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Root caries experience in Germany 1997 to 2014: Analysis of trends and identification of risk factors

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ABSTRACT

Introduction: We assessed time trends in root caries experience, i.e. the sum of filled and carious root surfaces (FRS, CRS), and evaluated risk indicators of FRS/CRS in Germany.
Methods: FRS and CRS from repeated waves (1997, 2005, 2014) of the nationally-representative German Oral Health Studies were analyzed in 35–44- and 65-74-year-olds (adults/younger seniors; n = 4388). Weighted means were interpolated cross-sectionally across age groups by fitting piecewise-cubic spline-curves, and population-level FRS and CRS calculated. We also projected population-level FRS and CRS to 2030. To evaluate risk indicators of FRS and CRS, zero-inflated negative-binomial regression was applied.
Results: In adults FRS increased from 1997 to 2005 at individual and population level (from a mean of 0.49 to 0.63 surfaces; from a total of 6.2 to 8.7 million surfaces) and then decreased to 2014 (to 0.16 surfaces/1.6 million surfaces). CRS constantly increased (1997: 0.37 surfaces/4.7 million surfaces; 2014: 0.94 surfaces/9.3 million). In younger seniors, FRS increased from 1997 to 2005 (from 0.67 to 1.92 surfaces; 5.0 to 17.5 million surfaces) and then decreased to 2014 (0.89 surfaces/7.5 million surfaces). CRS constantly increased (1997: 0.39 surfaces/2.9 million surfaces; 2014: 1.43 surfaces/12.1 million surfaces). Driven by demographic changes until 2030, population-level FRS and CRS is likely to increase in younger seniors, but not adults. Sex, toothbrushing behavior, age, coronal caries experience and the number of teeth with probing-pocket-depths ≥ 4 mm were associated with FRS and CRS.
Conclusions: While FRS does not show a clear trend, CRS has constantly increased since 1997. Concepts for preventing and managing CRS in Germany are needed.
Clinical significance: Evaluating time trends and assessing risk indicators of root caries experience is helpful to understand morbidity dynamics, plan resource allocation and identify individuals/groups at risk. While FRS shows no clear trend, CRS has increased since 1997 in Germany. Concepts for addressing the emanating treatment needs are needed.

1. Introduction

In many industrialized countries and most age groups, the prevalence and experience of coronal caries lesions has been decreasing in the last decades [1]. Consequently, the number of coronal restorations and missing teeth decreases. For example, in Germany, the number of filled teeth has declined dramatically over the last 20 years and will decline further in the future in all but the very old. Tooth loss has decreased by two-thirds since 1997, and is expected to decrease even further [2]. Hence, more teeth are retained lifelong, paired with an increasing lifespan of the individual [3,4].

These retained teeth are at risk for periodontal disease. For example, in Germany, periodontal treatment needs have increased in the elderly since 1997, and by 2030, the average senior is expected to show 12 teeth with probing pocket depths (PPDs) ≥ 4 mm [5]. Periodontally affected teeth often show exposed root surfaces; these are, in turn, prone for root caries lesions, especially in elderly with impaired dexterity and oral hygiene, and reduced salivary flow [6,7]. Generally, gingival recession and the resulting root exposure are risk factors for root caries [1].

Treating root caries lesions and re-treating existing root surface restorations is challenging due to difficulties in moisture control,

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suboptimal conditions for adhesive placement (with dentin being the sole adhesive substrate), and a lack of retention in often saucer-shaped root cavities with limited access (at least proximally), resulting in poor survival of root surface restorations [8–10]. These poor survival rates apply to a range of materials which can be used for this indication; composites, resin-modified and conventional glass ionomers all show high risk of failure in root surface lesions. So far, the evidence to support one specific material is not given; however, in contrast to most coronal restorations in permanent teeth, composites do not seem to necessarily perform better than glass ionomer cements [11]. Hence, to avoid needing to place any root restoration at all, individuals at risk for root caries should be identified early on for targeted prevention and to arrest initial lesions [12].

