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# Root surface caries among older Australians

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## Abstract

**Objectives:** Root caries has increased as a clinical problem in recent decades. However, the use of multiple waves of longitudinal follow-up data in estimating root caries increment has not been previously attempted. The aims of this study were to quantify root caries increment from a longitudinal study of older adults with 4 oral examinations over 11 years and to examine behavioural factors associated with root caries.

**Methods:** A secondary analysis was undertaken using data collected in 4 waves (baseline, 2-year, 5-year and 11-year) of the South Australian Dental Longitudinal Study which began in 1991/92. The study group consisted of a stratified random sample of people aged 60+ years at baseline. A total of 358 participants with complete oral examinations in all 4 waves were included. The examinations were performed by trained and calibrated dentists. Baseline behavioural risk factors (toothbrushing frequency, flossing frequency, dental visiting pattern, reason for dental visiting and tobacco smoking status) and time in years across the 4 waves were the main exposures. Baseline clinical oral conditions (gingival condition and gingival recession), demographic and socio-economic risk factors served as covariates. Root caries was measured as mean number of untreated root surfaces (root DS) and decayed/filled root surfaces (root DFS) at each wave of examinations. Multivariable multilevel growth model using linear regression analysis was used to get an estimate for root caries increment and associated oral health-related behaviours adjusting for all the covariates.

**Results:** Findings from the multivariable models indicated that the annual increment of root DS and root DFS were 0.07 (SE = 0.01) and 0.11 (SE = 0.02) surfaces, respectively. Irregular brushing (E [SE] = 0.25 [0.12]), visiting the dentist only for problems (E [SE] = 0.30 [0.13]) and smoking (E [SE] = 0.33 [0.12]) were risk factors for the increase in root DS. Irregular flossing and more frequent dental visit were associated with the increase in root DFS.

**Conclusions:** Root caries increased slowly across time among relatively healthier Australian older adults. Irregular brushing, unfavourable dental visiting and tobacco smoking were risk factors for the increase in untreated root caries, while irregular flossing and more frequent dental visiting were associated with the increase in root DFS.

KEYWORDS
increment, older adults, root caries

## 1 | INTRODUCTION

An increase in life expectancy and reduction in edentulism among Australian adults have resulted in a substantial increase in the total number of natural teeth retained among Australian.[1] However, gingival recession caused by normal ageing and periodontal disease has placed exposed root surfaces of these retained teeth at risk of developing root caries. Root caries has been shown to affect more than 20% of middle-aged adult population, and the burden has increased over time as the age of adults increased.[2,3]

Root caries is known to accumulate with age.[4,5] The accumulation of the disease can be measured in a number of ways. A straightforward way measures the increase in the count of root surfaces with untreated root caries or with untreated or treated root caries within a stated period of time. In this study, we have termed this root caries increment, an expression of the increase in the total burden of root caries in an individual over time. This is consistent with the traditional meaning of an increment in caries trials.[6] This is subtly different to the modern definition of caries incidence and increment where caries increment has been defined as "the number of new carious lesions, teeth or surfaces occurring in an individual within a stated period of time" and is usually measured by observing changes of sound surfaces to untreated and treated root caries.[7] While such an approach is appropriate when the focus is on identifying risk of root caries, it does not represent the accumulating burden of root caries. The increment of root caries accumulating over a period will vary by the length of time and the age and period through which individuals are followed. Many longitudinal studies of root caries involve only short time periods and one follow-up. There are only few longitudinal studies of root caries that have followed their participants for 3 or more time points with 2 or more follow-up oral examinations.[8-11] Three or more time points open the opportunity to examine trends in the increment of root caries. Use of multiple waves of longitudinal follow-up data in estimating root caries increment has not been previously attempted.

It is well established that dental caries is determined by biological, behavioural and environmental factors over the life course, and it is speculated that root caries and coronal caries share many common risk factors. Oral health-related behaviours, which are associated with gingival recession, have been associated with root caries, both in prevalence[12,13] and in incidence studies among the older adults.[14-16] However, evidence on the relationship between behavioural factors and root caries is still conflicting and not all studies have confirmed the relationships.[17-19] Moreover, the majority of longitudinal studies in root caries have been short-term research with 2- to 5-year periods of follow-up.[17]

The availability of data from the South Australian Dental Longitudinal Study (SADLS), the first comprehensive longitudinal study of the oral health of Australian older adults, provided an opportunity to estimate root caries increment within individuals over 11 years and explore the possible behavioural risk factors. Thus, the aim of this secondary analysis of data from SADLS was to quantify the 11-year root caries increment and to examine associated behavioural risk factors (toothbrushing, flossing, dental visit pattern, reason of visit and smoking) with root caries increment in Australian older adults, after adjusting for important covariates such as socio-demographics, socio-economic status (income), gingival status and number of sites with gingival recession.

## 2 | MATERIALS AND METHODS

### 2.1 | Study population and research design

This study is based on 4 separate waves of data collections from a cohort study of older adults in SADLS conducted in Adelaide and Mt Gambier. The details of the recruitment procedures have been published previously.[10,20-22] To summarize, at baseline, a stratified random sample of people aged 60+ years was selected from the South Australian Electoral Commission's database, which is a compulsory register for Australian citizens. Twenty-four strata were defined: 18 strata in the Adelaide region defined by 3 age groups, 2 sexes and 3 locality categories; and 6 strata in Mt Gambier defined by 3 age groups and both sexes. Within each stratum, different sampling rates were used to draw a simple random sample of older adults living in the community. Sampled people were notified by letter and a trained interviewer visited each person's address to advise about the study and encourage participation. Those who agreed to participate then took part in a face-to-face household interview and in a baseline oral examination in the nearby dental clinic in 1991/92. Samples were maintained through keeping contact details of the third parties who knew of a participant's circumstances or who would know of any new address, as well as by always sending birthday card each year to the participants.

