the limited age range, young age, small sample size, insufficient information on reliability and validity of periodontal measurements, and missing CAL data.

Dental Survey, 's-Hertogenbosch/The Netherlands

Two dental surveys were conducted in 1983 and 1995 in the city of 's-Hertogenbosch, The Netherlands [15]. Trend analyses were restricted to subjects aged 30–34, 40–44 and 50–54 years. In both surveys, pocket depth was recorded on "the buccal surface and the adjacent part of proximal surfaces of upper teeth, and the lingual surfaces and the adjacent part of proximal surfaces of lower teeth" using a WHO probe [15]. In 1983, PPD was measured in the full mouth, while in 1995 only two diagonal quadrants were alternately assessed. Recording protocols were not equalised. The percentage of teeth with PPD ≥3.5 mm was determined.

Though clinical signs of gingival inflammation declined between 1983 and 1995, the percentage of teeth with PPD ≥3.5 mm did not change significantly. However, the number of missing teeth and edentulism declined across all age groups [45].

Trends in the percentage of teeth with PPD ≥3.5 mm were moderately over-estimated due to changes in the periodontal examination protocol and low to moderate inter-examiner reliability for periodontal variables in duplicate measurements were reported. Also, because data for PPD were only reported as being <3.5/3.5–5.5/>5.5 mm, reasoning is limited.

The Jönköping Study, Jönköping/Sweden

Hugoson et al. reported on repeatedly conducted cross-sectional studies in Jönköping, Sweden, between 1973 and 2003, covering the age groups of 20–80 years [16, 46]. Probing depths and radiographically measured alveolar bone loss were assessed on molars and premolars. Periodontitis classification comprised five categories (group 1: periodontally healthy; group 2: gingivitis; group 3: moderate alveolar bone loss; group 4: pronounced alveolar bone loss; group 5: severe alveolar bone loss and angular bony defects and/or furcation defects).

Between 1983 and 1993, the percentage of sites with moderate or severe PPD decreased in all age groups, but increased afterwards, though to predominantly lower levels than in 1983. However, the mean periodontal proximal bone level increased consistently in all age groups between 1973 and 2003. Considering the periodontitis definition, the percentage of subjects with moderate or severe periodontitis (groups 4 and 5) increased between 1973 and 2003 among 40-year-old subjects. In subjects aged 50 years, the prevalence increased until 1993, but declined afterwards. In contrast, decreasing trends were seen in subjects aged 60 or 70 years after 1983. Having a closer look, the prevalence of group 5 remained at a high level in all age groups throughout the whole study period. In all age groups, prevalence of edentulism decreased considerably. In parallel, the mean number of present teeth in dentates increased.

Though the Jönköping study is unique as it covers a study period of 30 years, restriction to Jönköping and age groups with 10-year differences prevents generalization to the general population. Second, though alveolar bone levels provide more direct estimates of periodontal destruction, measurements were restricted to molars and premolars and, thus, periodontal disease severity was over-estimated. In addition, comparisons with other studies are limited because assessments of CAL are missing.

The Oslo Study, Oslo/Norway

In the Oslo Study, periodontal data were collected from randomly selected subjects aged 35 years over a period of 30 years, starting in 1973, with 10-year increments. In a subsample, marginal bone loss was measured and subjects were categorised according to the highest value. The CPITN was assessed in the latest three surveys.

Overall, periodontal health improved, with relevant decline of severe cases. The proportion of subjects with CPITN grade 4 halved between 1984 and 2003, while the proportion of subjects with grade 3 decreased between 1984 and 1993, but increased afterwards to the highest level. The percentage of subjects with no bone loss increased from 46 % in 1973 to 76 % in 2003. Likewise, percentages of subjects with moderate to severe bone loss declined.

Unfortunately, the Oslo Study provides only a very limited view on periodontal conditions. Issues hampering generalisability include the regional design and sampling of subjects at one specific age, at which periodontal disease prevalence is generally low and small sample size. The reporting of the CPITN, which is known to have severe limitations [47–49], cannot compensate for missing assessments of probing depths and attachment loss.

Discussion

Consistent with previous reviews on periodontal disease trends [2•, 46], reviewed studies support the assumption that periodontal disease prevalence is declining, though to a varying degree. The precise magnitude of the decline is difficult to ascertain due to high variability in periodontal disease definitions with sometimes questionable methodological quality. Thus, one should be cautious about drawing conclusions on any global trends.

