ROOT CARIES OVER THE GENERATIONS

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Abstract

Since the early 1980s root caries has become a subject of interest in dental research and practice. Improved life expectancy and reduction of tooth loss have led to more natural teeth are being retained for longer. While these are significant public health and dental health successes, it may put the older population at a higher risk of root caries. The current international scientific literature reports that root caries is observed in a significant proportion of older adults. Thus, it was hypothesised that retaining more natural teeth in older adults would elevate root caries to being a more prominent problem in the current generation than in the previous generation. This presumption was congruent with the ‘failure of success’ and ‘more teeth, more disease’ theories accepted in both the medical and dental fields. While this has been demonstrated in a cross-sectional study of coronal and root caries, these theories have not yet been verified in studies across the generations. This study aimed to contribute to the understanding of root caries and its risk factors in the contemporary population of older adults. In particular, this study tested the ‘failure of success’ or ‘more teeth, more disease’ theories in relation to root caries among Australian older adults by studying root caries across generations over a 22-year period.

This thesis combines a systematic review, meta-analysis and meta-regression study, with three empirical studies using the National Survey of Adult Oral Health 2004-06, the South Australian Dental Longitudinal Study 1 (SADLS1) (started in 1991/1992) and the Intergenerational Change in Oral Health Study in Australia (SADLS2) (started in 2013-2014).

This study found that there were a diverse range of root caries studies presented around the world. There is a need to conduct and report root caries research in a globally consistent way to be able to take advantage from a ‘pooled estimate’ of root caries in a future meta-analysis. This study found that root caries has remained a dental public health problem among Australian adults and older adults. The profile of risk indicators of root caries has remained stable across generations. The risk indicators are slightly different between untreated root caries (root DS), and treated related-root caries (root FS and root DFS). Root caries was also found to increase continuously, even among healthier adults.

The most important finding of this study was that, despite a higher retention of natural teeth, and a high prevalence of gingival recession in the current generation of Australians, they experienced less root caries than the previous generation. Improvements in the upstream determinants of oral

health such as living conditions, expansion of water fluoridation and wider use of dental services might have played a role in protecting the oral health of the older population.

In conclusion, the ‘failure of success’ or ‘more teeth, more disease’ theories were not supported in this study of root caries across generations of Australian older adults. The findings support the current population-based program of water fluoridation, and the promotion of healthy lifestyle in order to prevent root caries.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Signed: 13 / 07 / 2018

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References

References are provided in each Chapter separately. This thesis has followed the Council of Scientific Editors (CSE) 8th Name-Year (Author-Year) style of referencing (http://endnote.com/downloads/style/cse-style-manual-8th-ed-name-year). Chapter 4 of this thesis includes results that have been published as an article in *Gerodontology*. For this article, references were presented following the referencing style in *Gerodontology* (https://onlinelibrary.wiley.com/page/journal/17412358/homepage/forauthors.html). Chapters 5 to 7 of this thesis include results that are currently accepted or under peer-review in the journals *Community Dentistry and Oral Epidemiology* and *Journal of Dentistry*. For consistency, the three results (Results of a systematic review, with meta-analysis and meta-regression, empirical result 2 and 3) are formatted in this thesis using the Council of Scientific Editors (CSE) 8th Name-Year, but were submitted to the journals following their respective referencing styles.

- Journal: *Community Dentistry and Oral Epidemiology*: (https://onlinelibrary.wiley.com/page/journal/16000528/homepage/ForAuthors.html)
- Journal: *The Journal of Dentistry* (https://www.elsevier.com/journals/journal-of-dentistry/0300-5712?generatepdf=true)

Appendices

Appendices related to the results chapters are included at the end of those chapters. Appendices for the overall thesis are attached at the end of the thesis.

List of Abbreviations

ARCPOH	Australian Research Centre for Population Oral Health
Root DS (RDS)	Untreated decayed root surfaces
Root FS (RFS)	Filled root surfaces
Root DFS (RDFS)	Untreated decayed and/or filled root surfaces
RCI	Root caries index
NSAOH 2004-06	National Survey of Adults Oral Health 2004-2006
SADLS1	South Australian Dental Longitudinal Study 1
SADLS2	South Australian Dental Longitudinal Study 2/Intergenerational Change in Oral Health Study in Australia
SA	South Australia
SD	Standard Deviation
SE	Standard Error
95% CI	95% Confidence Interval
CATI	Computer-Assisted Telephone Interview
CEJ	Cemento-enamel junction
AIC	Akaike Information Criterion
DIC	Deviance Information Criteria = -2RLL
NOHSA 1987-88	National Oral Health Survey of Australia 1987-1988
NHMRC	National Health and Medical Research Council

Research outcome

Dissemination of the research findings has already commenced in order to create discussion and debate. The published article, oral and poster presentations to local, national and international audiences, as well as grants and awards received during the candidature are listed below.

Published article

One article (empirical result 1) has been published in *Gerodontology* with the following citation:

Hariyani N, Spencer J, Luzzi L, Do LG. Root caries experience among Australian adults. *Gerodontology*. 2017;34:365–376. https://doi.org/10.1111/ger.12275

Oral and poster presentations during time of candidature

20th October, 2017: Hariyani N, Spencer AJ, Luzzi L, Do LG. Time trend and associated behavioural factors of root caries – a multi-level growth model. Transdisciplinary Measurement and Evaluation Research Group (TMERG) meeting, University of Adelaide (Oral presentation).

26th September, 2017: Hariyani N, Setyowati D, Spencer AJ, Luzzi L, Do LG. Root caries incidence and increment in the population – a systematic review and meta-analysis of longitudinal studies. 57th Annual Scientific Meeting of IADR Australian & New Zealand Division. Adelaide (oral presentation).

20 September 2017: Hariyani N, Spencer AJ, Luzzi L, Do LG. The prevalence and severity of root caries across Australian generations. The 11th Annual Florey Postgraduate Research Conference (poster).

7th July, 2017: Hariyani N, Setyowati D, Spencer AJ, Luzzi L, Do LG. Root caries incidence and increment in the population – a systematic review and meta-analysis of longitudinal studies. Research Day, Adelaide Dental School. Adelaide Health & Medical Sciences. Adelaide (oral presentation).

24th March, 2017: Hariyani N, Spencer AJ, Luzzi L, Do LG. Time trend and associated behavioural factors of untreated root caries. IADR San Francisco (Oral presentation).

29th September, 2016: Hariyani N, Spencer AJ, Luzzi L, Do LG. Time trend of untreated root caries and associated behavioural factors among Australian elders: result from 11 years longitudinal study. The 10th Annual Florey Postgraduate Research Conference (poster).

29th July, 2016: Hariyani N, Spencer AJ, Luzzi L, Do LG. Time Trend of untreated root caries and associated behavioural factors among Australian elders: result from 11 years longitudinal study. Research Day, Adelaide Dental School. Adelaide Convention Centre. Adelaide (oral presentation).

24th August, 2015: Hariyani N, Spencer AJ, Luzzi L, Do LG. Root caries experience among Australian adults. 55th Annual Scientific Meeting of the IADR ANZ Division. Dunedin Public Art Gallery, Dunedin, New Zealand (Oral presentation).

12th June, 2015: Hariyani N, Spencer AJ, Luzzi L, Do LG. Root caries study over generations. Research Proposal Day, School of Dentistry. The University of Adelaide. Adelaide. (Oral presentation).

8th May, 2015: Hariyani N, Spencer AJ, Luzzi L, Do LG. Root caries study over generations. ARCPOH meeting, School of Dentistry. The University of Adelaide. Adelaide. (Oral presentation).

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(August 2015) Eustace International Travel Award from The University of Adelaide, Australia, to attend and present at the 55th Annual Scientific Meeting of the International Association for Dental Research Australia and New Zealand Division, Dunedin-NZ

1 Chapter 1: Introduction

1.1 Background of the study

There has been increased attention toward root caries in recent decades (Bansal et al., 2011). In many countries, there is an increase in life expectancy, resulting in an increase in the proportion of the aged population. At the same time, the enhanced awareness of dental health, better dental services and improved access to fluoride in high income countries has resulted in an increasing proportion of the population, especially the older adult population, retaining more natural teeth. In Australia, the total number of permanent natural teeth in the population was projected to increase by 13% by the year 2019 as a result of an increasing proportion of the population being dentate (Chalmers et al., 1999). This is a significant dental public health success. However, due to increased life expectancy and greater retention of natural teeth compared with previous generations, root caries has become an important oral health problem among dentate older adults. Gingival recession caused by normal ageing, and periodontal disease have put the root surface of retained teeth at risk of developing root caries (Saunders Jr and Meyerowitz, 2005; Oral Health in America, a report of the Surgeon General, 2000).

Cross-sectional data have confirmed that the more teeth retained in the mouth, the more caries and periodontal disease is encountered (Joshi et al., 1996). This theory, known as the 'more teeth, more disease' theory, represents a dental example of the 'failure of success theory' (Gruenberg, 1977; 2005) described two decades earlier. According to this theory, it is expected that people in the current generation will be more at risk of root caries compared to the previous one. However, current data, mostly collected in single cross-sectional studies, cannot be used for a comparison across generations to test the theory. Without this level of testing, we are unable to conclude whether different generations, with increasing numbers of teeth, will experience an increase in root caries. Up to now, there is no research to confirm whether a population with an increasing proportion of dentate people and with the dentate retaining more teeth would accumulate more root caries compared to previous generations. To test this theory, a comparison between studies at two separate time points, or in two different generations is needed.

At the same time, there are many changes happening in society which could lead to different risk factors of root caries between two generations. Previous generations might not have received the full benefit from water fluoridation, compared to the current generation, as water fluoridation was only introduced later in their life (Do et al., 2017; Slade et al., 2013). Another consideration is the increased consumption of sweetened beverages, such as soft drinks, by the current generation (Lee and Brearley Messer, 2011), which may have increased the current generation's susceptibility to root caries. Changes in the availability of dental services and in behavioural factors, such as the use of fluoridated toothpaste as part of improved oral hygiene, and an increase in awareness of the dangers of smoking, could also lead to changes in the profile of risk of root caries in different generations. Up to now, there is still a gap in our understanding of whether risk factors for root caries differed in two different generations or not. A study in two cohorts from different generations provided an opportunity to explore this issue.

1.2 Rationale

With the increased attention to root caries among the growing dentate older adult population, and the high level of expenditure needed for dental services to maintain the teeth of older adults, it is worthwhile to explore the assumption that a population with more teeth will develop more root caries. This study was the first study that tested the 'failure of success' (the 'more teeth, more disease') theory in regards to root caries experience using data from two cross-sectional studies across generations.

1.3 Purpose

The overarching purpose of the study was to investigate the distribution of root caries and its risk factors in the contemporary population, and across generations of Australian older adults.

1.4 Specific objectives

The specific objectives of the study were:

Aim 1: To describe the prevalence and the severity of root caries among a representative sample of general Australian adults, and Australian older adults, and to explore the risk and preventive factors of root caries.

Aim 2: To systematically review and synthesise patterns of root caries progression (in terms of the incidence and increment) from previously reported studies around the world, and to assess the source of heterogeneity.

Aim 3: To quantify the longitudinal increment of root caries experience, and to examine behavioural factors associated with root caries experience in Australian older adults.

Aim 4: To test the 'failure of success' or 'more teeth, more disease' theories for root caries experience, as well as to investigate the putative risk factors for root caries experience across generations.

1.5 Study hypotheses

The aims and specific objectives led to the following hypotheses:

1. Patterns of population distribution of root caries are not different across generations.
2. The population risk profiles of root caries experience are not different across generations of older adults.

1.6 Brief overview of methods

A systematic review with meta-analysis and meta-regression study was adopted to answer Aim 2, while the remaining aims (Aims 1, 3 and 4) were addressed using empirical research data.

1.7 Preview of subsequent chapters

This thesis is structured as a combined format of thesis by publication, and a conventional thesis format. Chapters 1 to 3 and Chapter 8 are written in a conventional thesis format while all of the findings are presented in publication formats in Chapters 4 to 7. Each 'finding' in a publication, or an article format, is preceded by a statement of authorship in accordance with the University of Adelaide's policy. In addition, each original article is preceded by a statement that links the original article to the body of research. The highlighted findings and future research directions are also provided.

Published articles are provided in PDF images. The accepted article is provided in the form it was accepted by the publisher. Submitted or under review articles are provided in the form they were submitted, or the latest reviewed version respectively, with tables and figures being incorporated within the text to enable ease of reading.

After this Introduction, the thesis contains seven subsequent chapters. Chapter 2 presents the literature review; Chapter 3 summarises the methodology adopted to answer each research question; Chapter 4 describes the first empirical study addressing the first aim (Aim 1); Chapter 5 presents the systematic review with meta-analysis and meta-regression study addressing the second aim (Aim 2); Chapters 6 to 7 present two empirical studies addressing the third (Aim 3) and the fourth (Aim 4) aims respectively, and Chapter 8 provides a general discussion and the overall conclusions.

Chapter 2 provides a review of the relevant literature about root caries. It consists of five sections: the ‘failure of success’ theory; epidemiology of root caries including its prevalence, incidence and increment; root caries in Australian adults; risk factors for root caries and applicable measurements of root caries in longitudinal research.

Chapter 3 presents the detailed methodologies used in the studies presented in this thesis (the systematic review with meta-analysis and meta-regression, as well as each of the empirical studies). It highlights the methods used to address each of the research aims and provides details about the data source, methods employed, and the analytical approach.

Chapter 4 explores root caries cases among general Australian adults 15+ years, with a separate analysis included for Australian older adults aged 60+ years. The analysis provided estimates representative of the Australian population at the state/territory and national level. This Chapter also explores the risk and preventive factors of root caries in general Australian adults and older adults. This Chapter was intended to answer Aim 1 of this thesis.

Chapter 5 presents the combination of a systematic review, meta-analysis and meta-regression of current longitudinal studies of root caries, reported around the world. The root DFS incidence and increment were estimated by a meta-analysis following a systematic review. Meta-regression was used to assess the source of heterogeneity. This Chapter was intended to answer the Aim 2 of this thesis.

Chapter 6 presents a study adopting a multi-level longitudinal growth model and estimated the annual root caries increment and its risk factors. This Chapter was intended to answer Aim 3 of this thesis.

Chapter 7 provides a comparison of the prevalence and the severity of root caries across Australia's generations in 22-year period to test the 'failure of success' or 'more teeth more disease' theory. This Chapter also explores the indicators for root caries across generations. This Chapter 7 was intended to answer Aim 4 of this thesis.

Finally, Chapter 8 provides a general discussion of the study findings, the strengths and limitations, the implications of this thesis to dental public health and research area, and conclusions.

1.8 Significance of the study

To the best of our knowledge, this study is the first to test the 'failure of success' or 'more teeth, more disease' theory in an across generations setting. Results from this study can be used by policy-makers to guide the planning and allocation of resources in provision dental care for older adults. An understanding of root caries risk factors can be used to focus preventive efforts to the most at risk population groups.

1.9 References

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2 Chapter 2: Literature review

2.1 The ‘failure of success’ or ‘more teeth, more disease’ theory

The ‘failure of success’ theory has been known in the medical field for almost 40 years. In 1977, Gruenberg proposed that the successfulness in reducing mortality caused by life threatening infectious diseases resulted in the increase of common chronic conditions in the population, which represent the failure of success (Gruenberg, 1977; 2005). This theory shows that at the same time older adults are suffering from chronic diseases they are gaining an extension of life; they are also getting an extension of disease and disability. However, in 1980, Fries proposed a theory of ‘compression for morbidity’ (Fries, 1980; 2002), in which he proposed that older adults in future cohorts will be more likely to achieve a maximum human lifespan than their predecessors. He argues that future older adults could also postpone the period of chronic disease until their advanced old age, as a result of a better access to health care and healthy lifestyles in their younger years. Even though there have been many debates (Schneider and Brody, 1983) surrounding acceptance of this theory, recent data has confirmed it. Data from many countries showed that there was an increase in life expectancy from previous generations to the present generation (Organisation for Economic Co-operation and Development, 2017; Sanna, Pompili and Miccadei, 2018). This phenomenon was shown not only in developed countries but also in developing countries (Sanna, Pompili and Miccadei, 2018).

Rosen and Haglund hypothesised that increased life expectancy in the 1980s was mainly due to healthy lifestyles, but in the 1990s it was due more to successful life-saving interventions in medical care (Rosen and Haglund, 2005). They used data from Sweden to support their hypothesis. The data reveals that there were a larger proportion of sick survivors among the very old in the current generation, compared to the previous generation. This research indicates that there would be increasing numbers of sick individuals who would survive to old age, resulting in the increase of healthcare needed for the population. This phenomenon brings us back to the ‘failure of success’ theory, as it shows the failure to achieve the goal of medical research and care – which is ‘to diminish disease and enrich life’, despite the success in prolonging people’s lives. Thus, the ‘failure of success’ theory is still an important theory in the burden of disease.

Along with the demonstrated increase in life expectancy, in the field of dentistry adults tend to be retaining more of their natural teeth into the later years of life. Data show that there is a significant reduction in edentulousness among the older adults (Crocombe and Slade, 2007;

Takala, Utriainen and Alanen, 1994). However, this success in population oral health has not been offset by a reduction in oral diseases, especially caries and periodontal diseases in older adults. As root caries can only happen when there is exposure of a root surface, and such exposure is usually associated with increased age, root caries are more common in older people. A theory, which later was called ‘more teeth, more disease’ theory, proposed by Douglass and Furino in 1990 (Douglass and Furino,1990; Joshi et al., 1996), brings us back to the theory of ‘failure of success’ raised by Gruenberg in 1977. The theory has an implication for the burden of oral diseases. Cross-sectional data have confirmed that the more teeth retained in the mouth, the more caries and periodontal disease were observed (Joshi et al., 1996; Nicolau, Srisilapana and Marcenes, 2000). According to this theory, it is expected that people in the present generation are at a higher risk of developing root caries than those in an earlier generation. However, up to now, there is no research to confirm whether a population, with an increasing proportion of dentate people who are retaining more natural teeth would accumulate more root caries compared to the previous generations. A comparison between studies at two separate time points, or in two different generations is needed to answer this question.