In the 2nd, 5th and 11th years, participants were contacted again to participate in an interview and an oral examination. Interviews were conducted by telephone. Where possible, the dental examination was undertaken in the same dental clinic, but for a small number of participants who had mobility problems, the examinations were conducted in their home.

The risk factors were selected before the analysis based on a directed acyclic graph (DAG) identifying possible associations[23] (See Figure 1). The outcome was root caries measured in 4 waves of oral examinations. The main exposures were behavioural risk factors (including brushing frequency, flossing frequency, dental visit pattern, reason for dental visit and smoking) and time in years across the 4 waves of examinations. The covariates were socio-demographics (including age, gender, highest education, residential place and private dental insurance), socio-economics (income) and clinical risk factors (including gingivitis and number of sites with gingival recession). As can be seen in the DAG, while gingival recession seems like a collider due to associations with both exposures and the covariates such as brushing frequency,[24] smoking,[25] gingivitis[25] and age,[26] it was included as a covariate in the analysis due to the fact that the association between gingival recession and root caries has not been confirmed as causal from the previous research.[17] Further, the association of brushing frequency as an exposure and

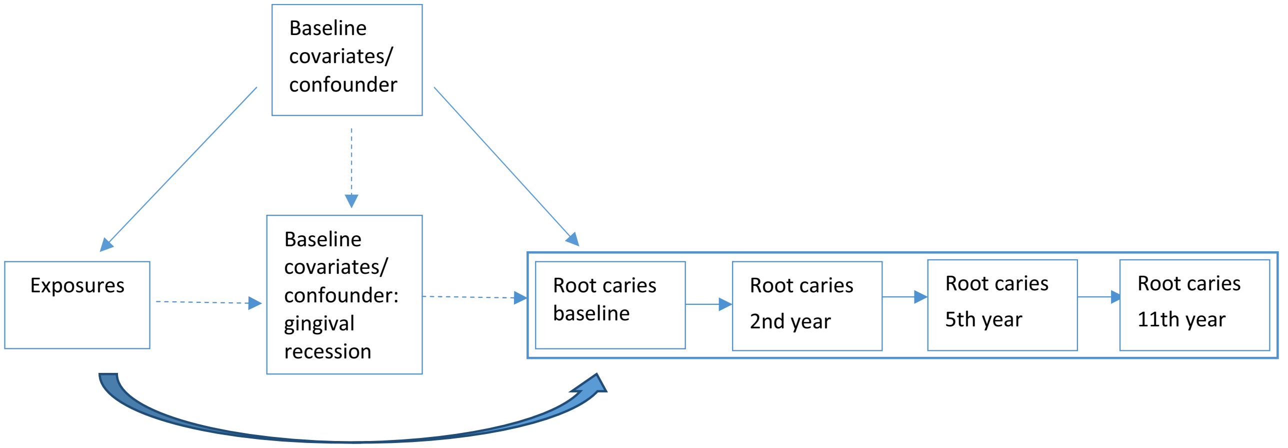


**FIGURE 1** Directed acyclic graph of root caries experience. Exposure: 1. Baseline oral health related behavioural risk factors including tooth brushing frequency, flossing frequency, dental visit, reason of visit and smoking; 2. Time, embedded into growth model. Covariates/confounder: 1. Baseline sociodemographic risk factors: age, gender, highest education, residential place, private dental insurance; 2. Baseline clinical risk factors: gingivitis, number of sites with gingival recession. ⇢ inconclusive relationship. Baseline root caries and number of teeth were excluded from the covariates[30]

gingival recession was conflicting.[27] As some people with gingival recession could increase their brushing frequency following a recommendation by their dentist, gingival recession could be a possible confounder in the association between behavioural factors including toothbrushing frequency and root caries. Thus, even though collider bias could be induced by covariate adjustment if covariates are effects of other exposures and covariates in the model,[28] we believe that including gingival recession in the model would not generate a substantial bias. Ding and Miratrix[29] demonstrated that collider bias was smaller than the confounder bias (bias from excluding factor that could be a confounder from the analysis). Thus, in this model, we treated number of sites with gingival recession as a covariate due to its position as a confounder, instead of a mediator.

Baseline root caries and number of teeth were not included as covariates because baseline disease levels and number of teeth are likely to be powerful predictors that may mask other potential risk factors for the development of root caries.[30] Moreover, baseline root caries was used as an intercept in modelling the root caries increment.

## 2.2 | Data collection

The oral examinations followed the US National Institute of Dental Research (NIDR) protocol.[31] All examinations were conducted by 1 of 4 calibrated dentists, all of whom underwent 3 days of prior training and standardization. Baseline examiners were trained and standardized by an international expert who had experience with the use of the protocol in surveys of older adults conducted in the United States. Some examiners from baseline were maintained as oral examiners in the year 2, 5 and 11 examinations. New examiners for the 2nd, 5th and 11th follow-up examination were trained by a gold standard examiner, who is 1 of the 2 calibrated examiners from the baseline examination who participated in all 4 waves of examinations. Baseline and all follow-up dental examinations were conducted under similar conditions. Mirrors and blunt NIDR probes were used under standardized illumination. Radiographs were not taken.

Root caries was recorded for all teeth and teeth roots present in the mouth, including third molars. Teeth were categorized as present if more than a quarter of the natural or restored coronal tooth structure was present. Teeth that were severely broken down, with more than 3-quarters of the coronal structure missing, were coded separately as tooth roots.

For each tooth present, the status of 4 root surfaces was recorded. Root caries was recorded by differentiating root surfaces which were decayed, filled or sound. To be registered as sound, the root surface had to be visible. Root surfaces in which there had been no recession of the gingival margin apical to the cementoenamel junction were recorded as unexposed. In the coding scheme, examiners differentiated recurrent/secondary caries from primary decay, as well as filled unsatisfactory from filled satisfactory. No distinction was made between caries-related and non-caries-related root restorations. For each tooth root present with more than 3-quarters of the coronal structure missing, it was coded as a retained sound or decayed root, and these codes were then inferred for the 4 root surfaces of the same tooth. The same procedure was applied in all oral examinations (baseline, 2nd, 5th and 11th years of follow-up examinations).