How Good is the Evidence for a Decline in Periodontal Prevalence?

The prevalence and, thus, the trend of periodontal diseases reported in any given survey is influenced by various methodological factors including the periodontal disease definition and the PRP [3]. Specifically, trend studies reported in this review varied immensely regarding methodology and quality of examiner reliability as well as in the periodontal measures and definitions applied. These aspects severely hampered inter-study comparisons. The implications of each of these aspects are discussed below.

Implications from Different Periodontal Measures and Periodontal Case Definitions

Various clinical measurements quantifying clinical inflammatory signs, pocket probing depth and degree of connective tissue loss were assessed in the studies, with PPD being most often reported [8, 10, 11••, 13–16]. Analogously, various periodontal disease measures (also utilising different thresholds, i.e. PPD ≥4 mm) and case definitions were reported in the reviewed studies (see Table 1). As seen in the New Zealand study [10], it is also increasingly recognised that the CPITN does not provide a proper description of the periodontal status [48, 50–53] and over-estimates treatment needs in a younger population. Nevertheless, we decided to report on the CPI because of limited data availability. At the least, CPI prevalence data can be used to deduct estimates for prevalences of PPD ≥4 and ≥6 mm [1, 10]. In the Jönköping study [16], a unique classification was used, classifying subjects based on gingival bleeding and radiographic findings. Last but not least, the CDC/AAP case definition [41] was reported for three studies [11••, 14]. However, it must be noted that different case definitions give inherently different periodontitis prevalences [54, 55]. This aspect contributed immensely to difficulties when comparing trends between studies.

The Choice of the Periodontal Recording Protocol and Probe

There is consensus that full-mouth examinations most accurately assess the prevalence, extent and severity of periodontitis in an epidemiologic study [2•, 56]. However, because of the time and cost intensiveness of full-mouth recordings, partial recording protocols (PRPs) are often applied. However, PRPs affect the validity of periodontal estimates to varying degrees. PRPs under-estimate periodontal prevalences, depending on the number of examined sites and teeth [39, 56], but also depending on the actual prevalence and extent of periodontitis in the targeted population and, thus, also on the age range of the targeted population. However, with regard to extent and severity, the selection of sites and teeth relevantly influences the direction of measurement bias. While for half-mouth protocols the percentage of incisors, premolars and molars is identical to that of full-mouth protocols, index teeth in DMS have an inherently higher percentage of molars (66.7 % vs. 28.7 %) and thus are expected to induce higher extent and severity estimates. However, if trend analyses are based on studies with different recording protocols, sites and teeth should be restricted or equalised to the least common set within both surveys. Otherwise, disease trends might be under- or over-estimated, depending on the degree to which each recording protocol results in an under- or over-estimation of the periodontal prevalence or extent. Of the reviewed studies, all except four studies [10, 11••, 14, 15] retained the recording protocol, while only two studies [11••, 14] reduced the recording protocol accordingly to six teeth at two sites. Two studies [10, 15] did not equalise their recording protocols.

Periodontal estimates might also be affected by the choice of the periodontal probe [4]. When transitioning to a different

Table 1 Overview of selected studies providing information on the trend of periodontal diseases