2.2 Epidemiology of root caries

Interest in root caries has been growing since the 1980s. It is generally accepted that only a tooth with a gingival recession is at a risk of developing root caries (Banting, 1986). Gingival recession caused by normal ageing and periodontal diseases is more common in older people. That is why older people are considered to be at higher risk to develop root caries than adults in general. As the population age pyramid expands toward older adults, it is expected that root caries will be a major public dental health problem in the future.

There are many reported concerns relating to the epidemiology of root caries in older adults. The first concern is about general methodological considerations in the conduct of an oral survey in an older population (Hunt and Beck, 1985). These considerations include sample selection, the place to conduct the oral examination, travel time and travel costs for the examining teams, and over-sampling to adjust for the probability of subject loss during a longitudinal study.

Another concern is about the clinical assessment of root caries. Case definition of root caries used in a research must be clearly set up and justified. This is because different definitions of a ‘case of root caries’ or a ‘case of root filling’ would produce different prevalence estimates even in the same population, (Beck, 1990). In the early 1980s, definitive criteria for the diagnosis of root caries had not been developed (Hunt and Beck, 1985). Thus, studies reporting root caries in that period sometimes used different criteria when defining root caries. Comparison of results of those studies needs to be viewed with caution (Beck, 1993). Recently, there is general agreement that the use of a combination of visual and tactile criteria (i.e. gentle to moderate blunt probe pressure) is more indicative in root caries assessment, than the use of visual criteria alone (Fejerskov, Nyvad and Kidd, 2008; Neuhaus et al., 2009). Using visual criteria, root caries lesions often look yellowish or light brown, and using tactile criteria, the lesions feel soft and leathery (Rodrigues et al., 2011). Root caries lesions are softer than adjacent normal root surfaces (Beighton, Lynch and Heath, 1993; Rodrigues et al., 2011). However, there are still many things that need to be agreed upon such as the location of the lesion in relation to the cemento-enamel junction (CEJ), whether third molars should be included, whether cavitation must be present, and how far the lesion must extend onto an adjacent surface to be counted as an additional surface.

This section provides an overview of root caries measurements both in cross-sectional and longitudinal studies of root caries, followed by an overview of the literature on the prevalence and/or the severity of root caries, as well as the literature on the incidence and increment of root caries among older adults.

2.2.1 Overview of root caries measurements

2.2.1.1 Root caries measurements in cross-sectional study

In a cross-sectional study, root caries could be measured and reported in different formats. The most frequently reported outcome in a cross-sectional study of root caries is root caries prevalence (Katz, 1980). Root caries prevalence showed a proportion of population with one or more root caries lesions (Beck, 1990). The selected unit of observation could be teeth or root surfaces. Root caries prevalence could be defined as the prevalence of untreated decayed root only, filled root only, or decayed and/or filled root. The other formats to measure and report root caries in a cross-sectional study are the severity of root caries and root caries index. The severity of root caries represents the mean number of root caries in an individual while root caries index reported the number of root caries lesions as a percentage of the total number of exposed surfaces present (Katz, 1980). However, it is difficult to make a comparison from studies with different population characteristics and different methods in reporting root caries. Thus, WHO recommended the use of simple prevalence and severity for international comparison reason (WHO, 2007).

2.2.1.2 Root caries measurements in longitudinal studies

A longitudinal design in root caries studies raises concerns about the detection of the root caries disease status of selected units of observation (teeth or tooth surfaces) over time. Usually, it requires the conduct of two or more clinical examinations in a specified time frame. There is typically some loss to follow-up between the first and subsequent examination(s) including subject-level factors (death, changed address, withdrawal) and tooth-level factors (extraction); and probably there is an increase in the number of observation units (exposed root) due to gingival recession between examinations (Slade and Caplan, 1999). All these changes should be taken into account in the root caries measurement chosen in a longitudinal study.

Root caries could be measured and reported in different formats. The most frequently reported outcome of root caries in longitudinal studies is the root caries increment (Slade and Caplan, 2000). Root caries increment represents the number of new carious lesions in an individual within a stated period of time. This increment could be measured using teeth as well as using root surfaces as units of observation. In some studies, root caries could be reported as ‘Simple’ Root Caries Increment, Crude Root Caries Increment, Net Root Caries Increment and Adjusted Root Caries Increment. Each of these root caries increments measure new carious lesions defined as decay only, decay and filled, or decay, filled and missing surfaces. The other formats to measure and report root caries in longitudinal studies are incidence and incidence density. The incidence of root caries is measured as the percentage of the population with one or more new lesions over the study period, while incidence density is measured as the number of root caries events divided by the total amount of observation time at risk. As with root caries increment, the events measured in incidence or incidence density could also be applied to decay only, decay and filled, or decay filled and missing surfaces.

Caries development in a longitudinal study could also be presented as a trend or trajectory (Bernabé et al., 2016; Ha et al., 2016). This showed an estimated annual increment within an individual over time. This type of presentation was used when at least three measurements were conducted on the same individual (baseline with at least two times of follow-up). Like other measurements, it also could be applied to decay only, decay and filled, or decay filled and missing surfaces. However, calculating only decay or decay and filled surfaces will under-estimate the root caries experience in adults with missing teeth during the study period.

Table 2.1 presents longitudinal studies on root caries in terms of the approach used in the measurement. It shows that the use of multiple waves of longitudinal follow-up data in estimating root caries increment has not been previously attempted. It shows that root caries studies mainly reported root caries incidence and increment from two time points of oral examinations based on decay and filled status or decay status only. As stated previously, with this kind of measurement, tooth loss was often not accounted for. The main reason for choosing this approach is because there is a lack of reliable information on reasons for tooth loss. However, some studies on the cause of tooth loss (Hand, Hunt and Kohout, 1991; Hunt et al., 1988) show that caries was the main cause of tooth loss in adults, and root caries and coronal caries play an almost equal role in tooth loss. Consequently, measuring root caries incidence and increment based on decay and filled surfaces only are likely to lead to underestimation of true caries progression.

In longitudinal studies of coronal caries, many approaches have been proposed to deal with the problem of tooth loss. Some proposed approaches include: to assign the same number of affected surfaces as were recorded at the most recent examination; to assign three surfaces for each extracted tooth, but to increase this value in cases where more than three decayed or filled surfaces had been present at the preceding examination; to assign one more surface than was recorded as being affected at the preceding examination (to a maximum of four for anterior teeth and five for posterior teeth); or to assign the maximum of four surfaces for an extracted anterior tooth or five for an extracted posterior tooth. Moreover, some studies have also reported that different measurement approaches will influence the result for caries incidence and increment (Broadbent and Thomson, 2005; Gilbert et al., 2001; Slade and Caplan, 2000). Thus, comparing studies with different measurement approaches should be made with caution.

Even though the methodological issues about coronal caries measurement in terms of tooth loss has been carefully scrutinised (Broadbent and Thomson, 2005; Slade and Caplan, 1999), and these methods have been the subject of some research, there appears to be no comparable standard method for root caries measurement (Slade and Caplan, 1999).

Table 2.1 Analytical approach to measure and report root caries incidence and increment

Approach	Brief Description	Advantages	Disadvantages	Example of articles
Incidence	Measured as % population with 1 or more new lesions over the study period	Simple to understand, especially for lay people. Allows the use of simple logistic regression modelling	Allows only a broad picture as the individual is the unit of analysis	Using root DFS: (Chalmers et al., 2002a; Gilbert et al., 2001; Joshi et al., 1993; Lawrence et al., 1995; Locker, 1996; Scheinin et al., 1992; Sugihara et al., 2014) Using root DS: (Locker, 1996) Using root DMFS:
'Simple' Root Caries Increment	Calculated the difference between baseline and follow up at the person level rather than the tooth or tooth surface level.	The quickest way to measure caries increment	Includes all reversals	
Crude Root Caries Increment	Caries increment was calculated using a surface by surface comparison of baseline and follow-up data, in which caries severity at baseline was simply substracted from that at follow up	More accurate than the previous approach as the changes in status for each surface is included	More difficult and time consuming in compute Does not allow for negative reversals	Using root DFS: (Chalmers et al., 2002a; Fure, 2004; Locker, 1996; Scheinin et al., 1992) Using root DS: (Narhi et al., 1999; Sánchez-García et al., 2011) Using root DMFS: -
Net Root Caries Increment	As above, but with number of reversals substracted from the number of positive caries increment in Crude Root Caries Increment	Include adjustment for negative reversals	Assumes that the number of examiner reversals made in each direction is the same	Using root DFS: (Chalmers et al., 2002a; Lawrence et al., 1995) Using root DS: - Using root DMFS: -
Adjusted Root Caries Increment	Uses a reversal adjusted caries increment, on the basis that 'examiner' reversals are more common than 'true' reversals. Frequency of examiner reversals proportional to time zero baseline caries	By taking reversals into account and adjusting them for baseline caries prevalence, it is not as harsh as the net caries increment, and offer a compromise between net caries increment and crude caries increment	Analytically more complex Should not be used when reversals are <10% of the caries lesion detected at baseline Does not distinguish between true reversals and examiner error	Using root DFS: (Chalmers et al., 2002a; Gilbert et al., 2001) Using root DS: - Using root DMFS: -
Incidence Density	Number of events divided by the total amount of observation time at risk	Accounts for the time that each surface is at risk and takes into account the censoring of events	Computing time at risk involves assumption which may or may not be valid. Complex measurement	Using root DFS: (Fure, 2004; Joshi et al., 1993; Lawrence et al., 1995) Using root DS: (Narhi et al., 1999) Using root DMFS: -

2.2.2 Root caries prevalence and/or severity

Since root caries has been a subject of interest in the dental public health research, there are now many studies reporting its prevalence and/or severity. There have been reviews of the literature, summarising root caries prevalence data from populations around the world and across time. A summary of studies on root caries prevalence, both the original studies and the reviews, in various older adult populations is presented in Table 2.2. Criteria for inclusion in the table was that the studies and reviews were written in English; studies were of root caries prevalence; studies were reviews of articles on root caries prevalence across the world, and published before 2017.

The general picture which emerges from these studies is that there is a considerable percentage of adults over the age of 50-years affected by root caries. This prevalence and severity of root caries varied, depending on characteristics of the population being studied. They are usually higher among patients of health clinics, hospitalised persons, and people living in a nursing home. The proportion of persons displaying root caries has been observed to increase across older age groups. Although the rates vary widely among the groups observed, a consistent age trend can be identified.

Table 2.2 Root caries prevalence and severity studies

Author/s, year published	Number of studies reviewed	Author/s, year published of reviewed studies	Location	Population	Number of participants analysed	Age Range	Mean Values						
							Teeth Present	% Population with RDS	% Population with RDFS	Mean RDS	Mean RFS	Mean RDFS	RCI
(Beck, 1990)	15	Brustman, 1986	USA	4 Communities Fluor. vs. Non-fluoride	278	60+			5 : 1 only in mandibular anterior				
		Burt, Ismail and Eklund, 1986	USA	2 communities Hi F & normal F	350	27-65		7.3 (Hi F) : 23.8 (1 ppm F)		0.08 vs 0.69			
		Banting et al., 1980	Canada	Hospitalised	59	36-89			83	7.6	2.6	10.2	
		Gustavsen et al., 1988	Norway	Dental patients	964,950,925	20+							21
		Iowa 65+ (Beck et al., 1985)	USA	2 rural counties	520	65+		25.3	63	0.6		2.3	
		Jensen and Kohout, 1988	USA	Non fluoridated community	810	54+						4.8 (placebo): 4.3 (test)	
		Katz et al., 1982	USA	Employees	473	20-64			42				11.4
		Locker et al., 1989	Canada	Urban Suburb	247	50+		37.2	56.8	1.3		2.6	
		Keltjens et al., 1988	Netherlands	Perio patients	83	22-71							6.3
		Kitamura et al., 1986	USA	Community and nursing home	47	55-95							0.4 mean RCI
		Vehkalahti, 1987	Finland	National	5,028	30+		24					
		Wallace et al., 1988	USA	community	603	60+			69.7				8.1
		NIDR 1987	USA	Working adults vs senior centre	15,132 vs 5,686	18-65 (Working			21.2 vs 56.9	0.4 vs 1.5		0.8 vs 3.2	

Author/s, year published	Number of studies reviewed	Author/s, year published of reviewed studies	Location	Population	Number of participants analysed	Age Range	Mean Values						
							Teeth Present	% Population with RDS	% Population with RDFS	Mean RDS	Mean RFS	Mean RDFS	RCI
						adults) vs 65+ (senior centre)							
		Piedmont study (Graves et al., 1989)	USA	Five counties	821	65+		24.2	43.7	0.8		1.7	
(Splieth, et al., 2004)	-	-	Pomerania, Germany									0.4 (25–34 years) - 2.3 (55–64 years)	4.6–10.6%
(Bharateesh and Kokila, 2014)	-	-	India	Dental patients	210	55+ Mean=61.7		41.9					
(Chalmers et al., 2002b)	-	-	Australia	Nursing home residents	224	75+ Mean=83.2	11.9			1.5	1.1		
(Douglass et al., 1993)	-	-	New England	Community dwelling	718	70+		22		3.3			
(Du et al., 2009)	-	-	China	residents	1080 (35-44 yo): 1080 (65-74 yo)	35-44 yo: 65-74 yo			13.1 (35-44 yo): 43.9 (65-74 yo)			0.21 (35-44 yo): 1.00 (65-74 yo)	6.29 (35-44 yo): 11.95 (65-74 yo)
(Fure and Zickert, 1990)	-	-	Gothenburg	inhabitants	208	55, 65, 75			89				
(Kim et al., 2012)	-	-	The US	Non-institutionalised people	13,070	20+		9.8					
(Joshi et al., 1994)	-	-	New England	Community dwelling	718	70+		22	52				
(Locker and Leake, 1993)	-	-	Canada	Community dwelling	907	50+	18.9		70.9			3.6	

Author/s, year published	Number of studies reviewed	Author/s, year published of reviewed studies	Location	Population	Number of participants analysed	Age Range	Mean Values						
							Teeth Present	% Population with RDS	% Population with RDFS	Mean RDS	Mean RFS	Mean RDFS	RCI
(Tan and Lo, 2014)	-	-	Hong Kong	Institutionalised elders	306	Mean=78.8				1.3		2.1	3.92
(Avlund et al., 2004)	-	-	Sweden	Community dwelling	129	80+			60 (men) : 60 (women)				
(Beighton et al., 1991)	-	-	Hastings, London	Dental patients	146	55+						6.43 (males) vs 3.76 (females)	
(Chalmers, Carter and Spencer, 2003)	-	-	Australia	Community dwelling	116	≤79 vs 80+		31.0 (dementia) vs 14.7 (non-dementia)	78.3 (dementia) vs 83.6 (non-dementia)				
(Christensen et al., 2015)	-	-	Denmark	Community dwelling	4369	21-89		3.7	26				
(Ferro et al., 2008)	-	-	Italy	Nursing home residents	595	Mean=83.2	8.4		51				
(Gokalp and Dogan, 2012)	-	-	Turkey	Community dwelling	1,631 (35-44) vs 1,545 (65-74)	35-44 vs 65-74			20.1 (35-44) vs 28.4 (65-74)				

RDS: untreated decayed root surfaces, RFS: filled root surfaces, RDFS: untreated decayed and/or filled root surfaces, RCI: root caries index.

2.2.3 Root caries incidence and increment

Studies of root caries incidence published in the last two decades have focused on institutionalised older adults, patients with periodontal disease, (Paraskevas et al., 2004; Pepelassi, Tsami and Komboli, 2005; Ravald and Birkhed, 1993) patients with HIV disease, (Phelan et al., 2004) participants in a clinical trial (Powell et al., 1999) and older adults living in the community (Fure, 2004; Gilbert et al., 2001; Hamasha et al., 2005; Luan et al., 2000; Narhi, Kurki and Ainamo, 1999; Nordström et al., 1998; Takano N, 2003). A summary of research on root caries incidence and increment in various older adult populations is presented in Table 2.3. Criteria for inclusion in the table were that the reports were longitudinal studies, written in English, participants of the study were the older adults living in the community, and published before 2017 in the English language. These studies reveal that root caries incidence varied from 12.4% over 10 years to 77% over 3 years in Sweden and the United States respectively. Root caries increment also varied from 0.4 to 17 surfaces. However, considering the differences in population characteristics, study designs, and the way results are reported, the comparison between these studies should be made with caution.