The present study determined trends in root caries experience from 1997 to 2014 in Germany based on three waves of the German Oral Health Studies (Deutsche Mundgesundheitsstudien, DMS), which are nationally representative investigations. Our analyses also consider the demographic changes occurring, as these decisively impact on the population-level burden and emanating treatment needs. In an auxiliary analysis, and assuming individual root caries experience to remain constant from 2014 onwards, we also projected the population-level of root caries experience to 2030. We further evaluated risk indicators for root caries experience.

2. Methods

Reporting of this study follows the STROBE statement [13] for observational studies and the TRIPOD statement [14] for development of a prediction model.

2.1. Data source and participants

Data from three waves of the DMS were used; DMS III from 1997, DMS IV from 2005 and DMS V from 2014. The DMS involved stratified multi-stage cross-sectional, nationwide probability samples of the civilian non-institutionalized German population, with clinical and socio-epidemiological examinations in different age cohorts (12-years-old, 35–44-years-old, 65-74-years-old, for DMS V also 75-100-years-old). The sampling design, data collection protocols and data availability statements can be found elsewhere [15–18].

Study participants were drawn from local residents' registration offices in 90 randomly selected communities (sample points) using a cluster-random sampling stratified for regions and areas of urbanization. A disproportional sample point selection was performed with 60 study sample points in the Western federal states of Germany and 30 study sample points in the Eastern states.

For the DMS III, 3065 participants were included (response rate of 63.6%); for DMS IV and V, these numbers were 4631 (63.1%) and 4609 (50.1%), respectively. Empirical non-responder analyses were conducted to compare the socio-dental characteristics of responders with the target population according to gender, educational level, dental visiting patterns, and dental/prosthetic status. Non-response bias was found to be minimal (Appendix Table S1 and S2). The study was ethically approved by the Medical Association North-Rhine (No. 2,013,384), as were all data collection protocols. All participants completed written informed consent. All methods were performed in accordance with the relevant guidelines and regulations.

2.2. Data collection

The dental examinations and the socio-scientific survey were carried out at the local sample points. To ensure reproducibility, interviewers and dental investigators were trained and calibrated by experts and multiple reliability checks were performed throughout the field phase (Appendix Table S3).

Dental examinations were performed by three teams working in parallel; each team consisted of one dentist, one interviewer, and one contact person.

Root caries lesions were determined as follows at up to four root surfaces per tooth (depending on the number of surfaces available, i.e. exposed). A root surface was assumed as carious if it was possible to establish cavity formation with or without softening (carious root surface, CRS). If a lesion on a root appeared to be a continuation of a coronal lesion not extending more than 2 mm onto the adjacent root area, this was not regarded as root lesion. Brown, yellow or reddish to brown root surfaces with varying substance loss and a soft to leathery texture (tactile examination using a blunt probe), but also dark brown to black, rather hard root surfaces were considered as root caries lesions. Note that the distinction between these different lesion characteristics, which may allow to classify lesions as active or inactive, had not been made in all DMS. Hence, we were unable to separate active and inactive lesions in this study. Also note that one could assume arrested lesions to not necessarily remain arrested. In this sense, even arrested lesions need to be recorded, as they may require (1) continuous arrestment therapy and (2) restorative treatment in case they progress (re-activate). Filled root surfaces (FRS) were also recorded. Root surfaces which, according to information provided by the individual, had been filled to improve aesthetics only, were not recorded as filled. If a restoration on a root appeared to be a continuation of a coronal restoration not extending more than 2 mm onto the adjacent root area, this was not regarded as FRS as well. The sum of CRS and FRS of an individual was the root caries experience (RCE).

Further parameters were assessed and employed in the current study as covariates. Coronal caries experience (DT, MT, FT) was recorded on 28 teeth (i.e. third molars were excluded), on five surfaces per posterior tooth (premolars and molars) and four surfaces per anterior tooth (incisors and canines), as described in detail elsewhere [4]. Periodontal assessment was performed according to different protocols throughout the DMS waves; a partial mouth recording was the common denominator with two sites (mesio-vestibular and mid-vestibular) measured on the following index teeth: 17, 16, 11, 44, 46, and 47. For the present study, the number of teeth with PPD $\geq$ 4 mm were assessed as covariate. Details on transformation of the partial mouth PPDs full mouth data have been described elsewhere [5].