Behavioural risk factors and time interval from the baseline examinations are the main exposures. Information on oral health behaviours was gathered through the baseline interviews and included brushing frequency, flossing frequency, dental visit pattern, reason for dental visit and smoking. Time interval from the baseline examinations was expressed in years. The covariates were derived from the baseline oral examination and the initial face-to-face baseline interview. The covariates from the oral examination included clinical risk factors such as gingival status (measured through any bleeding after probing in the mesio-buccal, mid-buccal and disto-lingual sites of each tooth or tooth root present) and the number of sites with gingival recession of 1 mm or more. Covariates from the baseline interview include socio-demographic (age, gender, highest education, residential place, private dental insurance) and socio-economic risk factors (income).

## 2.3 | Data management

At baseline, 913 dentate (have at least 1 tooth or tooth root present) participants had an oral examination. At the 2-year follow-up, data were available for 689 dentate people. Some 530 and 361 dentate participants had an oral examination at 5 and 11 years, respectively. During the 11 years of follow-up, 60.8% of study participants were lost to follow-up. This loss to follow-up could be due to death, loss contact, not interested in continuing to participate or an oral health reason such as change from dentate to edentulous.

As root caries increment was also influenced by treatment, the outcome variable was assessed as untreated decayed root surfaces only (root DS) and untreated and treated root caries (root DFS). Missing as a result of root caries could not be estimated as our data did not collect the reason for missing teeth. Root DS and root DFS were chosen instead of Root Caries Index following WHO recommendation to make an easier comparison from studies with different population characteristics and different methods in reporting root caries.[32] Furthermore, we have included the number of sites with gingival recession as 1 of the covariates. We recoded simple decayed and recurrent caries as decayed root surfaces, whereas filled unsatisfactory and filled satisfactory were recoded as filled root surfaces. Then the root DS measurement was calculated by summing only the number of decayed root surfaces while the root DFS was calculated by summing all decayed and filled root surfaces for both teeth and teeth roots present. Root caries outcome was measured for each wave from baseline to the 11th year follow-up.

The main exposures in this analysis were oral health-related behavioural risk factors and time. Oral health-related behaviours were toothbrushing frequency (twice a day or more vs less than twice a day), flossing frequency (once a day or more vs not every day), dental visit (last visit was <1 year ago vs last visit that was more than 1 year ago), reason for visit (check-up vs problem) and smoking status (never smoked vs currently or used to smoke). Time was expressed as yearly time interval from the baseline oral examination to be able to get the annual increment.

Among covariates including baseline socio-demographics, socio-economics and clinical risk factors, age was dichotomized into 60-69 years and ≥70 years. The level of education was dichotomized into trade/diploma or higher and senior high school or less. Residential place was divided into living in Adelaide and Mt Gambier, which also could represent the access of the study participants to water fluoridation in Adelaide. Adelaide the capital city of South Australia, had water fluoridated since 1971, while Mt Gambier's water was not fluoridated. Using baseline place of residence, it was assumed that residents remained in the same place for the 11-year duration of the study. Private dental insurance was categorized as having private insurance or not. Socio-economic status was measured by household income (<\$12 000, \$12 000-<\$16 000 and ≥\$16 000). Gingival status was categorized into normal gingiva (if there were no teeth with gingival bleeding after probing) and gingivitis (if at least 1 tooth had bleeding after probing). In the multivariable analysis gingival recession was expressed as a count of the number of sites in the mouth with recession of 1 mm or more. The presence of gingival recession was only presented in the descriptive analysis to provide summary characteristics on gingival health.

## 2.4 | Statistical analysis

The statistical analysis was performed in SAS-callable SUDAAN. Characteristics of the study participants in each wave, as well as the final data set used which contained 358 dentate participants in all 4 oral examinations, were initially analysed. The bivariate analysis of the root caries experience in each wave of oral examinations by key characteristics was also assessed. Bivariate analysis was conducted using the Mann-Whitney *U* test for the risk factors with 2 categories, the Kruskal-Wallis 1-way ANOVA for a risk factor with 3 categories and Spearman's rho correlation for continuous risk factor as all distributions were not normal.

In the multivariable analysis, time (in years) was used as a random factor in the model allowing for modelling variance between and within individuals. The intercept (baseline root caries experience) was also used as a random factor. Therefore, the slope is an estimated annual increment of root caries adjusting for between-individual variations in baseline caries experience and overtime within-individual changes. Even though it is possible to compare this annual estimated increment to an annual increment reported in another study,[11] it should be noted that this annual increment was not calculated directly by observing changes of sound surfaces to untreated and treated root caries across the baseline and follow-up examination, followed by a division with the year length between the 2 examinations, like the calculation of annual increment described in the previous study.[11]

A series of longitudinal models for the mean root DS and root DFS was assessed. The series of longitudinal models began with the reference (null) model examining only the increment, followed by a part adjusted model, full model and full model including interactions. The best model was a model presenting the lowest DIC (deviance information criteria) and Akaike information criterion (AIC).[33] Multilevel analysis using SAS Proc Mixed was used to fit these models[33,34] to examine the slope of the root caries increment and the between- and within-individual variations. The statistical significance of the associations was evaluated at $P < .05$.

## 2.5 | Ethical review

Ethical approval of SADLS was received by the University of Adelaide's Human Research Ethics Committee. As this particular study was a secondary data analysis, new ethics clearance was not required.