Table 2.3 Summary of longitudinal root caries study

Author/s, year published	Location	Number of participants analysed	Age at baseline	Incidence period	Root caries incidence	Root caries increment	
(Lawrence, Hunt and Beck, 1995)	North Carolina	452 (234 blacks and 218 whites)	65+	3 years	29% (blacks) 39% (whites)	Net increment	0.55 (blacks) 0.80 (whites)
						Attack rate	2.6 (blacks) 4.3 (whites)
(Beck, Lawrence and Koch, 1995)	North Carolina	452 (234 blacks and 218 whites)	65+	3 years	-	Crude RDFS Group1 Group2	Mean (SD) 0.97 (0.14) 1.34 (0.15)
(Lawrence et al., 1996)	North Carolina	452 (234 blacks and 218 whites)	65+	5 years	30% (blacks) 35% (whites)	Crude RDFS Group1 Group2	Mean (SD) 1.0 (0.18) 1.17 (0.15)
						Net RDFS Group1 Group2	Mean (SD) 0.52 (0.21) 0.42 (0.20)
(Scheinin et al., 1992)	Turku, Finland	100	Mean=62 Range=47-79	3 years	42%	Crude Increment	Range 0-17
(Thomson et al., 2002)	Australia	528	60+	5 years	59.3%	Net RDFS	1.90 (3.23)
						Adjusted	2.21 (2.83)

Author/s, year published	Location	Number of participants analysed	Age at baseline	Incidence period	Root caries incidence	Root caries increment	
						RDFS	
						Among incident cases	
						Net RDFS	3.08 (7.50)
						Adjusted RDFS	3.57 (2.96)
(Slade and Caplan, 2000)	Australia	693	60+	2 years	Crude RDFS None PD worn=48.8 % 1 or 2 PD worn=55.8 %	Crude RDFS None PD worn 1 or 2 PD worn	 1.1(0.1) 1.4(0.1)
(Joshi, Papas and Giunta, 1993)	US	130	45+	16 months	50.7%	Annualised Increment	Varied from 0.60 to 1.38*
						Attack rate	Varied from 2.07 to 3.51*
(Locker, 1996)	Ontario, Canada	493	50+	3 years	RDFS=27.4%	Crude RDFS Increment	0.60 (1.44)a
					RDS=15.60%	Crude RDS Increment	0.30 (0.96)
(Powell, Mancl and Senft, 1991)	Not reported	23	65+	1 year	61.%		
(Narhi et al., 1999)	Helsinki, Finland	103	Mean = 78.4	5 years	Not reported directly. 59 people	Crude increment	0.46 (1.84)
						Attack rate / RCI	0.09
(Sugihara et al., 2014)	Tokyo, Japan	141	20-59	5 years	24.1%	Not stated which root increment is it. Presumably Crude Increment	Varied from 0.1 to 1.3*
(Fure, 1997)	Goteborg, Sweden	148	55-75	5 years	62%	RDFS Men Women	Mean (SD) 3.4 (5.6) 5.7 (8.2)
						RDMFS Men Women	Mean (SD) 4.0 (6.3) 6.0 (8.0)
(Fure, 2003)	Goteborg, Sweden	102	55-75	10 years	-	RDS increment 65 years 75 years 85 years	Mean (SD) 2.5 (4.9) 5.3 (7.6) 10.9 (12.6)
						Crude RDFS 65 years	Mean (SD) 5.3 (6.4)

Author/s, year published	Location	Number of participants analysed	Age at baseline	Incidence period	Root caries incidence	Root caries increment	
						75 years 85 years	8.1 (9.3) 14.3 (12.2)
(Fure, 2004)	Goteborg, Sweden	102	55-75	10 years	DFS=12.4 %		
(Gilbert et al., 2001)	Florida	723	45+	2 years	36%	Adjusted RDFS	Mean (SD) 1.00 (2.2)
(Sánchez-García et al., 2011)	Mexico city	531	60+	12 months	21.7%	Crude Root Caries Increment	0.4
Hand and hunt, 1988a (Hand, Hunt and Beck 1988b) (Hand, Hunt and Beck 1988a)	Iowa, USA	451	65+	18 months	44.10%	Net increment Annual net	0.85 0.57
Hand, Hunt, Beck, 1988(Hand et al. 1988a)	Iowa, USA	338	65+	3 years	43.70%		Mean (SD) 1.07 (2.12)
(Hamasha et al., 2005)	Iowa, USA	74	65+	9 to 11 years	43%	RDS RFS RDFS	0.69 1.28 1.27
						Annualised RDS RFS RDFS	 0.07 0.13 0.12
(Powell et al., 1998)	Seattle, Washington	201	60+	3 year	77%		
(Takano N, 2003)	Japan	373	70	2 years	35.90%	Adjusted RDS	Mean (SD) 0.9 (1.7)
(Powell et al., 1999)	Washington	201	60+	3 years	Not reported directly. DS=49%		4.4
(Leske and Ripa, 1989)	New York	796	20-65 Mean=39.9	3 years	18.6%	Annual inc.	0.8
(Wallace, Retiet and Bradley, 1993)	Alabama	466	60+	4 years	-	Adjusted	1.00 (2.2)
(Ritter et al., 2016)	USA	155	21-80	3 years	49%	-	-

PD: Partial Denture. [a]Also calculated for DS increment, SD: Standard Deviation, RDS: untreated decayed root surfaces, RFS: filled root surfaces, RDFS: untreated decayed and/or filled surfaces, RDMFS: untreated decayed missing filled root surfaces

2.3 Root caries in Australian adults

Australia, like other industrialised countries (Hand et al., 1988a), is undergoing a demographic transition whereby the number and proportion of the older adults in the population is increasing as a result of the increase in life expectancy (Australian Bureau Statistics, 2014). At the same time, data shows that there is a decline of edentulousness among older Australians (Crocombe and Slade, 2007). This dental public health success was the result of the enhanced awareness of dental health, better dental services, and improved access to fluoride. The total number of permanent teeth in the Australian population was projected to increase by 13% by the year 2019 as a result of an ageing population, an increasing proportion of the population being dentate and the dentate increasing the number of teeth retained (Chalmers et al., 1999). Consequently, root caries has become an important oral health problem among Australian older adults.

Root caries cases among Australians have been documented through several studies (Chalmers, Carter and Spencer, 2002a; Chalmers et al., 2002b; Slade, Spencer and Roberts-Thomson, 2007; Slade and Spencer, 1997). Among those studies, there are two large population studies, namely the South Australian Dental Longitudinal Study (SADLS) and National Survey of Adult Oral Health (NSAOH).

The South Australian Dental Longitudinal Study 1 (SADLS1) was begun in 1991 as a baseline examination; then continued with 2-year, 5-year and 11-year follow-up examinations. This cohort study collected data on oral health status, including root caries status of a random sample of non-institutionalised people aged 60+ years living in two South Australian cities –Adelaide and Mt Gambier (Slade and Spencer, 1997). In 2013, the Intergenerational Change in Oral Health in Australia Study, which also known as the South Australian Dental Longitudinal Study 2 (SADLS2) was started. It collected the same information from the new generation living in the same areas as SADLS1.

Compared to South Australian Dental Longitudinal Study which only involved two regions in South Australia, the National Survey of Adult Oral Health conducted in 2004-06 was a survey of a representative sample of all Australian adults (Slade, Spencer and Roberts-Thomson, 2007).

Results reported from these two large studies reveal that root caries was a problem among Australians. Root caries severity (the mean number of decayed and/or filled root surfaces) reported in SADLS1 varied from 3.19 (baseline) to 4.63 (5-year follow up) (Thomson, 1999). In the National Survey of Adult Oral Health, root caries was reported as the prevalence of untreated root decay (the percentage of people who had at least one natural tooth, and who had one or more surfaces of the roots of their teeth decayed). The prevalence of untreated root caries in this study was 6.7% (varied from 1.6% to 17.3% across older age groups).

Other studies of root caries among the Australian population documented the root caries of specific older communities, namely residents in a nursing home and residents with dementia (Chalmers et al., 2002a; Chalmers, Carter and Spencer, 2005). The study among nursing home residents reveals an incidence of 48.5% over a one-year period with an increment of 1 untreated decayed and/or filled root surface; while the study among dementia patients showed an incidence of 62.1% over a one-year period, with an increment of 1.9 root surfaces.

Results from all studies of root caries in Australians show that root caries is a problem, especially in older age groups; and as the proportion of older Australians is projected to increase, this problem could become more prominent.

2.4 Risk factors for root caries

Root caries, like coronal caries, is a multifactorial disease. Many factors, such as socio-demographic factors, physical/medical factors, local oral risk factors, behavioural factors and environmental factors are associated with root caries (Thomson, 1999). Evidence of associations between these factors and root caries has been reported in cross-sectional studies. However, because a risk factor carries with it the idea of a causal relationship, associations derived from cross-sectional studies should not be thought of as risk factors, and are better-called risk indicators.

On the other hand, some studies have also attempted to investigate the risk factors of root caries through modelling of root caries incidence and increment using longitudinal data. However, a review concluded that among studies of the incidence of root caries, the small number of studies resulted in little agreement concerning root caries risk factors (Beck, 1990). A recent systematic review about root caries risk factors also revealed that root caries prediction by risk modelling, reported in the previous studies, was inconclusive and inconsistent (Ritter, Shugars and Bader, 2010). Previous studies have pointed out some significant risk factors of root caries such as baseline root DFS, number of teeth at baseline, plaque index, *lactobacilli* counts, age, smoking, medication use, sex, *streptococcus mutants* counts, saliva flow rate, saliva buffering capacity, dental visit pattern, race⁄ethnicity, prosthetic crown⁄fixed partial denture, use of interdental brush⁄floss, attachment loss, use of removable partial denture, *candida*, gingival recession, tooth loss during the study, follow-up time, dementia, and root fragments. Among all of these, only three were tested at least four times and were significantly associated with root caries incidence a majority of the time. These variables were root caries prevalence at baseline, the number of teeth, and plaque index (Ritter et al., 2010). This study called for further root caries risk factor studies.

Moreover, there are many changes occurring in society which probably lead to different risk factors for root caries between different generations. The previous generation did not receive substantial benefit from water fluoridation, compared to the current generation, as it has only been introduced later in their life (Do et al., 2017; Slade et al., 2013). However, as the current generation consumes more sweetened soft drinks (Lee and Brearley Messer, 2011), they are probably more susceptible to root caries. Different situations in terms of dental services and behavioural factors could also lead to different risk factors of root caries in different generations. Currently, there is a call of global action on the social determinant of health to tackle both general and oral health problem (Donkin, et al, 2017). The current consensus is that neighbourhood quality has significant impact on health outcomes (Newton and Bower, 2005). However, up to now, there is a gap in our understanding of whether the risk factors of root caries differ between different generations or not. Thus, a study in cohorts of different generations will provide an opportunity to explore this problem.

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3 Chapter 3: Research methodology

This Chapter explains the approaches used to achieve the research aims. It outlines the source of data used, the method of sampling, the mode of data collection employed, the data collection instruments and data items, aspects of sample size and power, and the analytical approach to answering each research question.

3.1 The general approach to the study

This thesis applied the triangulation method to contribute to the understanding of root caries. Triangulation is the practice of obtaining more reliable answers to research questions through integrating results from several different approaches, where each approach has different key sources of potential bias that are unrelated to each other (Lawlor et al., 2017). When results from the studies point to the same direction, they provide better evidence than an individual study.

Two general approaches were used. The first approach used a combination of a systematic review, meta-analysis and meta-regression study, while the second approach used empirical studies with different empirical data. The meta-analysis was preceded by a systematic review estimated root caries from studies already published around the world, while a meta-regression was used to assess the source of heterogeneity. The empirical studies involved analytical research based on empirical data.

Data from three studies were used to conduct the empirical studies. The first study was the National Survey of Adult Oral Health 2004-2006 (NSAOH 2004-06), which allowed an estimation representative of the Australian adult population at the state/territory and national level (Slade, Spencer and Roberts-Thomson, 2007). The two other studies were the South Australian Dental Longitudinal Study 1 (SADLS1) commencing in 1991-1992 (Slade, 1993; Slade and Spencer, 1994; 1997) and the South Australian Dental Longitudinal Study 2 (SADLS2) conducted under the title of the Intergenerational Change in Oral Health in Australia Study commencing in 2013-2014 (Harford et al., 2011). SADLS1 and SADLS2 were conducted in Adelaide and Mt Gambier, South Australia, collecting data from a representative sample of adults aged 60+ years in those areas. The SADLS1 consisted of four waves, the baseline, 2-year follow-up, 5-year follow-up, and 11-year follow-up. Up to now, the SADLS2 has consisted of the baseline and the 2-year follow-up.

The first data (NSAOH 2004-06) was used to describe the prevalence and the severity of root caries among a representative sample of Australian adults and to explore the associations with socio-demographic, socio-economic, clinical and behavioural factors. As the second and the third sets of data used in this thesis were specific for Australian older adults 60+ years, additional information from the NSAOH 2004-06 specific for older adults aged 60+ years was also presented.

The longitudinal increment in root caries was described using the data from SADLS1. All the four waves of SADLS1 were used (baseline (1991/92), 2-year follow-up, 5-year follow-up, and 11-year follow-up) and multi-level longitudinal growth analysis was applied. For studying root caries experience across generations in Australia, baseline data from both SADLS1 and SADLS2 was used (1991/1992 SADLS1 and 2013/2014 SADLS2).

3.2 Research design for the systematic review, meta-analysis and meta-regression study

Two major biomedical and pharmaceutical databases (PUBMED and EMBASE) were used to search for all longitudinal studies of root caries reporting root caries incidence and/or increment. The search terms used were root caries and incidence/increment. The inclusion criterion for all the searches was articles published in the English language prior to 2017. All step-by-step procedures followed the recommendation by PRISMA (Moher et al., 2009). Articles were included if they contained information sought in the search terms and were community-based or clinical trials research. Duplicate references were removed using EndNote X7.3 software. Two independent investigators performed the screening process and data extraction. The quality assessment of the papers was appraised using standardised critical appraisal instruments (Meta-Analysis of Statistics Assessment and Review Instrument (MAStARI)) recommended by The Joanna Briggs Institute (JBI) (The Joanna Briggs Institute, 2014). Any disagreement in each of the steps was resolved by consensus. Data adjustment was also performed by two authors independently, to check consistency.

Some possible sources of heterogeneity were checked using meta-regression analyses. This information was obtained from the incidence or increment studies included in the meta-analysis or their associated published baseline articles. The magnitude of the root caries problem around the world was estimated through meta-analysis. In the case of heterogeneity (chi-square P-value<0.05 or I2>50%), a random-effect model was preferred during the meta-analysis.

3.3 Study population and research design for the empirical studies

3.3.1 National Survey of Adult Oral Health 2004-2006 (NSAOH 2004-06)

3.3.1.1 Study design

NSAOH 2004-06 was Australia's second national oral examination survey of a representative sample of Australian adults. It was conducted in 2004-2006 and was aimed to describe the level of oral health including root caries in the population (Slade, Spencer and Roberts-Thomson, 2007). Survey participants were selected using a three-stage, stratified, clustered sampling design. The target population was Australian residents aged 15+ years (Australian adults).

The first stage of participant selection was selecting postcodes. Based on the Australian Bureau of Statistics postcode geographic classification, Australian postcodes in the six states and the Northern Territory were used to create two groups i.e. capital city ('metropolitan' stratum) and a remainder of the state ('non-metropolitan' stratum). In the Northern Territory, non-metropolitan stratum was limited to the regional centres of Alice Springs, Katherine, Tennant Creek and Nhulunbuy. The Australian Capital Territory was defined as a single metropolitan stratum. The postcodes represented the geographic clustering in the design and were selected with probability proportional to size (defined as the number of households listed in the 'electronic white pages' in each postcode).

The second stage was selecting a systematic sample of households within sampled postcodes. The sampling frame was households listed in the 'electronic white pages' in each sampled postcode, after a removal of some duplicate records. After elimination of non-residential phone numbers, thirty and forty households per metropolitan stratum and non-metropolitan stratum were selected respectively.

The third (final) stage was selecting a random person aged 15+ years per household. In households where there was only one person aged 15+ years, the person was selected as the participant, while in households with two or more persons aged 15+ years, a computer algorithm randomly selected either the person with most recent birthday or the person who would next have a birthday.

3.3.1.2 Aspects of sample size and statistical power

Sample size requirements were calculated for a range of key outcome variables, using both means and proportions. Parameter estimates, variances and design effects of the outcome variables were generated from the National Oral Health Survey of Australia 1987-1988 (NOHSA 1987-88), Australia's first national oral examination survey of a representative sample of Australian adults. The minimum sample size was required to detect a 25% difference in the mean number of decayed teeth and a 10% difference in mean number of DMFT. Type I and Type II errors were set at 0.05 and 0.20 respectively. More detailed information regarding this sample size calculation has been reported previously (Slade, Spencer and Roberts-Thomson, 2007).

3.3.1.3 Data collection

Data collected included self-reported information about oral health and associated characteristics gathered from a computer-assisted telephone interview (CATI), and information about the clinical oral status that was gathered from a standardised oral epidemiological examination. Methods in the CATI were based on Dillman's recommendations, including the mailing of a primary approach letter to households prior to telephoning, a protocol for contacting each household, and standardised procedures for asking questions and recording answers (Dillman, 2000). The interview consisted of 79 questions, based on those used in previous National Dental Telephone Interview Surveys conducted by the Australian Research Centre for Population Oral Health (Carter, 2002; 2003; 1994). It collected data on socio-demographic, socio-economic and behavioural factors. In total, 14,123 participants (respond rate=49%) were interviewed.

Survey participants who had one or more natural teeth were asked to attend a standardised oral epidemiological examination conducted by one of 30 dentist–examiners trained in the survey methods at a nearby dental clinic. A total of 5,505 participants (participation rate=43.7%) were dentally examined. During data collection, replicate examinations were conducted for a small number of participants for inter-examiner reliability against a gold standard examiner.