Further recorded clinical parameters were prosthodontic status, and developmental and acquired dental hard tissue defects. A paper-based questionnaire was completed by the subjects before the clinical examination, comprising questions on oral hygiene habits/prosthesis hygiene, utilization of dental services, questions on childhood and life course, smoking habits, and social demographics including education, income, place of residence and place of birth.

2.3. Missing data

Only the age groups of 35–44 and 65–74-years-old (adults and younger seniors) were used in the present study, resulting in a total number of cases of 5986. In these two age groups, data for FRS and CRS were available for 4449 dentate subjects. We did not impute missing values, hence, we discarded cases with at least one missing predictor variable (approx. 1%), resulting in a final data set with 4388 cases.

2.4. Cross-sectional imputation

In the three waves of the DMS, patient data were available for particular age cohorts. For FRS and CRS, we estimated the weighted means for two DMS age groups (35–44-years-olds and 65-74-years-olds) for each DMS wave (DMS III, IV and V). For age groups not sampled by the DMS we interpolated FRS and CRS cross-sectionally by fitting a piecewise cubic polynomial spline [19] to the weighted means. We set a boundary condition of zero for 12-year-olds. We then summed up FRS and CRS to obtain RCE for each age year with respect to each particular DMS study; the RCE was maximally 112.

2.5. Population level estimates

The number of FRS/CRS/RCE for each age group and year were combined with recorded (1997–2014) population estimates to yield population-level measures. These are more relevant for health services planning, for example, than individual estimates, and also consider demographic dynamics.

We also aimed to assess how future demographic changes may impact on FRS/CRS/RCE in the future. To do so, and in the absence of future data on FRS/CRS/RCE in adults or younger seniors, we conservatively assumed estimates to remain constant from 2014 onwards. We then combined these with predicted (2020–2030) population estimates to determine the overall absolute number of affected surfaces [20]. We used the so-called G1-L1-W2 scenario prediction model, assuming that fertility will remain nearly constant at the level of 1.4 children per woman (G1), that life expectancy will moderate increase to 84.8 years for men and 88.8 for women (L1), and that until 2021 the migration balance decreases to +200,000 persons per year, and remains constant thereafter (W2) [21].

2.6. Regression analyses

To evaluate associations between risk indicators and root caries, regression analyses were used. The outcome of our analyses were RCE, FRS and CRS. The following covariates were used for prediction: (1) Age in years, (2) sex, (3) low, middle or high educational position (4) tooth brushing frequency (once, twice or more per day versus less than once daily), (5) the number of teeth with coronal caries lesions, restorations, or missing teeth (DT, FT, MT), (6) the number of teeth with PPD ≥ 4 mm.

To examine the association between predictor variables and outcomes, thereby accounting for the high number of individuals without any root caries experience, zero-inflated negative binomial (ZINB) regression was performed [22]. We also applied zero-inflated Poisson regression; however, ZINB resulted in a slightly better fit as indicated by the log-likelihood. ZINB models are two-component mixture models combining the negative binomial distribution and the logit distribution. They are capable of dealing with excess zero counts and overdispersion, as count values and the excess zeros are modeled independently [23]. The binomial distribution was used to model the association between predictors and the odds (chance) of not being at-risk (susceptible) for root caries experience (that is, being a structural or inflated zero). Simultaneously, the negative binomial distribution was used to determine the strength of the association between predictors and the RCE/FRS/CRS in the population at-risk (which might also include accidental, that are non-structural, zeros). All predictors were used for both the count model as well as the zero-inflation model. We considered covariates to be statistically significant at $p < 0.05$. Statistical analysis was performed using Python and R. For modelling we used the R-package pscl.

3. Results

Individual and population level estimates of RCE, FRS and CRS 1997–2014 are shown in Table 1.

In adults, FRS increased from 1997 to 2005 at individual and population level (from 0.49 to 0.63 surfaces; from 6.2 to 8.7 million surfaces) and then decreased in 2014 (0.16 surfaces/1.6 million surfaces). CRS constantly increased (1997: 0.37 surfaces/4.7 million surfaces; 2014: 0.94 surfaces/9.3 million surfaces).