## 3 | RESULTS

### 3.1 | Characteristics of the study participants

Table S1 shows the baseline characteristics of participants in each wave of oral examinations and participants in all 4 oral examination waves in the final data set. During the 11 years of the study, 60.8% of study participants were lost to follow-up. As expected, the percentage of people age ≥70 years at baseline was reduced during the 11 years of study. In the final data set, there were only 31.6% participants who age 70+ years in the baseline, while it was almost 50% at the baseline examination. The data in Table S1 also show that people who were less educated and had a lower income tended to be lost to follow-up in the study. More than 60% participants had gingivitis. The data also revealed that more than 95% participants had gingival recession with mean number of sites affected being more than 24 sites.

There was little change in the characteristics of participants retained in the study in terms of oral health-related behavioural factors. In the final data set, around 70% of participants reported brushing twice a day or more, while <30% reported flossing once a day or more. More than 70% of participants reported having a dental visit in the previous year and around 50% reported an oral problem as the reason for the last dental visit. Slightly over 50% of participants were current or previous smokers.

### 3.2 | Bivariate analysis of root caries (root DS and root DFS) with the baseline explanatory variables

The mean number of root DS were 0.33 (SD = 0.88), 0.37 (SD = 1.24), 1.07 (SD = 2.19), 0.98 (SD = 2.42), while the mean number of root DFS were 2.92 (SD = 3.28), 3.37 (SD = 3.72), 4.75 (SD = 4.52), 4.02 (SD = 4.60) at the baseline, 2nd, 5th and 11th follow-up years, respectively (Table S2). Table S2 also shows the bivariate analysis of baseline characteristics and root caries measured both as root DS and root DFS in each wave of oral examinations.

In the bivariate analysis, different factors were found to be associated with different measurements of root caries at different waves. Participants who brushed less than twice a day and had their last dental visit more than 1 year ago had higher untreated root caries at baseline than those who brushing twice a day or more and who had their last dental visit <1 year ago (mean ± SD = 0.55 ± 1.18 vs mean ± SD = 0.22 ± 0.68 and mean ± SD = 0.50 ± 1.15 vs mean ± SD = 0.26 ± 0.74, respectively). Current and previous smokers had higher number of untreated root caries than those who never smoked at baseline (mean ± SD = 0.49 ± 1.11 vs mean ± SD = 0.16 ± 0.49), 5th year follow-up (mean ± SD = 1.35 ± 2.61 vs mean ± SD = 0.75 ± 1.56) and 11th year follow-up (mean ± SD = 1.21 ± 2.56 vs mean ± SD = 0.74 ± 2.24). Only reason for last dental visit was associated with untreated root caries in all waves of oral examinations. Gender and private dental insurance were also associated with untreated root caries at some follow-up points. Men had higher number of untreated root caries than women at the baseline and 11th year follow-up (mean ± SD = 0.47 ± 1.07 vs mean ± SD = 0.17 ± 0.56 and mean ± SD = 1.43 ± 3.03 vs mean ± SD = 0.46 ± 1.21, respectively) while people with no private dental insurance had higher number of untreated root caries in the 11th year follow-up than those with private dental insurance.

When root caries was measured as treated and untreated root caries (root DFS), being older, having last visited <1 year ago and check-up as a reason for dental visit were consistently associated with higher root DFS in all waves of oral examination.

### 3.3 | The increment and associated behavioural factors of root caries

Models for the untreated root caries are presented in Table 1. The null model showed that untreated root caries increased by 0.07 surfaces annually. There was a strong positive covariance between intercept and slope (E = 0.03, $P$ = .01), indicating that participants with the highest baseline untreated root caries had the steepest increase in untreated root caries. The annual increment of 0.07 surface was observed in the adjusted and the full (final) model. The final model showed that brushing less than twice a day, visiting a dentist only for a problem and tobacco smoking were associated with a steeper increase in untreated root caries (E [SE] = 0.25 [0.12], E [SE] = 0.30 [0.13] and E [SE] = 0.33 [0.12], respectively). Among all covariates, only number of sites with gingival recession was associated with root DS increment. We also observed full model with interactions but found that the model had a bigger DIC and AIC than the final model so these are not presented.

Table 2 presents models for the treated or untreated root caries (root DFS). The null model showed that root DFS increased by 0.10 surfaces annually. The root caries increment increased slightly to 0.11 surfaces annually in the adjusted and the full (final) model. The final model showed that not flossing every day and last dental visit being <1 year ago were associated with a steeper increase in root DFS (E [SE] = 0.81 [0.39] and E [SE] = 1.22 [0.44], respectively). Among all covariates, only number of sites with gingival recession was associated with root DFS increment. Full model with interactions showed bigger DIC and AIC than the final model so these are not presented.

## 4 | DISCUSSION

This study reported a root caries increment both measured as untreated root caries (root DS) and treated or untreated root caries (root DFS) among Australian older adults. Root DS and root DFS increased by 0.07 and 0.11 surfaces annually, respectively. The longitudinal nature of the data and the modelling method ensured a robust contribution to understanding progression of root caries in a population-based sample of older adults.

The measurements of root caries in this study (root DS and root DFS) are cumulative and chronic in nature, as they measure past and present root caries experience. However, the fact that the measurements are cumulative indexes does not mean that