3.3.1.4 Root caries assessment

Root caries assessment was performed in the oral examination together with the examination of other oral health conditions such as tooth loss, coronal caries and gum disease. The approximate time for the oral examination was 20 minutes. Dental mirrors, explorers and periodontal probes (NIDR probe) were used to record oral epidemiological indices. Infection control followed guidelines published by the relevant State/Territory public dental services. No x-rays were taken and no treatment was provided. Observations of gingival recession, decayed, filled, and sound root surfaces were recorded on four root surfaces for each tooth. Root surfaces without at least one millimetre of a gingival recession were categorised as unexposed. Root caries or a root filling was only considered if at least one millimetre of a carious lesion or filling was apical to the cemento-enamel-junction. No distinction was made between caries-related and non-caries related root restorations**.** When a lesion involved both the coronal and root surfaces, it was coded as both root and coronal caries. Root caries lesions were diagnosed using softness and discoloration of dentine as the main features. Root surfaces that were visible at the examination without any evidence of dental caries or filling were recorded as sound. A root surface was considered as having untreated root caries if there was a carious cavitation with soft and/or discoloured dentine or leathery feel upon tactile inspection with the periodontal probe. Arrested lesions that were hardened on probing were coded as sound, even if the lesions were cavitated. Full details of the examination protocol have been published elsewhere (NSAOH exam protocol, 2012).

3.3.1.5 Funding sources and ethic approval

NSAOH 2004-06 was supported by a National Health and Medical Research Council (NHMRC) Project Grant #299060, NHMRC Project Grant #349514, NHMRC Capacity Building Grant #349537, the Australian Government Department of Health and Ageing, Population Health Division, the Australian Institute of Health and Welfare, the Australian Dental Association, Colgate Oral Care, and the U.S. Centres for Disease Control and Prevention. Ethical approval of NSAOH 2004-06 was received by the University of Adelaide Human Research Ethics Committee (Project Approval Number: H-001-2004). Participants provided verbal consent prior to answering questions in the telephone interview (CATI) and signed informed consent prior to the oral examination.

3.3.2 South Australian Dental Longitudinal Study 1 (SADLS1)

3.3.2.1 Study design

The South Australian Dental Longitudinal Study 1 (SADLS1) was an 11-year cohort study which began in 1991/1992. The study was the first comprehensive longitudinal study of the oral health of Australian older adults. It included four waves, i.e. baseline, 2-year follow-up, 5-year follow-up and the 11-year follow-up. The study aimed to evaluate the longitudinal pattern of change in oral disease including root caries and social impact while comparing oral disease prevalence and incidence in the fluoridated city of Adelaide and a non-fluoridated city of Mt Gambier. Participants were selected using a two-stage, stratified sampling design. The sampling frame for the survey was the electoral database maintained by the South Australian State Electoral Department. The sampling frame consisted of 181,263 records representing all electors aged 60+ years in the two cities.

In the first step of sampling, 24 strata were created, 18 strata within Adelaide (defined by a distance to dental clinics, age and sex) and six strata within Mt Gambier (defined by age and sex). Within each stratum, different sampling rates were used to draw a simple random sample of adults. The participants of the study were non-institutionalised people 60+ years old, as those who were resident in nursing homes or hospitals (but not hostels for the aged) were excluded. A final step in selection took place when the residence of each sampled person was visited by an interviewer. At that time, a percentage of edentulous persons were excluded, ranging from 100 per cent (that is, all edentulous persons) in Mt Gambier, to 50 per cent among the adults aged 60-64 in Adelaide (Slade and Spencer, 1994).

3.3.2.2 Aspects of sample size and statistical power

The sample size was calculated using standard formulae (Meinert, 1986; World Health Organization, 1986) to allow sufficient numbers and groups to detect hypothesised group differences of 30% in prevalence with a Type I and Type II error of 0.05 and 0.20 respectively; and a non-equivalent group size of up to 40%. Estimated rates and standard deviations were derived from a pilot study and a study in a similar age group in Iowa (Hand, Hunt and Beck, 1988; Hand, Kohout and Cunningham, 1988). A correction factor of 1.1 was used to increase the sample size by 10% to compensate for the sampling design effect on standard errors. Details of the sample size estimation has been reported previously (Slade, 1993).

Since SADLS1 was a longitudinal study design; the baseline sample size considered an attrition effect to ensure that sufficient participants would be retained and reduce potential bias due to the loss of follow-up. An average of 90% and 75% participation rates for interviews and examinations was expected at 2 and 5 years respectively. This level of participation would ensure a sufficient number of dentate participants at the 5-year follow-up to examine the most critical differences.

3.3.2.3 Data collection

Interviews and oral examinations were conducted in each wave. At the beginning of the study in 1991/1992, sampled people were notified by letter, and a trained interviewer visited each person's address to advise about the study and encourage participations. 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. Samples were maintained by keeping contact details of the third parties who might know of a participant's circumstances or new address, as well as by always sending a birthday card each year to the participants.

In the 2-year, 5-year, and 11-year follow-ups, 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.

3.3.2.4 Root caries assessment

In this study, four root surfaces were checked for each tooth (Slade and Spencer, 1997). Data on decayed, filled, sound root, as well as missing teeth, was recorded. Reasons of missing teeth were not recorded and no distinction was made between caries-related and non-caries related root restorations**.** To be registered as sound, the root surface needed to be visible. Root surfaces in which there was no recession were not be recorded as sound but were categorised as unexposed. Lesions were considered root caries or root fillings if they were entirely or predominantly located on the root surface. When a lesion involved both the coronal and root surfaces, the examiner judged where the lesion commenced using the 'half rule' so that only the surface containing the larger proportion of the lesion/restoration was deemed to be involved. An exception occurred where the lesion/restoration was divided equally on root and coronal surfaces, in which case both coronal and root surfaces were coded. Root caries lesions were diagnosed using softness and discoloration as the main features, due to the fact that there is a general agreement that the use of a combination of visual and tactile criteria (i.e. gentle to moderate blunt probe pressure with periodontal probe) is more indicative of root caries than the use of visual criteria alone (Fejerskov, Nyvad and Kidd, 2008; Neuhaus et al., 2009). Lesions were often covered with plaque, and the surface looked yellowish or light brown, and more importantly, felt soft and leathery upon tactile inspection (Rodrigues et al., 2011). Root caries lesions were softer than adjacent normal root surfaces (Beighton, Lynch and Heath, 1993; Rodrigues et al., 2011).

The presence of oral debris and calculus made the diagnosis of root caries lesions difficult (Katz, 1990). There was a convention that examiners should clean the oral debris in the area of diagnostic concern, but for an area which was covered by calculus, it was assumed that there was no root caries in the area.

The same oral examination protocol was applied in each wave of oral examinations to ensure that all the results were comparable. During the study, there were some changes in oral examiners. Some examiners from baseline were maintained as oral examiners in the 2-year, 5-year, and 11-year follow-up oral examinations. New examiners for the 2-year, 5-year, and 11-year follow-up examinations were trained by a gold standard examiner, who was one of the calibrated examiners from the baseline examination who participated in all four waves of examinations.

3.3.2.5 Funding sources and ethic approval

SADLS1 was supported by a National Health and Medical Research Council (NHMRC) Grant No #910557 for the baseline study, the United States National Institute of Dental Research. Grant No. RO1-DE09588 for the 2nd year follow-up, the NHMRC Grant No #960451 for the 5th year follow-up and the NHMRC Grant No #207774 for the 11th year follow-up. Ethical approval of SADLS1 was received by the University of Adelaide’s Human Research Ethics Committee and the United States Public Health Service Ethical Committee (Approval Number: HHS 596).

3.3.3 Intergenerational Change in Oral Health Study in Australia / South Australian Dental Longitudinal Study 2 (SADLS2)

3.3.3.1 Study design

The South Australian Dental Longitudinal Study 2 (SADLS2) named the Intergenerational Change in Oral Health Study in Australia was a cohort study which commenced in 2013-2014 (Harford et al., 2011). The study's aims were to document changes in the distribution and determinants of oral disease including root caries between two cohorts of older Australians (the SADLS2 cohort and the SADLS1 cohort). The sample was taken from the same population as SADLS1 consisting of adults aged 60+ years from Adelaide and Mt Gambier. Drawing from the same background population as SADLS1 allows comparisons of the two cohorts with minimal confounding. Participants were selected using a stratified random sample design. The South Australian Electoral Roll, which is a compulsory register for Australian citizens, was the sampling frame for the survey.

3.3.3.2 Aspects of sample size and statistical power

The main outcome variables used to estimate the required sample size were tooth retention and coronal caries experience. Sample size estimates were based on a significance level of 5% and 80% power (Type I and Type II error of 0.05 and 0.20 respectively). Sample size estimates allowed for a design effect of 1.5 to accommodate the complex sampling design. A smaller sample size than the previous SADLS1 was sufficient as a greater proportion of the population in the current generation is dentate (Harford et al., 2011). Finally, the final sample size was calculated taking into account the expected rates of recruitment, participation and the retention of study participants, based on the experience of SADLS1. The measurement of required sample sizes was shown in table 3.1.

Table 3.1 Required sample sizes based on hypothetical differences from estimates of key variables

Estimates	Hypothetical difference [a] (rate ratio)	Sample size required, (number)
1. Increase in tooth retention [b] Missing teeth=14.7±7.6	1.15	282
2. Caries experience [c] Decayed, Missing, Filled Teeth = 23.3±5.1	1.05	453

(a) Percent difference between SADLS cohort and SA 60+ Year-olds from NSAOH. So expect to observe similar magnitude of difference between SADLS2 cohorts

(b) All persons: MT=14.7 ± 7.6 from SADLS cohort (Slade and Spencer, 1997)

(c) All persons: Coronal DMFT = 12.3 ± 5.1 from SADLS cohort (Slade and Spencer, 1997)

Retention of subjects across the follow-up period was promoted by posting birthday cards to all participants. An effort to minimise loss of participants to follow-up included consulting the SA register of births, deaths and marriages to determine whether the participants were still alive or not, and then to trace them from the electoral roll.

3.3.3.3 Data collection

Information on the main explanatory variables was collected by mailed questionnaire, using the 'Total Design Method' developed by Dillman (2000). Everyone in the sample received a primary approach letter introducing the study, followed by a questionnaire a week later. A reminder card and up to four follow-up mailings were sent to non-respondents to maximise response rate. Another questionnaire was sent in the 2-year follow-up to collect information on alterations from baseline. Oral examinations were conducted at baseline and the second follow-up using the same procedure.

3.3.3.4 Root caries assessment

The gold standard oral examiner in this study was the same gold standard oral examiner from SADLS1. The criteria for root caries assessment were also the same as that used in SADLS1.
Four root surfaces were coded for each tooth. Surfaces of tooth crowns and roots were categorised as sound, decayed, recurrent decay, filled, or filled unsatisfactorily. For root surfaces, an additional category of 'not exposed' was available for surfaces with no gingival recession apical to the cemento-enamel junction (CEJ). For root surfaces to be scored as sound, the root surface needed to be visible. Arrested lesions that were hardened on probing were coded as sound, even if the lesions were cavitated. When a lesion involved both the coronal and root surfaces and extended at least one millimetre on to both coronal and root surfaces, the lesion was coded for both surfaces.

3.3.3.5 Funding sources and ethic approval

SADLS2 was supported by a National Health and Medical Research Council. Grant No. 1011589.
Ethical approval of the SADLS2 was received by the University of Adelaide Human Research Ethics Committee (ethics Approval Number: H-2012-010) and the SA Health Human Research Ethics Committee (ethics Approval Number: HREC/13/SAH/28).

3.4 The analytical approach

Several analytical approaches were employed to achieve the main objectives of this study. The analytic methods employed to address each aim are summarised below:

3.4.1 Aim 1 (Empirical study 1): Root caries among a representative sample of Australian adults

Data used for Aim 1 came from NSAOH 2004-06. Root caries was presented as the prevalence and the severity in three different measurements namely root DS, root FS and root DFS. The explanatory variables chosen include socio-demographic status (age, sex and residential place), socio-economic status (maximum level of education or qualification and household income), two clinical measures (oral hygiene and gingival status) and behavioural factors (tooth brushing frequency, flossing frequency, dental visiting and smoking status).

A weighted analysis was used to allow estimates of root caries that were representative of the Australian population at the national level. All analysis was performed in SPSS 16 and SAS-callable SUDAAN 11.0 to perform the descriptive and bivariate analysis, and multivariable analysis, respectively. Multivariable regression using the PROC LOGLINK was used to generate log poison regression with robust standard error estimation. Prevalence ratios estimate (PR), mean ratio estimate (MR) and their 95% confidence intervals (95% CI) for root DFS, root DS and root FS were presented, resulting in six (6) models. An additional analysis specific for the older adults group (60+ years old) is presented to develop an understanding of root caries cases among Australian older adults 60+ years old.

3.4.2 Aim 2 (A systematic review with meta-analysis and meta-regression): Root caries incidence and increment in the population – a systematic review, meta-analysis and meta-regression of longitudinal studies

For Aim 2, a combination of systematic review, meta-analysis and meta-regression was adopted. All root caries studies involving incidence and increment from longitudinal studies around the world were traced back in a systematic review. The data from all the included studies were adjusted in a similar way following methods used by Griffin et al. (2004). When possible, the crude estimate was chosen. When it was not presented, the option was the adjusted estimate followed by the net estimate. For studies reporting root caries incidence and increment for a period greater than one year, it was assumed that the root caries cases were identically distributed for each year. When the incidence and increment were reported for separate groups, the incidence and increment for the study population was estimated by taking the weighted average of the reported results for the separate groups. The associated standard error was calculated using the following formula:

$$SE\ in\ all\ study\ population\ in\ the\ interval\ study = \sqrt{\frac{N1 * (SE\ group\ 1)^2 + N2 * (SE\ group\ 2)^2}{N1 + N2}}$$

To estimate the annual incidence, firstly the probability that no disease occurred during the study interval was estimated. The nth root of this value (where n represents number of years in the study) was then used to calculate the probability that no disease occurred in a given year. Finally, the annual incidence was estimated by subtracting the value from 1. To estimate the annual standard error, this formula was used:

$$annual\ SE\ incidence = \sqrt{\frac{incidence * (1 - incidence)}{N}}$$

To estimate the annual increment, the increment reported for the study was divided by the years of follow-up of the study. The annual standard error was estimated by dividing the standard error reported in the study with the square root of the years of follow-up of the study.

Further, some possible sources of heterogeneity were checked. They were taken from the incidence or increment studies included in the meta-analysis or their associated published baseline articles. Then, meta-analysis of root DFS incidence and increment were conducted using Stata 13.0 software (StataCorp., College Station, TX, USA). In case of heterogeneity (chi-square P-value<0.05 or I2>50%), the random-effects model was preferred. Additionally, meta-regression and sub-group analyses were performed to identify possible sources of heterogeneity between studies.

3.4.3 Aim 3 (Empirical study 2): Root surface caries among older Australians, a study of root caries increment

Data used came from the South Australian Dental Longitudinal Study 1 (SADLS1), a cohort study of Australian older adults 60+ years old. To quantify the increment in root caries, all four waves of oral examinations were used (baseline, 2-year, 5-year, and 11-year). As the 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). Root caries treated with an extraction could not be estimated, as the reason for missing teeth was not collected. 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 caries experience. However, a zero increment could indicate that no further caries has developed. A multivariable multilevel growth model, using linear regression analysis, was presented to assess the increment and the associated behavioural factors of root caries. Linear regression analysis was used to make a comparability with the standard method of increment measurement (Slade and Caplan, 1999; Hamasha et al., 2005), which usually was measured by directly calculating changes of sound surfaces to untreated and treated root caries across baseline and follow-up examination, followed by a division with the length of time between the two examinations.

3.4.4 Aim 4 (Empirical study 3): Understanding root caries's prevalence and severity across generations

Data used came from the two cohort studies, SADLS1 and SADLS2, conducted in 1991-1993 and 2013-2014 respectively. These two separate cohort studies collected data on health status of a random sample of non-institutionalised people aged 60+ years living in two South Australian cities; Adelaide, the state capital, and Mt Gambier, a regional city in the south-east of the state (Slade and Spencer, 1997). SADLS1 collected data of a population born before 1931 while SADLS2 collected data of a population born before 1953. Drawing from the same background population allows comparison of SADLS1 and SADLS2 data with minimal confounding. Figure 3.1 shows the research scheme.

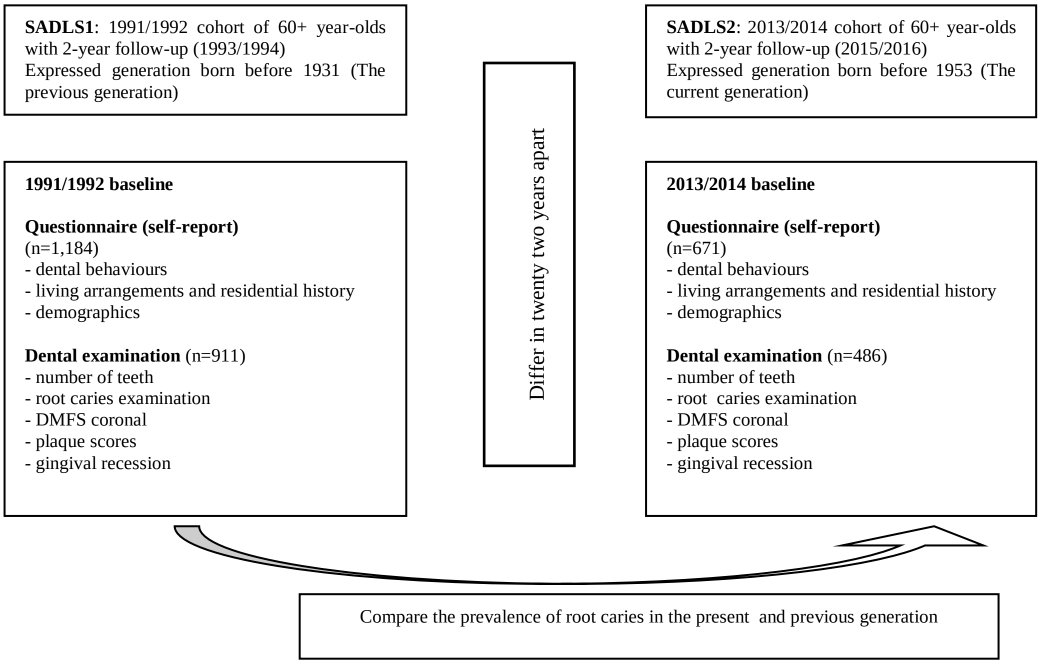

Figure 3.1 Research scheme containing data collection and analysis

In the analysis (empirical study 3), a comparison of the prevalence of root caries, across Australian generations, was performed by comparing the two generations with different retention of teeth.