In younger seniors, FRS increased from 1997 to 2005 (from 0.67 to 1.92 surfaces; 5.0 to 17.5 million surfaces) and then decreased in 2014 (0.89 surfaces/7.5 million surfaces). CRS constantly increased (1997: 0.39 surfaces/2.9 million surfaces; 2014: 1.43 surfaces/12.1 million).

Until 2030, we expect FRS and CRS to increase in seniors (to 10.3 and 16.5 million surfaces, respectively), but not adults.

Results of the regression modelling are shown in Tables 2 and 3. As described, the used zero-inflated models are two-component mixture models. The first model assessed the association between predictors and the odds (chance) of not being at-risk (i.e. the odds of having zero FRS/CRS/RCE, Table 2); the second model that between predictors the number of surfaces affected in individuals at-risk (Table 3). For the odds of not being at-risk for any root caries experience, a number of significant predictors were identified (Table 2). However, the overall explanatory value of the model remained limited. Females showed significantly higher odds of not being at risk for FRS, while no significant association with CRS or RCE was found. Older individuals showed lower odds of not being at risk for FRS/CRS/RCE (with each year of age, the chance of not having root caries decreased by 5%). With each decayed tooth (DT), the odds of not being at-risk for FRS decreased. Similarly, with each filled tooth (FT) the odds of not being at-risk for FRS/CRS/RCE decreased. The most important predictor was daily brushing, which significantly decreased the odds of not being at-risk (daily brushers had 86% decreased odds).

For those who showed any FRS/CRS/RCE (i.e. those who were a prevalent case), the number of surfaces affected by FRS/CRS/RCE was explored (Table 3). Again, the overall explanatory value of the model remained limited. Males showed significantly higher FRS/CRS/RCE, as did older individuals (with each year of age, the RCE increased by 0.03 surfaces). With each DT, CRS and RCE increased (by 0.32 and 0.27, respectively). With each MT and FT, RCE increased (by 0.04 and 0.06, respectively). With each tooth with PPD ≥ 4 mm, CRS and RCE increased (by 0.05 and 0.02, respectively).

4. Discussion

Caries research and prevention and management strategies for dental caries have long been focused on coronal caries, mainly in children. This was, as due to restorative or periodontal complications, teeth were usually lost before root caries lesions developed. With longer tooth retention in an ageing population, it could be assumed that root caries experience increases [1]. Considering this potentially growing burden, but also the limited knowledge around preventive and restorative strategies for root caries, research into root caries seems warranted [11,24].

In Germany and based on the present study, FRS in adults had peaked in 2005, and has since decreased back to the level of 1997. CRS in adults had constantly increased. The sum of CRS and FRS (the RCE) increased until 2005 and remained near constant since then. We assume a number of factors to contribute to these trends. (1) In 2005 and, more so, 2014 the number of teeth at-risk for root caries was drastically increased in this age group, resulting in an overall higher risk profile for root caries in many young adults. (2) In 2005, the risk for root caries was further aggravated by a high prevalence of periodontitis, which is another relevant risk factor for root caries [25]. In adults, however, periodontitis has decreased since then, possibly counterbalancing the increasing number of retained teeth [5]. Both factors jointly may explain the trend in combined FRS and CRS. (3) Treatment patterns may have changed; dentists may have restored more root lesions in 2005 than 2014 (when they were more skilled to control them non-restoratively). This may explain that in 2005, the large share of root caries experience was FRS, while the ratio of CRS to FRS has changed since then (less FRS, more CRS). Also, dental service's utilization in adults is relatively limited (compared with children and seniors) [16]; if patients do not attend the dentists, many CRS may not be transformed into FRS (as this is only possible by seeing a dentist).

The trends in younger seniors were similar (FRS peaked in 2005, likely due to the same reasons, and CRS constantly increased since 1997; notably, however, overall RCE showed a peak in 2005 and a decrease since then). Importantly, CRS in younger seniors may be carried into older age, where it is harder to manage both non-restoratively and restoratively [26]. More efforts on preventing root caries in this age group seem required.

Table 1
Mean individual and population-level number of filled or carious root surfaces (FRS, CRS) or both (root caries experience, RCE) across the DMS and projected to 2030.