**TABLE 1** Association between individual-level factors and untreated root caries (root DS) increment among 60+-year-old South Australians

| Characteristics | Reference model (Null model) | | | Model with individual-level socio-demographic and clinical factors | | | Final model with individual-level oral health-related behavioural factors | | |
|---|---|---|---|---|---|---|---|---|---|
| Baseline predictors | E | SE | *P* | E | SE | *P* | E | SE | *P* |
| Fixed effects | | | | | | | | | |
| Intercept | **0.39** | **0.06** | **<.01** | **0.60** | **0.18** | **<.01** | 0.01 | 0.26 | .97 |
| Annual increment | **0.07** | **0.01** | **<.01** | **0.07** | **0.01** | **<.01** | **0.07** | **0.01** | **<.01** |
| Socio-demographics | | | | | | | | | |
| Age | | | | | | | | | |
| 60-69 y (ref. ≥70 y) | | | | 0.09 | 0.12 | .50 | 0.02 | 0.12 | .87 |
| Gender | | | | | | | | | |
| Female (ref. Male) | | | | −0.18 | 0.12 | .12 | 0.06 | 0.13 | .67 |
| Highest education | | | | | | | | | |
| Senior high school or less (ref. Trade/diploma or higher) | | | | −0.13 | 0.12 | .29 | −0.15 | 0.12 | .23 |
| Residential place | | | | | | | | | |
| Adelaide (ref. Mt Gambier) | | | | −0.15 | 0.12 | .22 | −0.13 | 0.12 | .27 |
| Private dental insurance | | | | | | | | | |
| No (ref. Yes) | | | | 0.02 | 0.13 | .89 | −0.02 | 0.13 | .88 |
| Socio-economic | | | | | | | | | |
| Income | | | | | | | | | |
| <$12 000 (ref. ≥$16 000) | | | | 0.08 | 0.16 | .65 | 0.02 | 0.17 | .92 |
| $12 000-<$16 000 (ref. ≥$16 000) | | | | −0.14 | 0.14 | .31 | −0.19 | 0.14 | .17 |
| Clinical conditions | | | | | | | | | |
| Gingival status | | | | | | | | | |
| Gingivitis (ref. Normal) | | | | −0.02 | 0.12 | .87 | −0.03 | 0.12 | .77 |
| No of sites with gingival recession | | | | **0.01** | **0.003** | **<.01** | **0.01** | **0.004** | **<0.01** |
| Oral health-related behavioural factors | | | | | | | | | |
| Brushing frequency | | | | | | | | | |
| Less than twice a day (ref. Twice a day or more) | | | | | | | **0.25** | **0.12** | **.04** |
| Flossing frequency | | | | | | | | | |
| Not every day (ref. Once a day or more) | | | | | | | 0.09 | 0.13 | .47 |
| Dental visit | | | | | | | | | |
| Last visit is <1 y ago (ref. Last visit is more than 1 y ago) | | | | | | | 0.16 | 0.14 | .25 |
| Reason of visit | | | | | | | | | |
| Problems (ref. Check-up) | | | | | | | **0.30** | **0.13** | **.03** |
| Smoking | | | | | | | | | |
| Currently smoking and used to smoke (ref. Never smoke) | | | | | | | **0.33** | **0.12** | **<.01** |
| Deviance statistics | | | | | | | | | |
| Variability between intercepts | 0 | | | 0 | | | 0 | | |
| Covariance between intercept and slope | 0.03 | 0.01 | 0.01 | 0.02 | 0.02 | .19 | 0.02 | 0.02 | .32 |
| Variability between slopes | 0.02 | 0.004 | <0.01 | 0.03 | 0.005 | <.01 | 0.03 | 0.005 | <.01 |
| Residual | 2.10 | 0.09 | <0.01 | 2.11 | 0.10 | <.01 | 2.09 | 0.10 | <.01 |
| Model fit | | | | | | | | | |
| DIC | 5548.9 | | | 4657.2 | | | 4638.4 | | |
| AIC | 5554.9 | | | 4663.2 | | | 4644.4 | | |

Multilevel multivariable growth models of count of root DS.

E, estimate; SE, Standard error of estimates. AIC: Akaike information criterion (smaller is better); DIC: deviance information criteria = −2RLL (smaller is better).

Bold: Statistically significant estimates, Mixed model using SAS Proc Mixed, $P < 0.05$; Reference model: with intercept and time only as the random factors.

**TABLE 2** Association between individual-level factors and untreated or treated root caries (root DFS) increment among 60+-year-old South Australians

| Characteristics | Reference model (Null model) | | | Model with individual-level socio-demographic and clinical factors | | | Final model with individual-level oral health-related behavioural factors | | |
|---|---|---|---|---|---|---|---|---|---|
| Baseline predictors | E | SE | P | E | SE | P | E | SE | P |
| Fixed effects | | | | | | | | | |
| Intercept | **3.31** | **0.19** | **<.01** | **3.33** | **0.57** | **<.01** | **2.03** | **0.81** | **.01** |
| Annual increment | **0.10** | **0.02** | **<.01** | **0.11** | **0.02** | **<.01** | **0.11** | **0.02** | **<.01** |
| Socio-demographics | | | | | | | | | |
| Age | | | | | | | | | |
| 60-69 y (ref. ≥70 y) | | | | −0.39 | 0.39 | .32 | −0.42 | 0.38 | .27 |
| Gender | | | | | | | | | |
| Female (ref. Male) | | | | −0.14 | 0.37 | .71 | −0.07 | 0.40 | .87 |
| Highest education | | | | | | | | | |
| Senior high school or less (ref. Trade/diploma or higher) | | | | −0.30 | 0.38 | .42 | −0.39 | 0.37 | .30 |
| Residential place | | | | | | | | | |
| Adelaide (ref. Mt Gambier) | | | | 0.57 | 0.37 | .12 | 0.50 | 0.36 | .17 |
| Private dental insurance | | | | | | | | | |
| No (ref. Yes) | | | | −0.002 | 0.40 | 1.00 | 0.26 | 0.39 | .51 |
| Socio-economic | | | | | | | | | |
| Income | | | | | | | | | |
| <$12 000 (ref. ≥$16 000) | | | | 0.38 | 0.51 | .46 | 0.30 | 0.50 | .55 |
| $12 000-<$16 000 (ref. ≥$16 000) | | | | 0.20 | 0.44 | .65 | 0.30 | 0.43 | .48 |
| Clinical conditions | | | | | | | | | |
| Gingival status | | | | | | | | | |
| Gingivitis (ref. Normal) | | | | −0.008 | 0.37 | .98 | −0.11 | 0.36 | .77 |
| No of sites with gingival recession | | | | **0.10** | **0.01** | **<.01** | **0.10** | **0.01** | **<.01** |
| Oral health-related behavioural factors | | | | | | | | | |
| Brushing frequency | | | | | | | | | |
| Less than twice a day (ref. Twice a day or more) | | | | | | | −0.08 | 0.37 | .83 |
| Flossing frequency | | | | | | | | | |
| Not every day (ref. Once a day or more) | | | | | | | **0.81** | **0.39** | **.04** |
| Dental visit | | | | | | | | | |
| Last visit is <1 y ago (ref. Last visit is more than 1 y ago) | | | | | | | **1.22** | **0.44** | **<.01** |
| Reason of visit | | | | | | | | | |
| Problems (ref. Check-up) | | | | | | | −0.78 | 0.40 | .06 |
| Smoking | | | | | | | | | |
| Currently smoking and used to smoke (ref. Never smoke) | | | | | | | 0.47 | 0.37 | .21 |
| Deviance statistics | | | | | | | | | |
| Variability between intercepts | 9.52 | 0.96 | <.01 | 6.87 | 0.86 | <.01 | 6.33 | 0.83 | <.01 |
| Covariance between intercept and slope | −0.11 | 0.08 | .18 | −0.03 | 0.08 | .69 | −0.04 | 0.08 | .59 |
| Variability between slopes | 0.07 | 0.01 | <.01 | 0.08 | 0.01 | <.01 | 0.08 | 0.01 | <.01 |
| Residual | 5.69 | 0.30 | <.01 | 5.84 | 0.34 | <.01 | 5.86 | 0.34 | <.01 |
| Model fit | | | | | | | | | |
| DIC | 7512.2 | | | 6205.2 | | | 6162.5 | | |
| AIC | 7520.2 | | | 6213.2 | | | 6170.5 | | |