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4 Chapter 4: Empirical study 1

4.1 Linkage of the Chapter to the body of research:

This Chapter addresses Aim 1 of this research. It provides an analysis of root caries using the National Survey of Adult Oral Health data. It gives an overview of root caries prevalence and its severity among Australian general adults 15+ years and older adults 60+ years. The findings provide a national estimate of root caries cases that is representative of the Australian population in the state/territory and national level. This serves as background information for the population distribution of root caries. It helps interpret the findings in the next chapters where root caries experience of the two generations of Australian older adults 60+ years are reported. This Chapter also explores and discusses some risk factors of root caries in both of the populations (Australian adults and older adults).

4.2 Highlight

- The paper presented in this Chapter was accepted for publication in *Gerodontology* in April 2017, and first published online (early view) on May 2017.
- This research found that root caries was a significant problem among Australians. It affected 25% of Australian adults 15+ years old and 62% of older Australians 60+ years old. These root DFS estimates were representative of the Australian population at the state/territory and national level.
- Root caries was quite sensitive to a decision as to whether the treated and/or untreated root caries was included.
- The findings of this study suggest that risk factors of root caries between Australian general adults 15+ years old and older adults 60+ years were quite similar.

4.3 Future research direction

- The risk indicators found in this cross-sectional study need to be confirmed with longitudinal research
- This research suggested the importance of preventive efforts being focused on health behaviours, especially among disadvantaged population groups

4.4 Status of the result

The result presented in this Chapter has been published in *Gerodontology*.

Citation of the article: Hariyani N, Spencer J, Luzzi L, Do LG. Root caries experience among Australian adults. *Gerodontology*. 2017;00:1–12. https://doi.org/10.1111/ger.12275

4.5 Statement of authorship (empirical result 1)

Statement of Authorship

Title of Paper	Root caries experience among Australian adults
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
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Principal Author

Name of Principal Author (Candidate)	Ninuk Hariyani		
Contribution to the Paper	Initial conceptualization, preparing data request form, data preparation and analysis, presenting and discussing findings and writing the manuscript		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	27-02-2018

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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4.6 Empirical result 1

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ORIGINAL ARTICLE

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Root caries experience among Australian adults

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Background: Increase in life expectancy and tooth retention in contemporary Australian adults may increase population-level burden of having root caries. This study aimed to describe patterns and evaluate associations of root caries with socio-demographic, socio-economic, clinical and behavioural factors.

Methods: A secondary analysis was undertaken using data from the National Survey of Adult Oral Health 2004-2006, which included 5505 randomly general adults 15+ years old. Participants underwent an oral examination and completed an interview and a questionnaire. Prevalence and mean number of decayed/filled root (root DFS), untreated root (root DS), filled root (root FS), gingival recession, oral hygiene and gingival status were derived from examinations. Socio-demographic, socio-economic and behavioural factors were self-reported. Multivariable models were generated to estimate prevalence ratios (PR), mean ratios (MR) and confidence intervals (95% CI), adjusting for number of surfaces with gingival recession. Additional analysis for older adults 60+ years old was presented.

Results: The prevalence of root caries was 25.3% (CI=23.6-27.1) and 62.0% [CI=58.7-65.1] among general and older adults, respectively. Risk factors found were similar in both populations. Smokers had higher prevalence and mean number of root DFS, DS and FS than never-smokers. In contrast with poor oral hygiene, high income and frequent brushing were significantly associated with lower mean root DS. Frequent dental visiting was associated with higher root FS and DFS.

Conclusions: Root caries affected about a quarter of Australian general adults and more than a half of older adults. People who were smokers presented a significantly higher prevalence and severity of root caries.

KEYWORDS
Australian population, decayed filled root surfaces, decayed root surfaces, root caries

1 | INTRODUCTION

There has been increased attention towards root caries in recent decades.[1] Research has shown that root caries affects middle-aged as well as older adults.[1-4] In Australia, as in many countries around the world, there is an increase in life expectancy[5] resulting in an increase in the number and proportion of the population aged late middle-aged and older. At the same time, enhanced awareness of oral health, better access to and comprehensiveness of dental services and improved exposure to fluoride have resulted in an increased proportion of the population, especially those aged 50 years and above retaining more natural teeth. In Australia, the total number of permanent teeth in the population from 2004 to 2019 was projected to increase by 13% as a result of the ageing population and an increasing proportion of the population being dentate.[6] Many of the teeth expected to be retained among older adults will have a rich history of oral disease like coronal caries and its treatment and remain at risk of developing further

Part of this study has been presented in the 55th Annual Scientific Meeting of the International Association for Dental Research, Australia & New Zealand Division, in Dunedin, 23-26 August 2015.

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chronic destructive conditions. Destruction of the periodontal tissues including gingival recession can be a part of normal ageing, but also can result from periodontal disease and local trauma to the periodontal tissues. Gingival recession puts the exposed root surfaces of teeth at risk of developing root caries.[7,8] As a consequence of ageing and tooth retention, and associated gingival recession, root caries is expected to become a more significant oral health problem.

A considerable percentage of adults are affected by root caries. The prevalence of root caries lesions reported by various studies has ranged from 9.8% to 71%.[9,10] The prevalence estimate can vary depending on ages of the adults involved and whether the presence of root caries is defined by one of more surfaces with untreated root caries or one of more root surfaces with untreated or treated (filled) root caries. In the National Survey of Adult Oral Health in Australia 2004-06 (NSAOH 2004-06), the prevalence of untreated root caries was 6.7% in all adults 15+ years old, but increased to 7.1% in 35- to 54-year-olds, 12.6% in 55- to 74-year-olds and 17.3% in those aged 75+ years old. The prevalence of untreated root caries was higher in those with less education, eligible for public dental care, uninsured and who usually visit a dentist for a problem. Untreated root caries lesions reflect experience of the disease and a lack of access to dental services.

The picture of root caries described from NSAOH 2004-06 is incomplete as only the prevalence of untreated root caries and its association with key socio-demographic characteristics is considered. While this indicates what population subgroups have a higher likelihood of untreated root caries, this could be misleading about the overall experience of root caries in the population, as some population subgroups might experience the disease, but have had root caries lesions filled. Further it would be useful to examine the associations between root caries and a broader range of factors, including clinical and behavioural factors which may be closer to aetiology of the disease than social characteristics.

The availability of the NSAOH 2004-06 data provided the opportunity to report in more depth about root caries in Australian adults and to explore a broader range of factors with which root caries may be associated. Therefore, the aims of this study were to describe the prevalence and the severity of treated and untreated (root DFS), untreated (root DS) and treated (root FS) root caries among a representative sample of Australian adults and explore the associations with socio-demographic, socio-economic, clinical and behavioural factors. Additional information specific for older adults aged 60+ years is also presented.

2 | MATERIALS AND METHODS

2.1 | Study population and research design

This study presents findings on root caries experience from NSAOH 2004-06. NSAOH was conducted in Australia between 2004 and 2006. It used a three-stage, stratified clustered sample design with telephone numbers listed in a residential telephone directory database as the sampling frame. The first stage selected postcodes with probability proportional to size. The second stage selected households within sampled postcodes, and the third stage selected one person aged 15+ years from each sampled household. Full details of the study design and sampling are described elsewhere.[11] There were 14 123 respondents in NSAOH 2004-06, and some 5505 dentate respondents underwent the oral examination. For the purpose of this analysis, only data for participants who participated in a telephone interview and received an oral examination were included. A comparison of the participants' characteristics against population benchmarks (the 2001 census) was conducted and has been published elsewhere.[11] The results showed that the sample in this study may have overestimated the percentage of people who were Australian-born and English speakers but were otherwise quite similar in other socio-demographic characteristics to the Australian adult population.

2.2 | Data collection

Data on clinical conditions including gingival recession, root caries, oral hygiene and gingival status were collected during the oral examinations done by 30 trained and calibrated dentist examiners. Mirrors and probes were used under standardised illumination to assess the clinical conditions. A blunt probe (NIDCR probe), rather than sharp explorer, was used to prevent textural changes and destruction of root tissue. Radiographs were not taken. Observations of gingival recession, decayed, filled and sound root surfaces were recorded in four root surfaces for each tooth. Root surfaces without at least 1 mm of gingival recession were categorised as unexposed. Thus, the number of surfaces with gingival recession will equal to the sum of sound, decayed, filled root surfaces. If at least one millimetre of a carious lesion or filling was apical to the cemento-enamel-junction (using the one millimetre rule[12]), then the surface was considered to have root caries or a root filling. No distinction was made between caries-related and non-caries-related root restorations. When a lesion involved both the coronal and root surfaces, it was coded as both root and coronal caries. Cases of root caries lesions were defined using softness and discoloration of dentine as the main features, due to the fact that there is general agreement that the use of a combination of visual and tactile criteria (ie soft or leathery to slight probe pressure) is more indicative of root caries than the use of visual criteria alone.[13,14] Root surfaces that were visible at the examination without any evidence of dental caries or filling were recorded as sound. A root surface was considered as having untreated root caries if there was a carious cavitation with soft and/or discoloured dentine or leathery feel upon tactile inspection. Arrested lesions that were hardened on probing were coded as sound, even if the lesions were cavitated. Full details of the examination protocol have been provided earlier.[15]

Participants were re-examined by a gold standard examiner who had been involved in the development of the examination protocol and the training of examiners. The assessment of interexaminer reliability of decayed or filled root surfaces was performed using intraclass correlation coefficient and the results (.46 and .82, respectively) were published elsewhere.[11]

The explanatory factors chosen in this study included two clinical measures (oral hygiene and gingival status). Six index teeth (the most anterior molar in each quadrant and tooth 11 and tooth 31) were assessed for oral hygiene and gingival status. When an index tooth was not available, no substitute tooth chosen, and the oral hygiene and gingival status for the particular tooth were scored as missing. Oral hygiene status (plaque accumulation) and gingival status of each participant were determined using the plaque index and gingival index by Loe.[16,17] For the plaque accumulation, the following criteria were used for scoring: 0=no plaque present; 1=plaque was seen only after scraping the periodontal probe on the dried tooth surface; 2=moderate accumulation of plaque can be seen with the naked eye; 3=abundance of plaque easily visible with the naked eye. For gingival status, the following criteria were used for scoring: 0=no inflammation of the gingiva; 1=mild inflammation; 2=moderate inflammation; 3=severe inflammation.

Other explanatory factors were derived from an initial computer telephone interview. These included socio-demographic status (age, sex and residential place), socio-economic status (maximum level of education or qualification and household income) and behavioural factors (tooth brushing frequency, flossing frequency, dental visiting and smoking status).

2.3 | Data management

Root caries was measured in two formats: root caries prevalence and the severity of root caries. For each type of measure, root caries was defined as decayed or filled root surfaces (root DFS), decayed root surfaces only (root DS) and filled root surfaces only (root FS). Root DFS prevalence was the percentage of people who had at least one decayed and/or filled root surface, while root DS prevalence and root FS prevalence were the percentage of people who had at least one untreated decayed only and filled root surface only, respectively. The severity of root caries (root DFS) was calculated by summing the number of decayed and filled surfaces, while the severity of untreated root caries (root DS) and filled root caries (root FS) were calculated by summing only the number of untreated decayed root surfaces and the number of filled root surfaces, respectively. In this study, root caries experience was not measured by the Root Caries Index as a denominator for the total number of root surfaces with gingival recession was included in analyses. Furthermore, it is difficult to make a comparison from studies with different population characteristics and different methods in reporting root caries. Thus, WHO recommended the use of simple prevalence and severity for international comparison reason.[18]

To generate an overall picture of oral hygiene and gingival status in this study, the maximum score of the plaque index and gingival index from the six index teeth was identified. For oral hygiene, the maximum score of the plaque index then was recategorised into poor (if score≥2) and good oral hygiene (if score≤1). For gingival status, the maximum score of gingival index was recategorised into no gingivitis (if score 0) and gingivitis (if score≥1). Age was split into younger adults (15-44 years), middle-aged adults (45-59 years) and older adults (60+ years). Residential place of dwelling was divided into metropolitan and nonmetropolitan. Socio-economic status was measured by the highest level of school, postschool or tertiary educational attainment (trichotomised into senior high school or less, trade and university education or higher) and household income (<$40 000, $40 000-$80 000 and >$80 000). Behavioural factors were tooth brushing frequency (coded into less than twice a day vs twice a day or more), flossing frequency (not everyday vs once a day or more), dental visiting (last visit was 1 year or more ago vs last visit less than 1 year ago) and smoking status (never smoked vs currently smoke or used to smoke).

2.4 | Statistical analysis

All data were weighted to adjust for the different probabilities of selection arising from the stratified three-stage, clustered sampling design to produce sample estimates representative of the Australian population at the state/territory and national level. Additional analysis specific for the older adults group (60+ years old) will be presented. Data were managed using SPSS 16 (SPSS Co., Chicago, IL, USA) for complex samples which incorporate the sampling design specifications to estimate means, percentages and confidence intervals as well as to test differences in bivariate analysis. To adjust for the complex sampling design of the study, the multivariable analysis was conducted using SAS-callable incorporated with SUDAAN 11.0 (Research Triangle Institute, North Carolina) to perform multivariable regression using the PROC LOGLINK to estimate prevalence ratios (PR), mean ratio (MR) and their 95% confidence intervals (95% CI) for root caries, untreated root caries and filled root caries only, resulting in six models. PROC LOGLINK generates log Poison regression with robust standard error estimation. The number of surfaces with gingival recession was used to adjust the multivariable analysis, because many studies[7,8,19-21] suggest that gingival recession is related to the socio-demographic (age), socio-economic (income), behavioural indicators (tooth brushing frequency, smoking), as well as the root caries experience.

2.5 | Ethical review

Ethical approval of NSAOH 2004-06 was received by the University of Adelaide Human Research Ethics Committee. However, because this particular study involved only a secondary analysis, no new ethic clearance was required.

3 | RESULTS

A total of 5505 respondents underwent an oral examination and were included in this study. Study participants were aged between 15 and 91 years (mean: 50 [SD 16]), comprised equally of males and females. Table 1 shows the characteristics of study participants by age groups and overall. Only 31% of the respondents had a university degree or higher, and 65% of the study participants lived in metropolitan areas. Around 29% of the respondents had income more than $80 000. In the examination, 71% of the respondents were found to have good

TABLE 1 Background characteristic of NSAOH 2004-06 participants and different characteristics according to the age groups

Risk indicators	All participants / General adults (15+ yo) %[CI]	Young adults (15-44 yo) % [CI]	Middle-aged adults (45-59 yo) %[CI]	Older adults (60+ yo) %[CI]
All participants %[CI]	-	56.7 [54.6-58.8]	25.2 [23.6-26.9]	18.1 [16.7-19.5]
Socio-demographic				
Sex				
Male	50.0 [47.9-52.1]	50.3 [47.0-53.7]	49.9 [46.7-53.1]	49.1 [46.1-52.2]
Female	50.0 [47.9-52.1]	49.7 [46.3-53.0]	50.1 [46.9-53.3]	50.9 [47.8-53.9]
Residential place				
Metropolitan area	65.1 [63.6-66.6]	66.7 [63.8-69.5]	63.9 [61.0-66.7]	62.1 [59.0-65.1]
Nonmetropolitan area	34.9 [33.4-36.4]	33.3 [30.5-36.2]	36.1 [33.3-39.0]	37.9 [34.9-41.0]
Socio-economic				
Highest school/tertiary qualification				
Senior high school or less	40.7 [38.5-43.0]	44.0 [40.5-47.5]	31.1 [28.2-34.3]	43.8 [40.4-47.3]
Trade	28.3 [26.4-30.3]	24.0 [21.3-26.9]	35.2 [31.9-38.6]	32.5 [29.7-35.5]
University or higher	31.0 [28.9-33.1]	32.0 [28.9-35.3]	33.7 [30.4-37.2]	23.6 [20.5-27.0]
Income				
<$40 000	35.7 [33.7-37.8]	25.6 [22.8-28.6]	28.7 [26.0-31.6]	75.5 [72.3-78.5]
$40 000-$80 000	35.4 [33.5-37.4]	41.2 [38.1-44.5]	35.6 [32.4-39.0]	18.1 [15.5-21.1]
>$80 000	28.8 [26.8-31.0]	33.2 [29.9-36.6]	35.7 [32.2-39.2]	6.3 [5.0-8.0]
Clinical conditions				
Oral hygiene				
Good oral hygiene	71.1 [69.0-73.1]	75.7 [72.7-78.5]	69.8 [66.6-72.8]	58.4 [54.8-61.9]
Poor oral hygiene	28.9 [26.9-31.0]	24.3 [21.5-27.3]	30.2 [27.2-33.4]	41.6 [38.1-45.2]
Gingival status				
Normal	28.4 [26.1-30.9]	28.8 [25.7-32.1]	27.4 [24.2-30.8]	28.8 [25.0-33.0]
Gingivitis	71.6 [69.1-73.9]	71.2 [67.9-74.3]	72.6 [69.2-75.8]	71.2 [67.0-75.0]
Presence of gingival recession				
No	28.3 [25.7-31.1]	44.5 [40.6-48.4]	9.2 [7.3-11.5]	4.2 [2.9-6.2]
Yes	71.7 [68.9-74.3]	55.5 [51.6-59.4]	90.8 [88.5-92.7]	95.8 [93.8-97.1]
Number of surfaces with gingival recession (mean[CI])	13.6 [11.9-15.4]	8.88 [6.61-11.15]	16.80 [15.16-18.45]	24.20 [22.11-26.30]
Oral health behaviours				
Frequency of brushing				
Less than twice a day	43.1 [40.7-45.4]	49.0 [45.4-52.6]	35.8 [32.6-39.1]	36.5 [32.8-40.3]
Twice a day or more	56.9 [54.6-59.3]	51.0 [47.4-54.6]	64.2 [60.9-67.4]	63.5 [59.7-67.2]
Frequency of flossing				
Not everyday	82.1 [80.7-83.5]	86.5 [84.4-88.3]	78.0 [75.0-80.7]	74.3 [71.5-76.9]
Once or more a day	17.9 [16.5-19.3]	13.5 [11.7-15.6]	22.0 [19.3-25.0]	25.7 [23.1-28.5]
Dental visit				
Last visit was 1 y or more ago	41.4 [39.5-43.4]	49.0 [46.1-52.0]	30.8 [27.7-34.2]	32.3 [29.5-35.3]
Last visit was less than 1 y Ago	58.6 [56.6-60.5]	51.0 [48.0-53.9]	69.2 [65.8-72.3]	67.7 [64.7-70.5]
Smoking				
Never smoke	56.6 [54.5-58.6]	60.6 [57.5-63.7]	49.1 [45.9-52.3]	54.4 [51.2-57.5]
Currently smoke and used to smoke	43.4 [41.4-45.5]	39.4 [36.3-42.5]	50.9 [47.7-54.1]	45.6 [42.5-48.8]