DMS	Age group	Individuals in million	FRS per individual	FRS in million	CRS per individual	CRS in million	RCE per individual	RCE in million
DMS III (1997)								
	35–44-years-old	12.745	0.49	6.245	0.37	4.716	0.86	10.961
	65–74-years-old	7.39	0.67	4.951	0.39	2.882	1.06	7.833
	Total population*	77.250	0.42	32.445	0.27	20.858	0.69	53.303
DMS IV (2005)								
	35–44-years-old	13.881	0.63	8.745	0.45	6.247	1.08	14.992
	65–74-years-old	9.134	1.92	17.538	1.27	11.600	3.19	29.138
	Total population*	78.092	1.07	83.558	0.71	55.445	1.78	139.003
DMS V (2014)								
	35–44-years-old	9.943	0.16	1.591	0.94	9.346	1.1	10.937
	65–74-years-old	8.435	0.89	7.507	1.43	12.062	2.32	19.569
	Total population*	77.023	0.45	34.660	0.91	70.091	1.35	103.981
2030								
	35–44-years-old	10.69	0.16	1.710	0.94	10.049	1.1	11.759
	65–74-years-old	11.524	0.89	10.256	1.43	16.479	2.32	26.736
	Total population*	73.268	0.45	32.971	0.91	66.674	1.35	98.912

* ≥ 6 years.

Table 2
Association between predictors and the odds of not having any filled or carious root surfaces (FRS, CRS) or both (root caries experience RCE = 0) across the DMS. Exponentiated coefficients (Odds Ratio) are shown. Model fit is indicated by the Log Likelihood value. Bold: predictors with significant association. *p < 0.05, **p < 0.01. ***p < 0.001.

Predictor	FRS	CRS	RCE
Observations	4388	4388	4388
Log Likelihood	−4,432.83	−3,420.46	−5,995.90
Constant	584.91*** (177.76, 1924.62)	88.77*** (23.61, 333.68)	240.34*** (72.89, 792.50)
Female (ref: male)	1.45* (1.06, 1.96)	1.19 (0.81, 1.75)	1.33 (0.95, 1.87)
Age	0.94*** (0.93, 0.96)	0.97** (0.96, 0.99)	0.95*** (0.93, 0.96)
Low education (ref. high)	0.90 (0.61, 1.33)	0.87 (0.52, 1.45)	0.93 (0.60, 1.46)
Medium education (ref. high)	0.88 (0.57, 1.34)	0.85 (0.48, 1.47)	0.76 (0.47, 1.24)
DT	0.53*** (0.38, 0.73)	0.00 (0.00, *Inf*)	0.00 (0.00, *Inf*)
MT	1.00 (0.97, 1.03)	1.00 (0.97, 1.04)	1.03 (0.99, 1.06)
FT	0.86*** (0.83, 0.90)	0.95* (0.90, 1.00)	0.90*** (0.86, 0.94)
Daily tooth brushing (ref: no)	0.18*** (0.11, 0.32)	0.14*** (0.07, 0.26)	0.14*** (0.09, 0.24)
Number of teeth with PPD ≥ 4mm	0.98 (0.95, 1.02)	0.96 (0.92, 1.01)	0.96 (0.91, 1.00)

Table 3
Association between predictors and the number of filled or carious root surfaces (FRS, CRS) or both (root caries experience, RCE) across the DMS for cases with root caries. Coefficients (number of affected surfaces) are shown. Model fit is indicated by the Log Likelihood value. Bold: predictors with significant association. *p < 0.05, **p < 0.01. ***p < 0.001.