Multilevel multivariable growth models of count of root DFS.
E, estimate; SE, standard error of estimates; AIC, Akaike information criterion (smaller is better); DIC, deviance information criteria = −2RLL (smaller is better). Bold: Statistically significant estimates, Mixed model using SAS Proc Mixed, $P < .05$; Reference model: with intercept and time only as the random factors.

they cannot remain stable over time, indicating that no further caries has developed. The findings of this study confirm our knowledge that the presence of root caries increases across time. As our model also take age into account, we demonstrated that the increase over time was independent of the age of the participants at the baseline of the study. At this time, there is no comparable study of root caries increment using longitudinal data with at least 3 points of oral examinations. Future analysis with more contemporary data is needed to confirm the findings. However, our finding in annualized root DS and root DFS increments were comparable to those reported in an Iowan study with similar length of follow-up.[11]

Longitudinal studies always face a problem with attrition of the participants,[7] which was a limitation in this study. However, a series of checks for the impact of attrition in longitudinal data supported the conclusion that there was no serious bias in estimates of change and determinants of change due to attrition.[35] The attrition in this study was slightly higher than the longitudinal studies of root caries of the same length conducted in Sweden,[9] but much lower than that observed in Iowa.[11] Previous studies[10,36] have revealed that people who are lost to follow-up are those with higher root caries at baseline[36] and those with higher number of chronic medical conditions.[10] Thus, these results for root caries increment in this analysis are biased towards relatively young and healthy Australian older adults. However, even healthier older adults still experienced root caries increment and they could benefit from root caries prevention programs.

The baseline behavioural characteristics of participants retained in the study were comparable to those of 60 + years old participants in the National Survey of Adult Oral Health in Australia 2004-06 (NSAOH 2004-06).[37] In relation to the risk factors for root caries, this study found that different behavioural factors were associated with root DS and root DFS. Our analysis found that infrequent toothbrushing, visiting a dentist only for a problem and smoking were risk factors for higher increase in untreated root caries, while not flossing every day and frequent dental visiting (last dental visit <1 year ago) were risk factors for higher increase in treated or untreated root caries. An increased number of sites with gingival recession were associated with both root DS and root DFS increment.

Sugar availability and dental plaque are well-known aetiologic agents in dental caries.[38] Toothbrushing could mechanically remove plaque and together with fluoridated toothpaste could assist in altering the balance between demineralization and remineralization, having a preventive effect of root caries. The finding that infrequent brushing was risk factor for untreated root caries is consistent with previous studies.[37,39,40] A meta-analysis estimating the effect of toothbrushing frequency on dental caries from longitudinal studies (combining coronal and root caries) also found that infrequent brushers demonstrated higher incidence and increment of carious lesions than frequent brushers,[41] even though this effect could not be separated from the potential contribution of fluoride in toothpaste used in the toothbrushing activity.[42]

Smoking was related to the elevation of *mutans streptococci* and *lactobacilli* in saliva, which are associated with the initiation and progression of dental caries.[43] Also, smoking contributes to a lower buffering capacity of saliva, weakening a protective factor against dental caries.[44] Our finding that smoking was a risk factor for root caries was supported in some previous studies[14,37] while some other studies did not find any association.[15,45]

Visiting a dentist only for a problem was found to be a risk factor for untreated root caries. Previous research has demonstrated that routine check-up could be an effective way of promoting good health and avoiding disease as dentists can monitor dental health, suggest preventive treatment or detect disease in the early stage.[46] However, in this study we also found that more frequent dental visiting was related to a steeper increase in the number of treated or untreated root caries. This may suggest that the purpose of many dental visits is dental treatment and less likely to be prevention. Therefore, those who visited a dentist would receive more treatment, including treatment for root caries. As this study did not differentiate between caries-related and non-caries-related root restorations (restorations for cervical abrasion), it is also possible that more frequent visiting is associated with more fillings placed for both caries and other reasons on root surfaces such as wear or sensitivity. Walls et al[47] found that up to 55% of restorations placed by the UK dentists were placed because of wear rather than root caries. Thus, in terms of recurrent caries, some of the restorations that subsequently go on to be damaged by recurrent caries may also have been previously restored because of wear or sensitivity. Furthermore, dentists may recommend more frequent visiting for those with root caries. Not flossing every day was found to be risk factor for root DFS. This behaviour could be a proxy for less emphasis on tooth cleaning as a strategy for preventing root caries. Even though the effectiveness of flossing in preventing dental decay is still debatable,[48,49] the correct use of flossing could remove food trapped in the interproximal contact area between teeth, which further could prevent the root caries.