CI, 95% Confidence Interval; NSAOH 2004-06, National Survey of Adult Oral Health 2004-06 in Australia.

oral hygiene, but almost 72% of the respondents still had gingivitis. Among all of the participants, almost 72% had gingival recession with gingival recession present on a mean of 14 root surfaces. In relation to the oral health behaviours, 43% had a tooth brushing frequency of less than twice a day and around 82% reported not flossing everyday. Some 41% of study participants revealed having dental visit 1 year or more ago. In relation to smoking behaviour, 43% of respondents were either current smokers or former smokers. Characteristics of older adults (those aged 60+ years) were similar to adults in the other age groups and to the general adults group with the exception of income and the presence of gingival recession. Only 6.3% of older adults had income more than $80 000 and 96% had gingival recession with gingival recession present on a mean of 25 root surfaces.

The prevalence of root caries (root DFS 1+) in the general Australian adult population 15+ years old was 25.3%. Untreated root caries prevalence (DS 1+) was 6.7%, while the prevalence of filled root surfaces was almost 22%. The severities of root caries (root DFS and root DS) were 0.87 (CI=0.79-0.94) and 0.15 (CI=0.12-0.18), respectively. The mean number of filled root was 0.72. The results from the bivariate analysis are presented in Table 2. The prevalence of root caries, based on root DFS, root DS and root FS only, were significantly higher among older adults (age 60+ years old) than the younger adults. The severity in root DFS, root DS and root FS ranged from 0.2 to 2.6, 0.08 to 0.32 and 0.12 to 2.3, respectively, according to the aged group (younger to older adults). Older, lower income and current or previous smoking all were associated with a higher prevalence and more severe root caries.

The results of the multivariable models in all participants are presented in Table 3. These models show that age was a factor associated with the prevalence and severity of root caries, except for the mean root DS. Untreated root caries prevalence was twice, while the root caries prevalence was almost five times higher as age increased from young adults to older adults. The mean of filled root surfaces was eleven times higher among older adults.

All six models showed that the prevalence and the severity of root caries were associated with smoking status and the number of surfaces with gingival recession. Smokers were two times more likely to have untreated root caries than nonsmokers, while number of surfaces with gingival recession was associated with increased probabilities of having root caries in all models among Australian adults.

The high-income group had lower root DFS and DS than the low-income group. Oral hygiene and tooth brushing frequency were only associated with untreated root caries. Participants with poor oral hygiene had a higher root caries DS prevalence (PR[CI]=1.59 [1.16-2.19]) and mean root DS (MR[CI]=1.96 [1.28-2.99]) than those with good oral hygiene. Participants who brushed twice a day or more had a lower untreated root decay prevalence (PR[CI]=0.63 [0.47-0.86]) and mean root DS (MR[CI]=0.56 [0.36-0.86]) than those who brush less than twice a day.

When root caries experience was measured as root DFS and root FS, both in the prevalence or the severity, participants who flossed once a day or more and those who visited a dentist once or more in the previous year had higher root caries than those who did not floss everyday, and those whose last visit was a year or more ago, respectively. Participants who lived in a nonmetropolitan area had a lower mean root DFS (MR [CI]=0.77 [0.63-0.94]) and mean root FS (MR [CI]=0.69 [0.55-0.85]) than those who lived in a metropolitan area. Higher education was only significantly associated with root FS prevalence.

Table 4 presents the multivariable analysis only for the older adults group. The overall picture was the same except in the relation to flossing frequency and gingivitis to root caries. Among older adults, flossing frequency was not significantly associated with root DFS and root FS, while respondents with gingivitis had a lower mean root DFS (MR [CI]=0.68 [0.53-0.86]) and mean root FS (MR [CI]=0.64 [0.49-0.82]) than those who did not have gingivitis.

4 | DISCUSSION

A considerable percentage of general and older Australian adults affected by root caries and the burden of the disease in all measurements was higher for those who were smokers. This study also found associations among some factors and root caries when it expressed as decayed and filled root caries, untreated root caries only or filled root surfaces only.

The strength of this study lies in the nature of data collected in a national survey, allowing estimates of root caries that were representative of the Australian population at the national level and the investigation of a wider range of factors for their association with root caries. The cross-sectional study design is the limitation of this study as it could not investigate beyond associations. While such associations help formulate causal hypotheses, they cannot confirm or refute them.

The prevalence and severity of root caries was quite sensitive to decisions about whether treated and untreated root caries is included. Overall, it was found that one in four general Australian adults aged 15+ years had experienced root caries, while only 7% had untreated root caries. It was also found that one in five Australian 15+ years had root caries filled. The prevalence of untreated root caries in this study was slightly lower than that reported in the United States, where 9.8% participants aged 20+ years was reported to have one or more untreated root caries lesion.[10] The prevalence of untreated root caries among older adults (Australian 60+ year old) was high at 15%. However, the Australian older adults' root DS prevalence was lower than among adults aged 50+ and 60+ years in Canada and Germany, respectively, where some 27% had untreated root caries.[9,22] The lower root caries prevalence among Australian older adults aged 60+ years compared to their counterparts in comparable countries could reflect lower root caries activity, better access to dental services or a combination. However, this could also be caused by the decision to exclude arrested lesion that were hardened on probing.

The findings of this study suggest that risk factors of root caries between Australian general adults 15+ year and older adults 60+ years were quite similar. It was found that smokers have a higher prevalence and severity of root caries. It also showed that increases in the number of surfaces with gingival recession were associated with increased probabilities of having root caries in all models.

TABLE 2 Bivariate analysis of root caries with explanatory factors among general Australian adults

	Weighted					
	Root DFS prevalence %[CI]	Root DFS mean[CI]	Root DS prevalence %[CI]	Root DS mean[CI]	Root FS prevalence %[CI]	Root FS mean[CI]
Total	25.3% [23.6-27.1]	0.87 [0.79-0.94]	6.7% [5.9-7.6]	0.15 [0.12-0.18]	21.9% [20.2-23.6]	0.72 [0.64-0.79]
Socio-demographic						
Age*						
Young adults (15-44 yo)	**8.2 [6.8-10.0]**	**0.21 [0.15-0.26]**	**3.2 [2.4-4.3]**	**0.08 [0.05-0.12]**	**5.8 [4.6-7.3]**	**0.12 [0.09-0.15]**
Middle-aged adults (45-59 yo)	**37.6 [34.5-40.7]**	**1.07 [0.94-1.20]**	**8.8 [7.2-10.7]**	**0.18 [0.13-0.22]**	**33.4 [30.4-36.4]**	**0.89 [0.78-1.01]**
Older adults (60+ yo)	**62.0 [58.7-65.1]**	**2.66 [2.42-2.90]**	**14.7 [12.7-17.1]**	**0.32 [0.25-0.40]**	**56.4 [52.9-59.9]**	**2.33 [2.11-2.56]**
Sex						
Male	25.1 [22.6-27.8]	0.84 [0.74-0.95]	7.8 [6.6-9.3]	0.18 [0.14-0.22]	21.2 [18.9-23.7]	0.66 [0.57-0.75]
Female	25.5 [23.4-27.8]	0.89 [0.78-1.00]	5.6 [4.6-6.7]	0.12 [0.08-0.15]	22.6 [20.6-24.8]	0.77 [0.67-0.87]
Residential place						
Metropolitan area	25.3 [23.2-27.5]	0.87 [0.78-0.96]	6.0 [5.1-7.0]	0.12 [0.10-0.15]	22.2 [20.2-24.4]	0.74 [0.66-0.83]
Nonmetropolitan area	25.4 [22.4-28.5]	0.86 [0.71-1.01]	8.1 [6.7-9.7]	0.20 [0.14-0.26]	21.3 [18.6-24.2]	0.66 [0.54-0.79]
Socio-economic						
Highest school/tertiary qualification						
Senior high school or less	22.8 [20.3-25.5]	0.80 [0.68-0.92]	7.3 [6.0-8.8]	0.19 [0.13-0.24]	18.5 [16.2-20.9]	0.61 [0.51-0.71]
Trade	28.3 [25.3-31.4]	0.94 [0.81-1.07]	7.5 [6.0-9.4]	0.16 [0.11-0.20]	24.4 [21.7-27.3]	0.79 [0.67-0.90]
University or higher	24.3 [21.4-27.5]	0.80 [0.67-0.92]	**4.5 [3.5-5.9]**	0.08 [0.04-0.11]	22.5 [19.7-25.6]	0.72 [0.60-0.84]
Income*						
<$40 000	**37.7 [34.7-40.9]**	**1.44 [1.28-1.60]**	**11.5 [9.9-13.5]**	**0.29 [0.22-0.36]**	**32.0 [29.1-35.0]**	**1.15 [1.02-1.29]**
$40 000-$80 000	22.9 [20.3-25.8]	**0.72 [0.60-0.84]**	**6.2 [4.9-7.7]**	**0.13 [0.09-0.17]**	19.5 [17.1-22.2]	0.59 [0.49-0.70]
>$80 000	17.7 [15.1-20.6]	**0.48 [0.39-0.58]**	**3.0 [2.1-4.3]**	**0.04 [0.02-0.05]**	16.1 [13.6-18.9]	0.45 [0.35-0.54]
Clinical conditions						
Oral hygiene						
Good oral hygiene	**22.7 [20.8-24.8]**	**0.75 [0.67-0.84]**	**4.6 [3.8-5.4]**	**0.08 [0.06-0.10]**	20.8 [18.9-22.7]	0.67 [0.59-0.75]
Poor oral hygiene	**31.6 [28.4-34.9]**	**1.12 [0.97-1.27]**	**11.7 [10.1-13.7]**	**0.29 [0.22-0.35]**	24.6 [21.7-27.8]	0.83 [0.70-0.96]
Gingival status						
No gingivitis	20.9 [18.3-23.7]	0.76 [0.62-0.90]	**3.5 [2.6-4.7]**	0.09 [0.04-0.15]	18.9 [16.5-21.6]	0.67 [0.55-0.79]
Gingivitis	24.9 [22.8-27.1]	0.81 [0.72-0.90]	**7.5 [6.5-8.6]**	0.16 [0.13-0.19]	21.0 [19.1-23.1]	0.65 [0.57-0.73]

(Continues)

TABLE 2 (Continued)

	Weighted					
	Root DFS prevalence %[CI]	Root DFS mean[CI]	Root DS prevalence %[CI]	Root DS mean[CI]	Root FS prevalence %[CI]	Root FS mean[CI]
Oral health behaviours						
Frequency of brushing						
Less than twice a day	**23.8 [21.0-26.9]**	**0.75 [0.64-0.86]**	8.1 [6.6-9.9]	**0.19 [0.14-0.24]**	**19.2 [16.6-22.1]**	**0.56 [0.46-0.66]**
Twice a day or more	**29.6 [27.1-32.2]**	**1.03 [0.91-1.15]**	5.6 [4.6-6.9]	**0.10 [0.08-0.12]**	**27.4 [25.0-29.9]**	**0.93 [0.82-1.04]**
Frequency of flossing						
Not everyday	**22.9 [21.2-24.8]**	**0.75 [0.67-0.82]**	6.7 [5.9-7.6]	0.16 [0.13-0.19]	**19.3 [17.7-21.2]**	**0.59 [0.52-0.66]**
Once a day or more	**36.2 [32.5-40.0]**	**1.42 [1.22-1.61]**	6.8 [5.1-8.9]	0.12 [0.08-0.16]	**33.5 [29.9-37.4]**	**1.29 [1.10-1.49]**
Dental visiting						
Last visit ≥1 y ago	**18.4 [16.3-20.6]**	**0.57 [0.48-0.65]**	7.1 [5.9-8.5]	0.17 [0.13-0.22]	**13.6 [11.8-15.7]**	**0.39 [0.32-0.46]**
Last visit <1 y ago	**30.2 [28.0-32.5]**	**1.08 [0.97-1.19]**	6.5 [5.4-7.7]	0.13 [0.10-0.17]	**27.7 [25.6-29.9]**	**0.94 [0.84-1.05]**
Smoking*						
Never smoked	**21.7 [19.7-23.8]**	**0.70 [0.61-0.80]**	**4.5 [3.7-5.5]**	**0.09 [0.06-0.12]**	**19.4 [17.6-21.4]**	**0.61 [0.53-0.69]**
Currently smoke or used to smoke	**30.0 [27.4-32.8]**	**1.08 [0.96-1.19]**	**9.6 [8.3-11.2]**	**0.23 [0.18-0.27]**	**25.1 [22.6-27.8]**	**0.85 [0.75-0.96]**

CI, 95% Confidence Interval; DFS, decayed filled surfaces; DS, decayed surfaces; FS, filled surfaces.
Bold; significant.
*significant in all root caries measurements.

TABLE 3 Multivariable analysis of root caries in the general adults group

Risk indicator	Root caries measurement					
	Root DFS prevalence PR [95% CI]	Root DFS MR [95% CI]	Root DS prevalence PR [95% CI]	Root DS MR [95% CI]	Root FS prevalence PR [95% CI]	Root FS MR [95% CI]
Socio-demographic						
Age						
Young adults (15-44 yo)	1.00	1.00	1.00	1.00	1.00	1.00
Middle-aged adults (45-59 yo)	3.72 [2.90-4.78]*	4.11 [2.98-5.65]*	1.85 [1.17-2.93]*	1.25 [0.70-2.25]	4.59 [3.46-6.10]*	5.72 [4.08-8.02]*
Older adults (60+ yo)	4.90 [3.75-6.40]*	7.65 [5.54-10.56]*	2.08 [1.26-3.45]*	1.78 [0.89-3.55]	6.24 [4.62-8.44]*	11.21 [7.97-15.77]*
Sex						
Male	1.00	1.00	1.00	1.00	1.00	1.00
Female	1.07 [0.92-1.24]	1.01 [0.84-1.23]	0.83 [0.59-1.16]	0.76 [0.50-1.14]	1.07 [0.92-1.25]	1.08 [0.88-1.32]
Residential place						
Metropolitan area	1.00	1.00	1.00	1.00	1.00	1.00
Nonmetropolitan area	0.92 [0.79-1.07]	0.77 [0.63-0.94]*	1.13 [0.80-1.59]	1.31 [0.80-2.15]	0.86 [0.72-1.02]	0.69 [0.55-0.85]*
Socio-economic						
Highest school/tertiary qualification						
Senior high school or less	1.00	1.00	1.00	1.00	1.00	1.00
Trade	1.11 [0.95-1.29]	1.05 [0.85-1.29]	0.81 [0.55-1.17]	0.89 [0.54-1.45]	1.15 [0.97-1.35]	1.09 [0.87-1.35]
University or higher	1.13 [0.95-1.34]	1.12 [0.89-1.39]	0.69 [0.46-1.05]	0.82 [0.36-1.86]	1.26 [1.05-1.52]*	1.17 [0.93-1.47]
Income*						
<$40 000	1.00	1.00	1.00	1.00	1.00	1.00
$40 000-$80 000	0.98 [0.84-1.15]	0.90 [0.74-1.10]	0.76 [0.52-1.11]	0.65 [0.38-1.14]	0.98 [0.82-1.16]	0.95 [0.78-1.17]
>$80 000	0.80 [0.65-0.99]*	0.71 [0.54-0.92]*	0.43 [0.25-0.75]*	0.25 [0.14-0.44]*	0.84 [0.67-1.04]	0.83 [0.63-1.10]
Clinical conditions						
Oral hygiene*						
Good oral hygiene	1.00	1.00	1.00	1.00	1.00	1.00
Poor oral hygiene	1.05 [0.90-1.21]	0.96 [0.80-1.16]	1.59 [1.16-2.19]*	1.96 [1.28-2.99]*	0.91 [0.78-1.07]	0.83 [0.68-1.01]
Gingival status						
No gingivitis	1.00	1.00	1.00	1.00	1.00	1.00
Gingivitis	1.03 [0.90-1.18]	0.86 [0.71-1.05]	1.27 [0.85-1.91]	1.03 [0.53-1.99]	1.04 [0.90-1.20]	0.84 [0.69-1.03]
Exposed root surfaces[a]	1.01 [1.01-1.02]*	1.02 [1.02-1.02]*	1.01 [1.01-1.02]*	1.01 [1.01-1.02]*	1.01 [1.01-1.02]*	1.02 [1.02-1.03]*
Oral health behaviours						
Frequency of brushing						
Less than twice a day	1.00	1.00	1.00	1.00	1.00	1.00
Twice a day or more	0.93 [0.82-1.06]	0.97 [0.81-1.15]	0.63 [0.47-0.86]*	0.56 [0.36-0.86]*	0.99 [0.86-1.15]	1.09 [0.90-1.31]
Frequency of flossing						
Not everyday	1.00	1.00	1.00	1.00	1.00	1.00
Once a day or more	1.15 [1.01-1.32]*	1.25 [1.05-1.49]*	1.04 [0.69-1.55]	0.82 [0.52-1.28]	1.19 [1.04-1.38]*	1.28 [1.07-1.55]*

(Continues)

TABLE 3 (Continued)

Risk indicator	Root caries measurement Root DFS prevalence PR [95% CI]	Root DFS MR [95% CI]	Root DS prevalence PR [95% CI]	Root DS MR [95% CI]	Root FS prevalence PR [95% CI]	Root FS MR [95% CI]
Dental visiting						
Last visit ≥1 y ago	1.00	1.00	1.00	1.00	1.00	1.00
Last visit <1 y ago	1.26 [1.08-1.46]*	1.28 [1.05-1.56]*	0.97 [0.69-1.38]	0.74 [0.45-1.23]	1.43 [1.20-1.70]*	1.46 [1.17-1.83]*
Smoking[a]						
Never smoked	1.00	1.00	1.00	1.00	1.00	1.00
Currently smoke or used to smoke	1.27 [1.12-1.45]*	1.48 [1.26-1.75]*	1.89 [1.33-2.67]*	2.29 [1.45-3.64]*	1.23 [1.07-1.41]*	1.40 [1.17-1.67]*

CI, 95% confidence interval; DFS, decayed filled surfaces; DS, decayed surfaces; FS, filled surfaces; MR, mean ratio; PR, prevalence ratio.
[a]Number of surfaces with gingival recession (ref. No gingival recession).
*Significant; Log Poison Regression model.