Predictor	FRS	CRS	RCE
Observations	4388	4388	4388
Log Likelihood	−4,432.83	−3,420.46	−5,995.90
Constant	−1.87*** (−2.70, −1.04)	−1.87*** (−2.58, −1.15)	−1.99*** (−2.52, −1.46)
Female (ref: male)	−0.10 (−0.27, 0.07)	−0.29** (−0.48, −0.10)	−0.21** (−0.34, −0.08)
Age	0.02*** (0.01, 0.03)	0.02*** (0.01, 0.03)	0.03*** (0.02, 0.03)
Low education (ref. high)	0.04 (−0.17, 0.25)	0.09 (−0.18, 0.35)	0.09 (−0.09, 0.26)
Medium education (ref. high)	0.05 (−0.19, 0.30)	0.08 (−0.20, 0.36)	0.03 (−0.15, 0.22)
DT	−0.04 (−0.11, 0.03)	0.32*** (0.26, 0.38)	0.27*** (0.23, 0.32)
MT	0.02** (0.01, 0.04)	0.04*** (0.02, 0.06)	0.04*** (0.02, 0.05)
FT	0.07*** (0.05, 0.10)	−0.02 (−0.04, 0.00)	0.06*** (0.04, 0.07)
Daily tooth brushing (ref: no)	0.06 (−0.42, 0.53)	−0.08 (−0.49, 0.33)	0.03 (−0.29, 0.34)
Number of teeth with PPD ≥ 4mm	0.00 (−0.02, 0.02)	0.05*** (0.03, 0.07)	0.02** (0.01, 0.03)

Our study combined individual-level estimates with population data, allowing to estimate the cumulative numbers of FRS and CRS in Germany. These numbers reflect both disease patterns with time and demographic dynamics. With around 33–34 million restored surfaces, the cumulative FRS in 2014 was similar to that in 1997. The number of filled root surfaces is only a fraction of the number of coronally filled teeth in Germany (470 million in 2014). It would be relevant to quantify the need emanating from replacing such root surface restorations. Routine data on survival of such restorations from German healthcare would be useful for this purpose. So far, however, the German statutory insurance does not report on restoration types and locations. Given that root surface restorations have been found to show lower survival probabilities than coronal restorations in a number of other studies, the emanating need for retreatment may be considerable, though [11,27]. The significant increase in the cumulative CRS since 1997 is more worrisome; CRS had nearly quadrupled since 1997. In 2014, there were more surfaces with untreated root caries (70 million) than teeth with untreated coronal caries lesions (46 million) in Germany [4].

We also explored the possible cumulative burden of root caries in 2030. The underlying prediction was made based on the assumption that individual estimates (FRS, CRS) remain constant from 2014 to 2030. This was, as we could not identify a clear trend in root caries experience (mainly FRS); making predictions is not easily possible in such case. Our model allows to capture population dynamics and its impact on the population-level root caries experience, but not any possible changes in root caries experience on an individual level. A number of factors may alter this individual root caries experience in the future. Improved (home or professional) preventive measures or specifically developed products for root caries prevention may be introduced and decrease root caries experience. Retaining a higher number of teeth until high age and increasing recession and periodontal disease in the group of elderly may increase it instead (as briefly discussed above). As we don't know how these possible factors may impact on root caries experience, we regard our prediction made until 2030 as conservative. Based on it, we expect only very limited changes in the cumulative burden. This was despite a growth in the group of elderly, i.e. those who carry the main burden of root caries, mainly as the overall population in Germany will shrink. We do not expect great increases in treatment needs for root caries – but also no decreases, which is the opposite to the widely observed decline of coronal caries experience [28]. Root caries will remain a significant oral condition in the future and concepts for successful prevention and management are needed.

These concepts will benefit from identifying individuals or groups at risk. While our study uses repeated cross-sectional data and cannot make any predictions as to the future risk of an individual developing root caries, it can inform us about possible indicators of the disease, thereby guiding diagnostic pathways of clinicians and informing public health efforts. We used two-component mixture models to assess (1) the odds of not being at-risk, and (2) the number of affected surfaces if one was at-risk. We found that brushing teeth daily was increasing the odds for being at-risk for root caries experience. We ascribe this counter-intuitive finding to the fact that with an irregular brushing behavior, MT increases, and with it the odds of not being at-risk (as one has fewer units at-risk). The loading onto the covariate brushing may also explain why MT itself was not significantly associated with the odds of not being at-risk. Furthermore, gathering brushing behavior data using a questionnaire may not fully capture the quality of plaque control, introducing some bias. For those individuals with root caries lesions, the number of affected surfaces increased with age (reflecting the fact that root caries is a cumulative condition) and with DT (indicating the patient being, overall, at high caries risk).