Increased gingival recession was associated with both increased in root DS and root DFS. Gingival recession could be caused by periodontal disease but has also been related to ageing. Gingival recession has been identified as a preliminary phase for root caries[50] as the exposed root surfaces will be in contact with the oral environment. Some research has found that root caries can also occur without gingival recession.[51] Dentists who observe gingival recession in their older adult patients often encourage more cleaning including toothbrushing to prevent root caries. This underlies the inclusion of the number of sites with gingival recession in this analysis, as it could be a confounder in the association between behavioural factors including toothbrushing frequency and root caries. We found that gingival recession was significantly associated with both increased in root DS and root DFS suggesting this approach was appropriate.

This research found that some behavioural risk factors such as infrequent toothbrushing, visiting a dentist only for a problem and smoking were associated with untreated root caries, thus changing in these behaviours should be routinely promoted among older adults. However, it is understandable that the ability to carry out daily living activities and cognitive function diminishes with ageing,[52] resulting in older adults having functional limitations which could disrupt normal daily living activities, including normal oral hygiene and use of dental services. This understanding about root caries risk factors should be also promoted among the carers of older adults.

There were some strengths in this study. This cohort study provides high-level evidence in the association between oral health behaviours with root caries. Moreover, the 11-years length of follow-up in this study gives an adequate time for the development of root caries, and finally, this study provides new data on root caries increment over time that was gathered through longitudinal study with more than 3 follow-up oral examinations. However, as the behavioural factors were self-reported, social desirability bias was a possible limitation, as respondents could report behaviours considered socially desirable or under-report undesirable ones.[53] Furthermore, the reporting of untreated root caries and treated or untreated root caries in this study could lead to the underestimation of root caries increment as they do not address the effect of missing teeth extracted because of root caries. There is no standard method for adjusting root caries measurement for tooth loss[7] as the reason for tooth extraction generally remains unknown.

## 5 | CONCLUSIONS

Root caries increased over time among population-based Australian older adults. However, the rate of increment was slow among relatively healthier older adults in this study. Irregular brushing, dental visiting only for a problem and smoking were risk factors for the increase in untreated root caries. Not flossing every day and more frequent dental visiting were associated with the increase in treated or untreated root caries. Where appropriate, changing these behaviours should be routinely promoted among older adults.

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### REFERENCES

1. Chalmers J, Ettinger R, Thomson W, Spencer AJ. *Aging and Dental Health*. Adelaide, SA: University of Adelaide – AIHW Dental Statistics and Research Unit; 1999.
2. Thomson WM, Broadbent JM, Foster Page LA, Poulton R. Antecedents and associations of root surface caries experience among 38-year-olds. *Caries Res*. 2013;47:128-134.
3. Holm-Pedersen P, Avlund K, Morse DE, et al. Dental caries, periodontal disease, and cardiac arrhythmias in community-dwelling older persons aged 80 and older: Is there a link? *J Am Geriatr Soc*. 2005;53:430-437.
4. Fure S. Five-year incidence of coronal and root caries in 60-, 70- and 80-year-old Swedish individuals. *Caries Res*. 1997;31:249-258.
5. Banting DW. Dental caries in the elderly. *Gerodontology*. 1984;3:55-61.
6. Horowitz HS, International Dental Federation, F.D.I. Commission on classification and statistics for oral conditions working group 1 (COCSTOC), World Dental Congress. Classification of epidemiologic studies of dental caries and definitions of related terms. FDI technical report. 62nd. London; 1975.
7. Slade GD, Caplan DJ. Methodological issues in longitudinal epidemiologic studies of dental caries. *Community Dent Oral Epidemiol*. 1999;27:236-248.
8. Lawrence HP, Hunt RJ, Beck JD, Davies GM. Five-year incidence rates and intraoral distribution of root caries among community-dwelling older adults. *Caries Res*. 1996;30:169-179.
9. Fure S. Ten-year incidence of tooth loss and dental caries in elderly Swedish individuals. *Caries Res*. 2003;37:462-469.
10. Thomson WM, Spencer AJ, Slade GD, Chalmers JM. Is medication a risk factor for dental caries among older people? *Community Dent Oral Epidemiol*. 2002;30:224-232.
11. Hamasha AA-H, Warren JJ, Hand JS, Levy SM. Coronal and root caries in the older Iowans: 9- to 11-year incidence. *Spec Care Dentist*. 2005;25:106-110.
12. Joshi A, Douglass C, Jette A, Feldman H. The distribution of root caries in community-dwelling elders in New England. *J Public Health Dent*. 1994;54:15-23.
13. Locker D, Leake JL. Coronal and root decay experience in older adults in Ontario, Canada. *J Public Health Dent*. 1993;53:158-164.
14. Phelan JA, Mulligan R, Nelson E, et al. Dental caries in HIV-seropositive women. *J Dent Res*. 2004;83:869-873.
15. Locker D. Incidence of root caries in an older Canadian population. *Community Dent Oral Epidemiol*. 1996;24:403-407.
16. Takano NAY, Yoshihara A, Miyazaki H. Factors associated with root caries incidence in an elderly population. *Community Dent Health*. 2003;20:217-222.
17. Ritter AV, Shugars DA, Bader JD. Root caries risk indicators: a systematic review of risk models. *Community Dent Oral Epidemiol*. 2010;38:383-397.
18. Beck J. The epidemiology of root surface caries. *J Dent Res*. 1990;69:1216-1221.
19. Beck JD. The epidemiology of root surface caries: North American studies. *Adv Dent Res*. 1993;7:42-51.
20. Slade GD, Spencer AJ. Periodontal attachment loss among adults aged 60+ in South Australia. *Community Dent Oral Epidemiol*. 1995;23:237-242.
21. Slade GD, Spencer AJ. Distribution of coronal and root caries experience among persons aged 60+ in South Australia. *Aust Dent J*. 1997;42:178-184.
22. Thomson WM. Medications, dry mouth and dental caries among older people: a longitudinal study (doctoral dissertation). University of Adelaide, Department of Dentistry; 1999.
23. Merchant AT, Pitiphat W. Directed acyclic graphs (DAGs): an aid to assess confounding in dental research. *Community Dent Oral Epidemiol*. 2002;30:399-404.
24. Vehkalahti M. Occurrence of gingival recession in adults. *J Periodontol*. 1989;60:599-603.
25. Chrysanthakopoulos NA. Prevalence and associated factors of gingival recession in Greek adults. *J Invest Clin Dent*. 2013;4:178-185.