Age is considered to be an important predisposing condition for the prevalence and the severity of root caries.[23,24] Among general adults, older age was associated with a higher root caries. However, after adjusting for the number of surfaces with gingival recession, age was not significant in one of the models (root DS model), probably as number of surfaces with gingival recession was also associated with age. Smoking and number of surfaces with gingival recession remain associated with higher prevalence and severity of root caries in all models.

The finding that smoking and older age was associated with higher root caries experience is consistent with the results of other studies.[9,23-25] The increase in root caries in smokers and older adults could partly be explained by effect of smoking and age on gingival recession. Gingival recession increases across age[19-21,26-28] as sites of periodontal tissue destruction accumulate. There is a greater frequency of gingival recession in smokers than nonsmokers.[27,29] The oxygen concentration in healthy gingival tissues appears to be lower in smokers than in nonsmokers, influencing the inflammatory process and occurrence of gingival recession.[30] The greater frequency of gingival recession leads to increased root caries as more root surfaces are exposed to oral environment and are at risk of developing root caries.

However, this study showed that even after adjustment with the number of surfaces with gingival recession, smoking was still associated with higher root caries experience. Previous research[31] has pointed out that smoking was related to an elevated level of *mutans streptococci* and *lactobacilli* in saliva, which are associated with the initiation and progression of dental caries. Moreover, smoking also contributes to a lower buffering capacity of saliva,[32] which is a protective factor against coronal caries. These explanations could also be relevant to root caries helping explain the association between smoking and root caries even after adjustment for the number of surfaces with gingival recession.

In this study, we report root caries as decayed root surfaces, filled root surfaces and decayed filled root surfaces, following WHO recommendation for international comparison, instead of using Root Caries Index.[18,33] This approach allowed for analytical techniques commonly used for coronal dental caries. Furthermore, we controlled for the number of sites with gingival recession in the multivariable analysis. We found that the number of gingival recession was significantly associated with root caries in all models. It was evident that this approach was more appropriate for our objective than using Root Caries Index.

Higher socio-economic position was associated with a lower severity of root DS, both among general and older Australian adults. Root caries experience is socially patterned; people in a lower socio-economic position bear more of the root caries burden. This finding was also consistent with a previous reported study.[34] Socio-economic position is associated with less healthy behaviours and more limited access to dental services, either treatment or preventive services. A combination of these factors could increase the risk of having more untreated root caries lesions.

Oral hygiene, significantly associated with all measurements for root caries in the bivariate analysis, was only significantly associated with untreated decayed root surfaces in the multivariable analysis. Good oral hygiene and more frequent tooth brushing are associated with lower root caries experience presented as decayed root surfaces only, supporting a previous study.[35] As tooth brushing could mechanically remove plaque, and fluoridated toothpaste used in tooth brushing could assist in altering the balance between demineralisation and remineralisation, tooth brushing has a preventive effect of root caries.

General adults and older adults who lived in a nonmetropolitan area had a lower mean root FS and DFS but higher root DS than those who lived in a metropolitan area (even some of them are not significant). This finding shows that people living in nonmetropolitan area tend to receive less dental treatment compared to their counterpart living in metropolitan areas. This finding supports a previous reported study showing that people living in nonmetropolitan area are less likely reported using dental services in the previous 12 months.[36] Older adults with gingivitis were found to have lower mean number of root DFS and root FS, probably related to their lower dental visiting status as well.

Moreover, more frequent flossing and dental visiting showed a relation to higher adults' root caries experience presented as root FS

TABLE 4 Multivariable analysis of root caries in the older adults group (n=1557)

Risk indicator	Root caries measurement in the older adults group (60+ yo) Root DFS prevalence PR [95% CI]	Root DFS MR [95% CI]	Root DS prevalence PR [95% CI]	Root DS MR [95% CI]	Root FS prevalence PR [95% CI]	Root FS MR [95% CI]
Socio-demographic						
Sex						
Male	1.00	1.00	1.00	1.00	1.00	1.00
Female	0.90 [0.77-1.05]	0.95 [0.75-1.21]	0.71 [0.45-1.13]	0.71 [0.42-1.22]	0.93 [0.79-1.10]	0.98 [0.76-1.27]
Residential place						
Metropolitan area	1.00	1.00	1.00	1.00	1.00	1.00
Nonmetropolitan area	0.99 [0.85-1.15]	0.73 [0.59-0.90]*	1.06 [0.67-1.67]	1.00 [0.52-1.90]	0.92 [0.78-1.08]	0.70 [0.56-0.86]*
Socio-economic						
Highest school/tertiary qualification						
Senior high school or less	1.00	1.00	1.00	1.00	1.00	1.00
Trade	1.02 [0.86-1.23]	1.02 [0.81-1.29]	0.68 [0.41-1.11]	0.77 [0.42-1.43]	1.08 [0.89-1.32]	1.06 [0.83-1.36]
University or higher	0.98 [0.82-1.16]	1.08 [0.80-1.47]	0.87 [0.48-1.58]	1.90 [0.67-5.39]	1.01 [0.84-1.21]	1.02 [0.77-1.35]
Income*						
<$40 000	1.00	1.00	1.00	1.00	1.00	1.00
$40 000-$80 000	1.12 [0.93-1.34]	0.95 [0.74-1.22]	0.76 [0.42-1.38]	0.42 [0.20-0.90]*	1.18 [0.97-1.42]	1.02 [0.79-1.32]
>$80 000	1.00 [0.77-1.31]	1.00 [0.57-1.74]	0.47 [0.12-1.86]	0.17 [0.04-0.69]*	0.99 [0.75-1.31]	1.14 [0.66-1.97]
Clinical conditions						
Oral hygiene*						
Good oral hygiene	1.00	1.00	1.00	1.00	1.00	1.00
Poor oral hygiene	1.12 [0.96-1.30]	1.09 [0.86-1.38]	1.55 [1.02-2.36]*	2.07 [1.21-3.54]*	1.05 [0.88-1.25]	0.98 [0.76-1.27]
Gingival status						
No gingivitis	1.00	1.00	1.00	1.00	1.00	1.00
Gingivitis	0.89 [0.76-1.05]	0.68 [0.53-0.86]*	1.31 [0.75-2.29]	1.24 [0.61-2.53]	0.84 [0.70-1.01]	0.64 [0.49-0.82]*
Exposed root surfaces[a]	1.01 [1.01-1.01]*	1.02 [1.02-1.02]*	1.01 [1.00-1.01]*	1.01 [1.00-1.02]*	1.01 [1.01-1.01]*	1.02 [1.02-1.03]*
Oral health behaviours						
Frequency of brushing						
Less than twice a day	1.00	1.00	1.00	1.00	1.00	1.00
Twice a day or more	1.05 [0.92-1.20]	0.97 [0.77-1.21]	0.76 [0.50-1.16]	0.54 [0.31-0.94]*	1.10 [0.95-1.27]	1.07 [0.85-1.35]
Frequency of flossing						
Not everyday	1.00	1.00	1.00	1.00	1.00	1.00
Once a day or more	1.08 [0.94-1.25]	1.19 [0.93-1.51]	0.80 [0.47-1.39]	0.74 [0.38-1.45]	1.14 [0.98-1.33]	1.21 [0.94-1.56]
Dental visiting						
Last visit ≥1 y ago	1.00	1.00	1.00	1.00	1.00	1.00
Last visit <1 y ago	1.25 [1.05-1.49]*	1.54 [1.18-2.02]*	0.93 [0.61-1.42]	0.55 [0.30-0.99]*	1.41 [1.15-1.73]*	1.92 [1.45-2.53]*
Smoking*						
Never smoked	1.00	1.00	1.00	1.00	1.00	1.00
Currently smoke or used to smoke	1.15 [0.99-1.33]	1.39 [1.11-1.73]*	1.97 [1.20-3.22]*	2.29 [1.18-4.47]*	1.10 [0.95-1.28]	1.32 [1.05-1.66]*

[a]Number of surfaces with gingival recession (ref. No gingival recession).

*significant; Log Poison Regression model.

CI, 95% confidence interval; DFS, decayed filled surfaces; DS, decayed surfaces; FS, filled surfaces; MR, mean ratio; PR, prevalence ratio.

and DFS, while only dental visiting showed a relation to higher root FS and DFS among older adults. The possible explanation for the positive association between flossing frequency and root FS or root DFS is due to increase attention in healthy behaviour among sick people. In this case, people with root caries fillings understand that they have the disease and probably this leads them to do more frequent flossing as an additional tooth cleaning strategy. This flossing strategy could also be recommended by the dentist. Thus, in this case, the increase in root FS and root DFS probably is not the outcome, but the cause of the increase in flossing frequency. Among older adults, this behaviour was not significant as older adults were known to have reduced natural teeth than adults. In terms of the positive association between dental visiting pattern and root FS and DFS among adults and older adults, it is understandable that the purpose of dental visits is most likely dental treatment, and less likely prevention. Therefore, those who visited a dentist would obviously have a worse oral health report, including root caries experience. As this study did not differentiate between caries-related and non-caries-related root restorations, it is also possible that more frequent visiting is associated with more fillings placed for root caries and other lesions on root surfaces like cervical abrasion. Alternatively, the dentist may recommend more frequent visiting for those with root caries.

5 | CONCLUSIONS

This first detailed population-based study has reported that root caries affected a significant proportion of Australian adults. Preventive efforts should focus on targeting health behaviours, especially among disadvantaged population groups.

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5 Chapter 5: Systematic review with meta-analysis and meta-regression study

5.1 Linkage of the Chapter to the body of research:

This Chapter addresses Aim 2 of this research. It provides a systematic review and meta-analysis of longitudinal studies of root caries worldwide. It gives estimates of root caries incidence and increment from published articles around the world, and analyses the possible source of their heterogeneity. This Chapter explores the diversity of root caries research in relation to a population under study, root caries measurements, as well as the way researchers reported root caries data. As the earlier research in the same subject area only gathered evidence from either the shorter or longer longitudinal studies available, here all the longitudinal studies were collected and the influence of the study length on root caries estimates is evaluated.

5.2 Highlight

- This research found that root caries was a problem worldwide with significant progression annually.
- For all included studies, the annualised root caries incidence and increment were 18.25% [CI=13.22%-23-28%] and 0.45 [CI=0.37-0.53] root DFS respectively. However, this analysis revealed significant heterogeneity across the studies.
- The annual root DFS incidence and increment from studies with less than 2 years follow-up were 32.95% and 0.64 root surfaces respectively, while in the studies with longer than 5 years of follow-up, the cumulative annual root caries incidence and increment were 9.4% and 0.43 root surfaces respectively.
- Many factors influence the heterogeneity across root caries studies, including differences in the way researchers presented root caries data and the population of interest.
- The estimated result should be interpreted with caution.

5.3 Future research direction

Future root caries research should adopt similar methods, both in collecting and presenting root caries data, to get the most advantage of pooled disease estimates from future meta-analyses.

5.4 Statement of authorship (systematic review with meta-analysis and meta-regression)

Statement of Authorship

Title of Paper	Root Caries Incidence and Increment in the Population – A systematic review and meta-analysis of longitudinal studies
Publication Status	☐ Published ☐ Accepted for Publication ☑ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Hariyani N, Setyowati D, Spencer J, Luzzi L, Do LG. Root Caries Incidence and Increment in the Population – A systematic review and meta-analysis of longitudinal studies. Journal of Dentistry. 2018.

Principal Author

Name of Principal Author (Candidate)	Ninuk Hariyani		
Contribution to the Paper	Initial conceptualization, preparing data searching, conducting study selection, quality assessment, data extraction and adjustment, performing the analysis, presenting and discussing findings and writing the manuscript		
Overall percentage (%)	85%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	27-02-2018

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Dini Setyowati		
Contribution to the Paper	Conducting study selection, quality assessment, data extraction and adjustment		
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Name of Co-Author	A. John Spencer		
Contribution to the Paper	Provided intellectual contribution and revised the manuscript		
Signature		Date	27-02-2018
Name of Co-Author	Liana Luzzi		
Contribution to the Paper	Provided intellectual contribution and revised the manuscript		
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Name of Co-Author	Loc Giang Do		
Contribution to the Paper	Supervised the data analysis and interpretation. Provided intellectual contribution and revised the manuscript		
Signature		Date	27-02-2018

5.5 Result of the systematic review with meta-analysis and meta-regression

ABSTRACT

Objectives: Previous meta-analyses of root caries incidence and increment studies reported different estimates due to the limited number of studies, heterogeneity and variations in studies included. Currently, new publications and approaches to handle heterogeneity are available. This research aims to systematically review and meta-analyse root caries incidence and increment, and use meta-regression to analyse heterogeneity.

Sources: PUBMED and EMBASE databases were searched systematically.

Study selection: Longitudinal studies on root caries incidence and increment, published in the English language prior to 2017, were independently checked by two authors. A pooled incidence and increment of decayed/filled root surfaces (DFS) was estimated and meta-regression analysis was performed by length of follow-up (<2 years; 2 years; 3-4 years and 5+ years) and study type (observational population-based and clinical trial).

Data: Of 737 articles, 20 were included for meta-analysis. The annualised root caries incidence and increment were 18.25%[CI=13.22%-23.28%] and 0.45[CI=0.37-0.53] root DFS respectively. Length of follow-up influenced the estimates, but not the study type. The annual root DFS incidence and increment from studies <2 years were 32.95%[CI=29.13%-36.77%] and 0.64[CI=0.38-0.89] root surfaces respectively. Studies with 5+ years follow-up, the annualised root caries incidence and increment were 9.4%[CI=3.32%-15.48%] and 0.43[CI=0.21-0.64] root surfaces respectively.

Conclusions: Length of follow-up influenced root caries estimates due to a bias towards relatively healthier older adults retained in the study. Root caries increased over time even among the healthier older adults.

Clinical significance: The increase in root caries, even among the healthier older adults, should be considered by both clinicians and healthcare planners/policy makers in their provision of services.

Key words: root caries; incidence; increment; systematic review; meta-analysis; meta-regression

INTRODUCTION

Root caries has received more attention in the last two decades due to research showing the high prevalence of root caries in populations (Banting, 1984). With the increase in life expectancy and the increase in natural teeth retained among older adults, root caries has been predicted to become a significant public health problem (Bansal et al., 2011).

Root caries reported around the world is varied with root caries prevalence varying from 9.8% (Locker and Leake, 1993) to 71% (Kim et al., 2012), while the incidence and increment of root caries vary from 12.4% (Fure, 2004) to 77% (Powell et al., 1998) and 0.3 (Locker, 1996) to 4.4 (Powell et al., 1998) on root surfaces respectively. Some reviews conducted in the 1980s concluded that those variations were caused by a lack of consistency of reporting among the studies undertaken and the wide spectrum of population groups investigated (Banting, 1986).