This study has a number of strengths. First, it builds on three waves of nationally representative data spanning a time period of nearly two decades. The studies allowed to identify trends and to assess clinical, demographic and behavioral risk indicators for root caries. Second, combining our morbidity estimates with population numbers and projecting these over time allows to grasp the population-level changes which have occurred and may occur in the future, yielding actionable evidence both for policy makers and healthcare planers. Third, this study used a number of models and explored their statistical value; we are confident that the used model is as suitable as possible for the data and task at hand. Note, however, that alternative black-box models and ensemble learning methods, such as random forests [29] etc. may achieve higher predictive power, but are less helpful for interpreting associations. As a weakness, the explanatory value of our models was limited, as indicated by the degree of the association (e.g. per tooth with PPD $\geq$ 4 mm, the RCE increased by 0.02; even in patients with 10 teeth with PPD $\geq$ 4 mm, the RCE would, in mean, be increased by only 0.2 surfaces, which may be clinically of minor importance). The fact that many covariates nevertheless had a significant association with the outcome can hence be ascribed to the large sample size and not necessarily to clinical relevance. Also, our extrapolation was based on the very simple assumption that CRS and FRS remained constant on an individual level from 2014 onwards. We discussed the drawbacks of this approach.

In conclusions and within the limitations of this study, FRS/RCE showed no clear trend between 1997 and 2014, while CRS has increased since 1997 in Germany. A range of indicators were significantly associated with FRS/CRS/RCE, while a large degree of the observed variance in RCE and its components remains unexplained. Concepts for addressing the stubbornly high population-level treatment needs of root caries are needed.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jdent.2018.08.013.

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Appendix

Non-response analysis

Table S1: Non-response (NR) estimable model for adults

	DMS III (1997)				DMS IV (2005)				DMS V (2014)			
	Subjects	NR subjects	Non participants	total	Subjects	NR subjects	Non participants	Total	Subjects	NR subjects	Non participants	Total
Nr. of cases (n)	655	243	281	1179	925	342	507	1774	966	348	673	1987
Sampling rate (%)	65	20	24	100	52	19	29	100	49	18	34	100
Characteristics (%)												
Male	47,3	49,6	?	48,3	50,6	54,7	?	52,6	46,9	48,9	?	48,4
Low educational level	28,1	30,0	?	28,9	49,4	45,3	?	47,7	53,1	51,1	?	52,6
Very good/good self-rated oral health status	33,7	48,7	?	40,3	40,6	53,2	?	46,7	47,9	65,0	?	57,3
Regular dental check-ups	68,9	62,1	?	65,9	76,1	64,9	?	70,7	76,7	67,6	?	72,7
Denture rate	68,2	72,5	?	70,1	68,1	63,2	?	65,7	76,7	67,6	?	72,7

Table S2: Non-response (NR) estimable model for younger seniors

	DMS III (1997)				DMS IV (2005)				DMS V (2014)			
	Subjects	NR subjects	Non participants	total	Subjects	NR subjects	Non participants	Total	Subjects	NR subjects	Non participants	Total
Nr. of cases (n)	1367	480	577	2424	1040	359	469	1868	1042	428	549	2019
Sampling rate (%)	56	20	24	100	56	19	25	100	52	21	27	100
Characteristic (%)												
Male	44,7	33,4	?	39,8	46,2	42,1	?	44,4	47,0	40,9	?	44,1
Low educational level	75,3	76,0	?	44,0	65,8	62,6	?	64,4	47,7	50,6	?	49,1
Very good/good self-rated oral health status	47,1	39,96	?	44,0	36,5	41,8	?	38,8	45,6	51,2	?	48,3
Regular dental check-ups	56,4	44,1	?	51,0	72,2	70,9	?	71,6	91,4	73,9	?	83,0
Denture rate												

Reliability analysis

Table S3: Inter-rater-reliability of root caries parameter in DMS III (1997), DMS IV (2005), and DMS V (2014)

	CRS	FRS	RCI
DMS III	0.94[1]	0.93[1]	0.93[1]
DMS IV	0.76[1]	0.61[1]	./.
DMS V	n/a	n/a	0.69[2]

CRS: carious root surface; FRS: filled root surface; RCI: root caries index
[1]Kendall´s tau-b; [2]Intra class coefficient; n/a not assessed (only the RCI was reliability-tested)