26. Albandar JM, Kingman A. Gingival recession, gingival bleeding, and dental calculus in adults 30 years of age and older in the United States, 1988–1994. *J Periodontol*. 1999;70:30-43.
27. Rajapakse PS, McCracken GI, Gwynnett E, Steen ND, Guentsch A, Heasman PA. Does tooth brushing influence the development and progression of non-inflammatory gingival recession? A systematic review *J Clin Periodontol*. 2007;34:1046-1061.
28. Glymour MM. Using causal diagrams to understand common problems in social epidemiology. In: Oakes JM, Kaufman JS, eds. *Methods in Social Epidemiology*. San Francisco, CA: Jossey-Bass, 2006:393-428.
29. Ding P, Miratrix LW. To adjust or not to adjust? Sensitivity analysis of m-bias and butterfly-bias *J Causal Inference*. 2015;3:41-57.
30. Beck JD. Risk revisited. *Community Dent Oral Epidemiol*. 1998;26:220-225.
31. National Institute of Dental Research, US Department of Health and Human Services. Oral health of United States adults. National findings. 1987;NIH Publication No. 87-2868.
32. WHO. *Oral Health Surveys. Basic Methods*, 4th ed. Geneva: World Health Organization; 2007.
33. Singer JD. Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models. *J Educ Behav Stat*. 1998;23:323-355.
34. Ha DH, Lalloo R, Jamieson LM, Do GL. Trends in caries experience and associated contextual factors among indigenous children. *J Public Health Dent*. 2016;76:184-191.
35. Deeg DJH. Attrition in longitudinal population studies: Does it affect the generalizability of the findings? An introduction to the series. *J Clin Epidemiol*. 2002;55:213-215.
36. Slade GD, Gansky SA, Spencer AJ. Two-year incidence of tooth loss among South Australians aged 60+ years. *Community Dent Oral Epidemiol*. 1997;25:429-437.
37. Hariyani N, Spencer AJ, Luzzi L, Do LG. Root caries experience among Australian adults. *Gerodontology*. 2017;00:1-12.
38. Sheiham A, James WPT. Diet and dental caries. *J Dent Res*. 2015;94:1341-1347.
39. Gokalp S, Dogan BG. Root caries in 35-44 and 65-74 year-olds in Turkey. *Community Dent Health*. 2012;29:233-238.
40. Vehkalahti MM, Paunio IK. Occurrence of root caries in relation to dental health behavior. *J Dent Res*. 1988;67:911-914.
41. Kumar S, Tadakamadla J, Johnson NW. Effect of toothbrushing frequency on incidence and increment of dental caries: a systematic review and meta-analysis. *J Dent Res*. 2016;95:1230-1236.
42. Tinanoff N. Individuals who brush their teeth infrequently may be at greater risk for new carious lesions. *J Evid Based Dent Pract*. 2017;17:51-52.
43. Sakki T, Knuuttila M. Controlled study of the association of smoking with lactobacilli, mutans streptococci and yeasts in saliva. *Eur J Oral Sci*. 1996;104:619-622.
44. Wikner S, Söder PÖ. Factors associated with salivary buffering capacity in young adults in Stockholm, Sweden. *Eur J Oral Sci*. 1994;102:50-53.
45. Gilbert GH, Duncan RP, Dolan TA, Foerster U. Twenty-four month incidence of root caries among a diverse group of adults. *Caries Res*. 2001;35:366-375.
46. Crocombe LA, Broadbent JM, Thomson WM, Brennan DS, Poulton R. Impact of dental visiting trajectory patterns on clinical oral health and oral health-related quality of life. *J Public Health Dent*. 2012;72:36-44.
47. Walls AWG, Silver PT, Steele JG. Impact of treatment provision on the epidemiological recording of root caries. *Eur J Oral Sci*. 2000;108:3-8.
48. Sambunjak D, Nickerson JW, Poklepovic T, et al. Flossing for the management of periodontal diseases and dental caries in adults. *Cochrane Database Syst Rev*. 2011;(12):CD008829.
49. Vernon LT, Seacat JD. In defense of flossing: Can we agree it's premature to claim flossing is ineffective to prevent dental caries? *J Evid Based Dent Pract*. 2017;17:71-75.
50. Banting DW. Epidemiology of root caries. *Gerodontology*. 1986;5:5-11.
51. Burt BA, Ismail AI, Eklund SA. Root caries in an optimally fluoridated and a high-fluoride community. *J Dent Res*. 1986;65:1154-1158.
52. Plassman BL, Langa KM, Fisher GG, et al. Prevalence of cognitive impairment without dementia in the United States. *Ann Intern Med*. 2008;148:427-434.
53. Phillips DL, Clancy KJ. Some effects of "social desirability" in survey studies. *Am J Sociol*. 1972;77:921-940.

## SUPPORTING INFORMATION

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

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