Authors, year Study name Region	Study period	Number of participants (response)	Age (years)	Periodontal measures	Recording protocol and probe	Main statements on trend	Direction	Bias susceptibility[a]	Overall support for declining trend[b]
National studies									
White et al. [8], 2011 Adult Dental Health Survey England	1998 2009	2,186 (72.6 %)[c] 5,622 (62 %)[c]	16–24/25–34/35–44/45–54/55–64/65–74/≥75	PPD ≥4 mm PPD ≥6 mm	Two sites (mesial and distal; buccally on upper teeth and lingually on lower teeth); all teeth; worst score in each sextant was recorded; same probe	Prevalence PPD ≥4 mm Prevalence PPD ≥6 mm	↘ ↗	NR: + PRP: + ER: – R: –	+
Schützhold et al. [11••] (submitted) German Oral Health Studies Germany	1997 2005	2,022 (56.1 %) 3,642 (54.0 %)	35–44/65–74	CAL (prevalence, % and number of teeth affected) PPD (prevalence, % and number of teeth affected) CDC/AAP case definition Number of missing teeth	Midbuccal and mesiobuccal sites at 6 teeth (17, 16, 11, 44, 46, 47); WHO probe	West Germany, 35–44: Prevalence and extent CAL ≥3/5 mm Number of missing teeth West Germany, 65–74: Prevalence and extent CAL ≥3/5 mm Number of missing teeth East Germany: Prevalence and extent CAL ≥3/5 mm Prevalence and extent PPD ≥4/6 mm CDC/AAP severe Number of missing teeth	↘ ↘ ↗ ↘ ↗ – ↘ ↘	NR: – PRP: + ER: + R: +	++
Haisman-Welsh and Thomson [10], 2012 New Zealand Health Surveys New Zealand	1988 2009	1,388 (71/80/80 %)[d] 3,196 (41 %)[e]	20–24/35–44/65–74	1988: CPI 2009: PPD Edentulism	1988: CPI, 6 sites at index teeth; WHO probe 2009: PPD at 3 sites (mesiobuccal, midbuccal, distolingual) at index teeth, converted to CPI; PCP2 probe	20–24 years: CPI score 3 or 4 35–44/65–74 years: CPI score 3 or 4 65–74: Edentulism	– ↘ ↘	NR: – PRP: – ER: + R: –	+
Dye et al. [40], 2007 The National Health and Nutrition Examination Survey (NHANES) United States	1988–1994 1999–2004	16,128 (85.7 %)[f] 13,159 (85.8 %)[f]	20–64/≥65	PPD CAL CDC/AAP case definition Number of missing teeth	Two sites (mesio- and mid-facial) in 2 randomly selected quadrants (1 maxillary and 1 mandibular), excluding third molars; PCP2 probe	Prevalence and mean PPD Prevalence and mean CAL CDC/AAP moderate or severe Number of missing teeth	↘ ↘ ↘ ↘	NR: + PRP: + ER: + R: +	+++
Mamai-Homata et al. [9], 2010 Pathfinder Survey Greece	1985 2005	741 (n.a.) 1,182 (n.a.)	35–44	CPI	Index teeth; WHO probe	Score 3 Score 4	↘ ↘	NR: – PRP: + ER: – R: –	+
Regional studies									
Schützhold et al. [11••] (submitted) Study of Health in Pomerania West Pomerania, Germany	1997–2001 2008–2012	3,736 (68.8 %) 3,620 (50.1 %)	<25/25–34/35–44/45–54/55–64/65–74/≥75	CAL (prevalence, % and number of teeth affected) PPD (prevalence, % and number of teeth affected) CDC/AAP case definition Number of missing teeth	Four sites (distobuccal, midbuccal, mesiobuccal, midlingual/midpalatinal); half-mouth 1997–2001: PCP11 2008–2012: PCP15	Prevalence and extent CAL ≥3/5 mm Prevalence and extent PPD ≥4 mm Prevalence and extent PPD ≥6 mm CDC/AAP severe Number of missing teeth	↘ – ↘ ↘ ↘	NR: – PRP: + ER: + R: +	+++
Röthlisberger et al. [13], 2007	1985 1996	757 (n.a.) 419 (n.a.)	18–24 (male recruits)	PPD Number of missing teeth	Six sites, full-mouth; Michigan M1 probe	Mean PPD (1996–2006)	– ↘	NR: – PRP: +	+

Table 1 (continued)

Authors, year Study name Region	Study period	Number of participants (response)	Age (years)	Periodontal measures	Recording protocol and probe	Main statements on trend	Direction	Bias susceptibility[a]	Overall support for declining trend[b]
Survey of Young Army Recruits Thun, Switzerland	2006	626 (n.a.)				Prevalence PPD ≥5 mm (1985–2006) Number of missing teeth	– –	ER: – R: –	
Kalsbeek et al. [15], 2000 Dental Survey ´s-Hertogenbosch, The Netherlands	1983 1995	503 (43.3 %) 436 (58.2 %)	30–34/40–44/50–54	PPD ≥3.5 mm (% of teeth affected) Number of missing teeth	Buccal surface and adjacent part of proximal surfaces of upper teeth; lingual surfaces and adjacent part of proximal surfaces of lower teeth; WHO probe 1983: full-mouth 1995: half-mouth	Extent PPD ≥3.5 mm Number of missing teeth	– ↘	NR: – PRP: – ER: – R: –	+
Hugoson et al. [16], 2008 Jönköping Study Jönköping, Sweden	1973 1983 1993 2003	600 (n.a.) 677 (74.4 %)[g] 655 (72.0 %)[g] 589 (64.7 %)[g]	20/30/40/50/60/70/80	PPD Bone loss Classification according to clinical and radiographic findings Number of missing teeth	PPD: 4 sites, full-mouth; Hilming probe Bone loss: mesially and distally for each molar and pre-molar tooth in the lower jaw	Prevalence PPD 4–5/≥6 mm: 1983–1993 1993–2003 Number of sites with PPD 4–5/≥6 mm 1983–1993 1993–2003 Bone loss Classification: Group 4 Group 5 Number of missing teeth	↘ – ↘ – ↘ ↘ – ↘	NR: + PRP: + ER: – R: +	+++
Skudutyte-Rysstad et al. [12], 2007 Oslo Study Oslo, Norway	1973 1984 1993 2003	117 (66 %) 156 (80 %) 121 (68 %) 149 (64 %)	35	CPI (1984–2003) Bone loss (1973–2003) Number of missing teeth	CPI: index teeth; WHO probe Bone loss: mesial and distal sites at all teeth	CPI score 4 Bone loss Number of missing teeth	↘ ↘ –	NR: – PRP: + ER: + R: +	++

AAP American Academy of Periodontology, *CAL* clinical attachment loss, *CDC* Centers for Disease Control and Prevention, *CPI* Community Periodontal Index, *n.a.* not annotated, *PPD* pocket probing depth, , ↗ increase, ↘ decrease, – no change

[a] To assess bias susceptibility, four criteria were evaluated: high and/or differential non-response (NR), bias related to different recording protocols (PRP), quality of examiner reliability (ER), and quality of reporting (R)

[b] The decision on the overall support for a declining trend was based on the combination information on main statements on trend and bias susceptibility

[c] Percentage of subjects with dental examination based on the number of dentate adults eligible for examination

[d] For three age groups

[e] Response rate for subjects with dental examination aged 2 to ≥75 years, considering that the 2009 NZOHS was a follow-up survey to the 2006/2007 NZHS

[f] Number of subjects with oral health examination relative to the number of sampled persons completing a Home Interview Questionnaire

[g] Calculated based on Hugoson et al. [31]

periodontal probe in sequential surveys, it is important to understand the impact of instrument changes when making inferences on time trends. Change in the periodontal probe was reported for two studies [10, 11••]. Schützhold et al. argued that "the use of different periodontal probes […] may have led to a possible overestimation of PD≥3 mm and underestimation of PD≥4 mm in SHIP-0 as compared to SHIP-Trend" [11••], possibly resulting in an over- and under-estimation of trends for PPD ≥3 mm and PPD ≥4 mm variables, respectively.

Issues of Examiner Reliability

Large surveys generally necessitate the involvement of multiple examiners. However, if they are not sufficiently well-calibrated, bias of over- or under-estimation of prevalences with unknown effects on disease trends might be introduced. We rated the quality of examiner reliability documentation in consideration of (i) reporting of intra- and inter-rater kappa or ICC (depending on the scale) and (ii) evidence of at least good reliability, meaning kappa [21] and ICC [22] >0.6. These criteria were fulfilled by only four studies [10, 11••, 14, 25], raising the validity of these studies as opposed to the other studies. Only partial information on inter- or intra-reliability measures was reported in five studies [9, 12, 13, 15, 16], while for the UK Adult Dental Health Survey, calibration data for PPD were not available at all [23, 57].

Reporting of Periodontal Prevalence, Severity and Extent

When reporting data from epidemiologic studies, one should provide information on prevalence, severity and extent of periodontal disease. Prevalence estimates allow a first insight into disease distribution but do not address the extent of the disease within the mouth. Thus, extent measures, defined as the number or percentage of sites or teeth with a given level of severity, should be reported for varying thresholds. However, few studies comprehensively reported their collected data. While prevalence data (using various periodontitis definitions) were reported among the majority of the reviewed studies (except the Dutch Dental Study [15]), extent data were only provided in seven [11••, 12–16] of ten studies.

Conclusions on Trends in Periodontitis Prevalence

Taken together, the highest quality of study conduct and periodontal examination standardisation was achieved by NHANES [14] and the two regional studies from Pomerania [11••] and Jönköping [16]. These studies support a decline of periodontitis prevalences, though with higher degrees in NHANES [14] and Jönköping [16] than in SHIP [11••]. Additionally, the Jönköping study [16] provided particularly valuable information because it covered an extended time span. Improvements were consistently found in the DMS [11••] and the Oslo Study [12], which were ranked to provide moderate overall support for a declining trend. Similar trends were reported for studies from England [8], New Zealand [9], Greece [9], Thun [13], and ´s-Hertogenbosch [15]; however, these studies had a less precise methodology and thus validity of the results must be questioned. Importantly, because data originate from Europe, New Zealand and the USA, one should be cautious with extrapolations to global trends.

Contribution of Periodontal Trends to Improved Tooth Retention

In recent decades, fluoridated toothpastes and comprehensive caries prevention campaigns have been introduced in industrialised countries. These measures have resulted in a dramatic decline in overall levels of caries [58–61], which in turn led to markedly improved tooth retention and less edentulism [11••, 12, 14, 23, 45, 62]. In the elderly, periodontitis constitutes a comparably important risk factor for tooth loss [63, 64]. Given that the majority of studies reported a marked decline in periodontal disease prevalence, this decline might have partially contributed to positive developments in tooth retention, though to a minor degree compared with caries.

Interpretation of Trend Data with Regard to the Whole Population

For future resource planning and estimation of future periodontal treatment needs, two aspects need to be considered. First, in terms of periodontal treatment needs, it must be questioned whether the reduction in the percentage of periodontally diseased sites or teeth outweighs the increased number of retained teeth in terms of the absolute number of teeth displaying treatment needs. In most studies, prevalences and relative extents of moderate to severe probing depths (or grades 3 and 4 for CPI/CPITN, respectively) declined over recent years [9, 10, 12–14, 16]. However, none of the studies, except SHIP and DMS [11••], provided information on the number of moderately or severely affected sites or teeth. Considering that pocket depths ≥4 mm indicate periodontal treatment needs, a closer look at the SHIP and DMS data revealed that, although prevalences and relative extents of moderate to severe probing depths did not change significantly in most age groups in both studies, the simultaneous increase of the number of present teeth led to an increased number of teeth with moderate or severe probing depths [11••]. This means that the absolute number of teeth requiring periodontal treatment increased. However most periodontally diseased teeth with moderate probing depths could be treated

by dental auxiliaries. Since trends in the number of affected teeth have so far only been reported for SHIP and DMS, it remains unclear whether such developments have also been seen in other studies/countries.

Second, it must be considered that in the decades to come we will face an overall declining but aging population [65, 66]. Because of rising prosperty, better nutrition and improved living environments, people will not only live longer, but also stay healthy for a longer time. The percentage of elderly people (≥65 years) living in the EU will increase from 17.1 % in 2008 to 25.4 % in 2035 and to 30.0 % in 2060 [67]. In contrast, the number of young people (<25 years) will decline by 12 %. For the USA, similar trends are expected: 20 % of the adult population will be older than 65 years [68]. These demographic trends will clearly result in an increased number of elderly people.

Reasoning on the increasing number of teeth with periodontal treatment needs and the expected demographic changes, we will probably face higher treatment demands in the future, which will, in turn, present a major challenge for health policy planners.

Trends in Periodontal Risk Factors

Periodontal diseases commonly share various modifiable risk factors related to lifestyle with the main chronic diseases, including cardiovascular diseases, diabetes, chronic obstructive pulmonary diseases and cancer [60]. Thus, periodontal diseases have a high prevention potential through their modifiable risk factors. These risk factors mainly include oral hygiene and care, smoking, diabetes and obesity. All of these risk factors are in turn influenced by social and economic conditions. Consequently, changes in periodontal disease prevalences also depend on time trends of modifiable periodontal risk factors. And, indeed, declining prevalences of smoking [69–71], especially in men [71–74], improved dental hygiene and care [12, 23, 75, 76], and improved social conditions [74, 77] might have contributed to the declining prevalence of periodontitis. Consequently, there is a high potential to benefit from prevention measures aimed at common risk factors.

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Compliance with Ethics Guidelines

Conflict of Interest Dr. Birte Holtfreter, Svenja Schützhold and Dr. Thomas Kocher each declare no potential conflicts of interest.

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- •• Of major importance

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