Meta-analysis is regarded as an approach that provides a high level of evidence from a body of studies (Haidich, 2010). Meta-analyses are ideally a subset of systematic reviews (Haidich, 2010). A systematic review attempts to collate empirical evidence that fits eligibility criteria to answer a specific research question (Haidich, 2010). Meta-analysis obtains a weighted average of results from various studies, and in addition to pooling effect sizes, meta-analysis can also be used to estimate disease frequencies, such as incidence and prevalence (Barendregt et al., 2013). However, combining studies that differ substantially in design and other factors can yield a meaningless summary result (Haidich, 2010). In this case, the evaluation of reasons for the heterogeneity among studies can be insightful. Examination of heterogeneity is an important task in meta-analysis (Haidich, 2010). Meta-regression is a mechanism to analyse heterogeneity in a meta-analysis; it allows the evaluation of the impact of covariates on the pooled estimate (Petticrew and Roberts, 2008). Considering that root caries studies differ in design and other features, meta-analysis of root caries studies should be accompanied with a mechanism to assess heterogeneity such as meta-regression and the results should be interpreted with caution.

There are two systematic reviews with a meta-analysis of root caries incidence and increment, pooling the effect estimates of decayed and/or filled root surfaces (root DFS) (Griffin et al., 2004; Leake, 2001). The estimates achieved were markedly different mainly due to differences in the length of follow-up in the included studies. The first meta-analysis, which gathered evidence from available longer longitudinal studies, revealed an incidence of 8.2% annually (Leake, 2001) while the second meta-analysis, which gathered evidence from shorter longitudinal studies, revealed an incidence of 23.7% annually (Griffin et al., 2004). The second meta-analysis claimed its estimate was better as the shorter the study, the lower the attrition of study participants.

However, even after the application of length of follow-up time criteria, the included studies were quite varied in length. The first analysis, which stated that it gathered evidence from the longer longitudinal studies, actually gathered its estimates from studies varying from three to five years in follow-up time (Leake, 2001). The studies used by the second analysis, which included the shorter longitudinal studies, varied from one to five years in follow-up time (Griffin et al., 2004).

Furthermore, both meta-analyses included studies with observational population-based and clinical trial designs when pooling the estimate of root caries in the population. Different study designs may impact on the population root caries estimate. The sampling for a clinical trial is built around the aim of measuring the efficacy of a preventive regimen under optimal circumstances in the trial and may involve a convenience sample. Observational population-based studies may be based on a probability sample.

In the more recent meta-analysis (Griffin et al., 2004), possible sources of heterogeneity were identified (including the study length but not the type of study), but have not been factored into the analysis through a meta-regression. Baseline age was presented as the only contributing factor for the heterogeneity in root caries incidence.

In addition to these methodological issues new studies are available to be included in a contemporary meta-analysis (Ritter et al., 2016; Sugihara et al., 2014).

Considering the shortage of studies in this field and the limitations of the previous analyses, we performed a systematic review and a quantitative meta-analysis and meta-regression of root caries incidence and increment. The research questions were:

1. What are the estimates of the root caries incidence and increment at the population level around the world?
2. Are there any differences in the estimation of the root caries incidence and increments according to the length and types of studies?
3. What are some possible sources of heterogeneity among root caries studies around the world?

MATERIALS AND METHODS

Search strategy

For the systematic review, all step-by-step procedures followed the recommendations by PRISMA (Moher et al., 2009). The authors searched PUBMED and EMBASE databases as sources for studies. PUBMED and EMBASE databases were chosen as they are major biomedical and pharmaceutical databases (Griffin et al., 2004). The search terms used were root caries and increment/incidence. The search strategies are presented in Appendix 1. The inclusion criterion was all articles published in the English language prior to 2017. Articles would be included if they contained information sought in the keyword of the search and were community-based or clinical trial research. All root caries measurements were included.

Study selection

Firstly, duplicate references were removed using EndNote X7.3 software. Effort was made to track the relevant citations from reviews to make sure that there were no studies missing from the search result. Two independent investigators then screened all citations (titles and abstracts) to exclude articles which were not relevant. In case of disagreement regarding eligibility, a third reviewer's opinion was sought for further discussion and a decision was made by consensus. The full texts of included citations were downloaded. Articles that were not found electronically were requested from the authors. During the full text reading, generally, articles were included if they addressed the question and presented the data so that it could be abstracted. Articles were excluded if upon closer reading they did not address the question or we could not abstract the sought data.

Data extraction

Data were extracted from the articles using a pre-defined spread-sheet by two reviewers independently. Initially, all information such as authors, year of publication, country of the study, population being studied, the case criteria used for measurement and sample size were extracted. The synthesis also included age at baseline, follow-up period, as well as root caries incidence or increments together with its variance (standard deviation or standard error) in all kinds of root caries measurements. The root caries estimates from clinical trial studies were taken from the control group or both from control and treatment groups if root caries estimates were found to be not statistically different between the groups ($p \geq 0.05$). The results were extracted and compiled into evidence Tables. Research that was reported in more than one article was retained only if it was reported on a different length of follow-up for the study. If research on the same length of follow-up was reported in more than one article, the one with the more complete data was retained for the meta-analysis.

Sources of heterogeneity included the population's baseline age, some study design characteristics (length of study (<2 years; 2 years; 3-4 years and 5+years), type of study (population-based study vs clinical trial study), source of participants (random vs volunteer), and root caries data adjustment (crude vs adjusted/net)) and clinical condition at baseline (the number of decayed and filled root surfaces, mean number of exposed root surfaces and mean number of teeth at baseline) were also recorded. For some articles that did not include this information, further searching from related study articles was done to get the information.

Methodological quality

The results of the quality assessment are presented as follows. Two independent reviewers have assessed the quality of the articles using a standardised critical appraisal instruments called 'Meta-Analysis of Statistics Assessment and Review Instrument' [(MAStARI), Appendix 2] as recommended by Joanna Briggs Institute (The Joanna Briggs Institute, 2014) and any disagreements were resolved through consensual decisions. This standard appraisal is a checklist of nine items in which the reviewer checks a 'Yes'/'No' or 'Unclear' for each item which helps to classify studies for quality by calculating the number of 'Yes' answers. Thus, for the nine items used to assess each study, a score of 0-9 was obtained for each study and the studies were then categorised as low quality (0-3), medium quality (4-6) or high quality (7-9) (Peres et al., 2015)[18]. All articles from the final search were included in the meta-analysis regardless their methodological qualities, to broaden the evidence capture. However, the results of the quality assessment are presented.

Data adjustment procedures

Methods for data adjustment followed those used by Griffin et al. (Griffin et al., 2004). When possible, the crude estimate was chosen. For studies reporting caries incidence and increment for a period greater than one year, it was assumed that the root caries cases were identically distributed for each year. For some studies, the incidence and increment of all the study population could be directly extracted from the article. However, in other studies, the incidence and increment were reported for separate groups. For these studies, the incidence and increment for the study population was estimated by taking the weighted average of the reported results for the separate groups. The associated standard error was calculated using the following formula:

$$SE\ in\ all\ study\ population\ in\ the\ interval\ study = \sqrt{\frac{N1 * (SE\ group\ 1)^2 + N2 * (SE\ group\ 2)^2}{N1 + N2}}$$

To estimate the annual incidence, firstly the probability that no disease occurred during the study interval was estimated. The nth root of this value (where n represents number of years in the study) was then used to calculate the probability that no disease occurred in a given year. Finally, the annual incidence was estimated by subtracting the value from 1. To estimate the annual standard error, this formula was used:

$$annual\ SE\ incidence = \sqrt{\frac{incidence * (1 - incidence)}{N}}$$

To estimate the annual increment, the increment reported for the study was divided by the years of follow-up of the study. The annual standard error was estimated by dividing the standard error reported in the study with the square root of the years of follow-up of the study.

Possible sources of heterogeneity

Several possible sources of heterogeneity were checked. They included the length of the study (<2 years; 2 years; 3-4 years and 5+years), type of study (population-based study vs clinical trial study), source of participants (random vs volunteer), root caries data adjustment (crude vs adjusted/net), the age of participants at baseline and some clinical conditions at baseline oral examination (mean number of root DFS, mean number of exposed root surfaces, and mean number of teeth). This information could be taken from the incidence or increment studies included in the meta-analysis or their associated published baseline articles.

Meta-analysis and meta-regression procedures

Meta-analysis and meta-regression were conducted using Stata 13.0 software (StataCorp., College Station, TX, USA). In the case of heterogeneity (chi-square P-value<0.05 or I2>50%), a random-effect model was preferred. Additionally, meta-regression and sub-group analyses were performed to identify possible sources of heterogeneity between studies. Initially, univariate analysis was performed, and all related variables ($P \leq 0.20$) in the univariate analysis were included in the final multivariable meta-regression model. Only variables with $P < 0.05$ in the final model were considered statistically significant.

RESULTS

The initial search yielded 519 articles from PUBMED and 218 articles from EMBASE. Some 183 articles (24.83%) were excluded due to duplication and 45 articles were excluded due to non-English language (6%). A further 470 articles were excluded after abstract reading (63.8%) based on the inclusion criteria. Details of the search flowchart are presented in Figure 5.1. In total, 41 articles were included for full text reading, and in the end 20 articles were included in the meta-analysis.

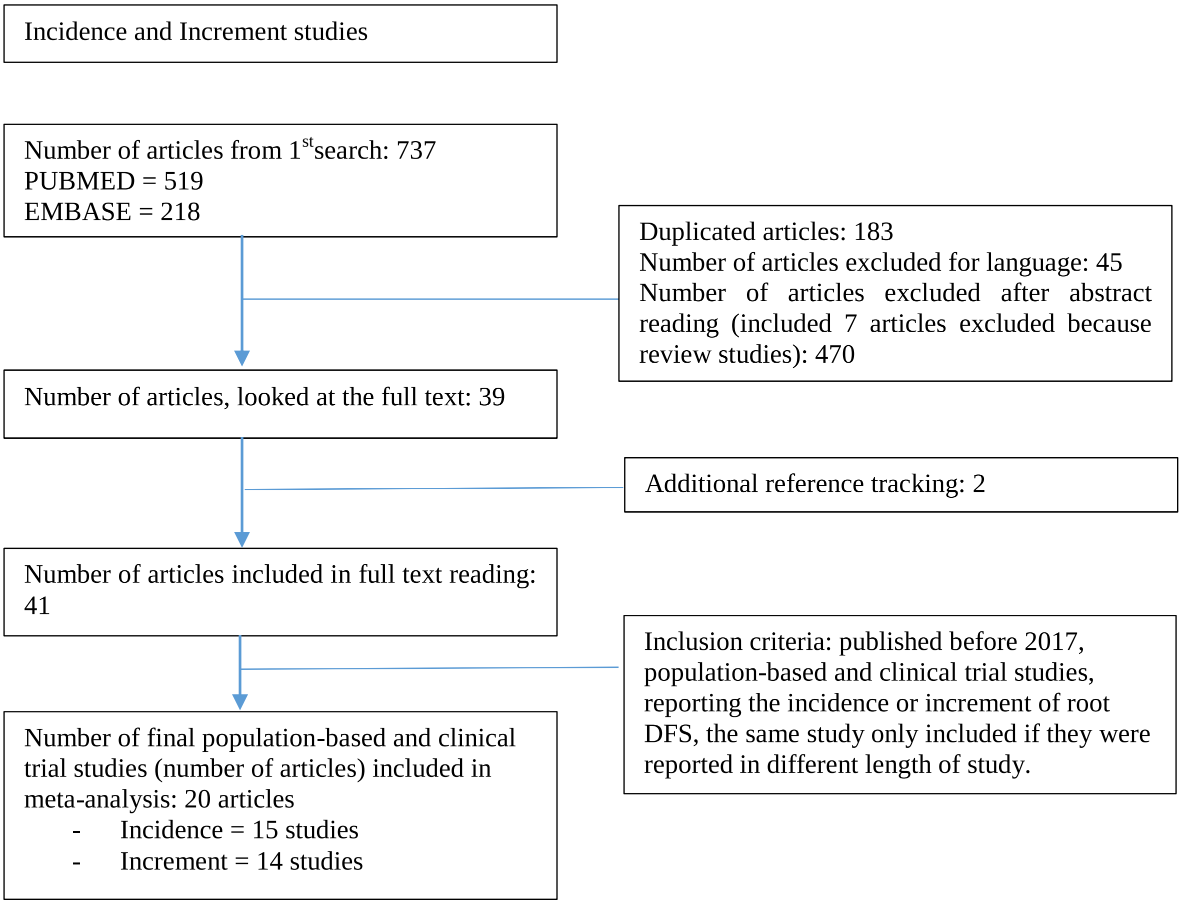

Figure 5-1 Flow charts of searching

During the systematic review (Appendices 3 and 4), it was found that the overall quality of evidence applying the JBI-MAStARI approach was medium for all studies included in the meta-analyses. All studies were conducted in high-income countries, including Australia, Sweden, Japan and the USA. Four studies were reported in more than one article with a different length of follow-up in the studies. The most recent study of root caries incidence in the United States across multiple centres reported incidence of root caries measured using ICDAS II (Ritter et al., 2016). However, the criteria used for non-cavitated, cavitated and other root caries lesions applied in this study were reasonably similar to the criteria applied in other studies of root caries (including colour and tactile criteria), thus this study was included in the meta-analysis.

Figures 5.2 and 5.3 show sub-analysis of the pooled incidence and increment according to the lengths of the follow-up in the included studies respectively. For all included studies, the annualised root caries incidence and increment were 18.25% [CI=13.22%-23-28%] and 0.45 [CI=0.37-0.53] root DFS respectively. This analysis revealed significant heterogeneity across the studies. Length of follow-up time influenced the estimates. The annual root DFS incidence and increment from studies with less than 2 years follow-up were 32.95% [CI=29.13%-36.77%] and 0.64 [CI=0.38-0.89] root surfaces respectively. In the studies with 5+ years follow-up, the cumulative annualised root caries incidence and increment were 9.4% [CI=3.32%-15.48%] and 0.43 [CI=0.21-0.64] root surfaces respectively. Figures 5.4 and 5.5 show the sub-analysis of the pooled incidence and increment according to the study type respectively. The type of study (population-based vs clinical trial) did not influence the estimates.

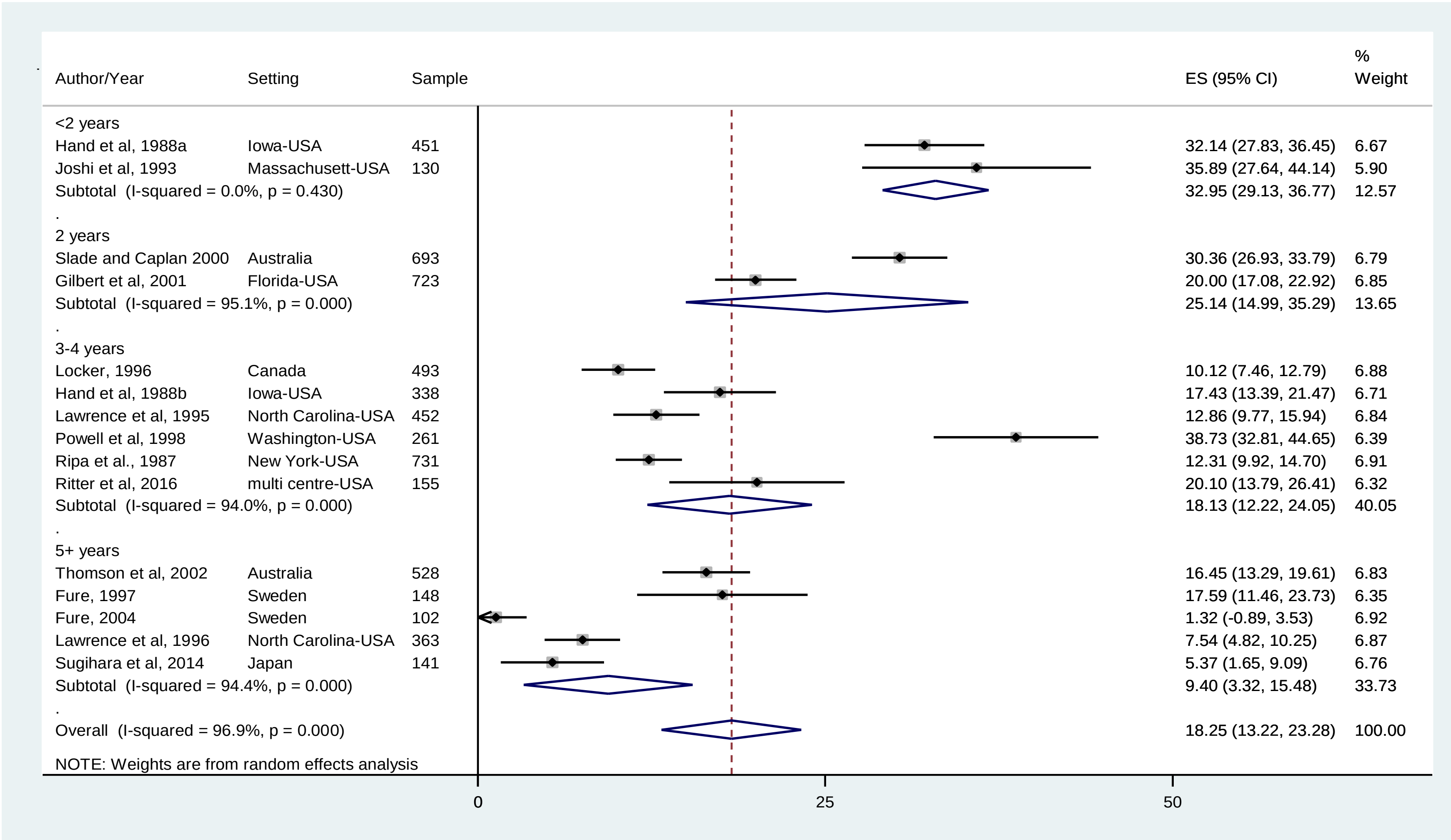

Figure 5-2 Annual root caries incidence and 95% confidence interval by length of study

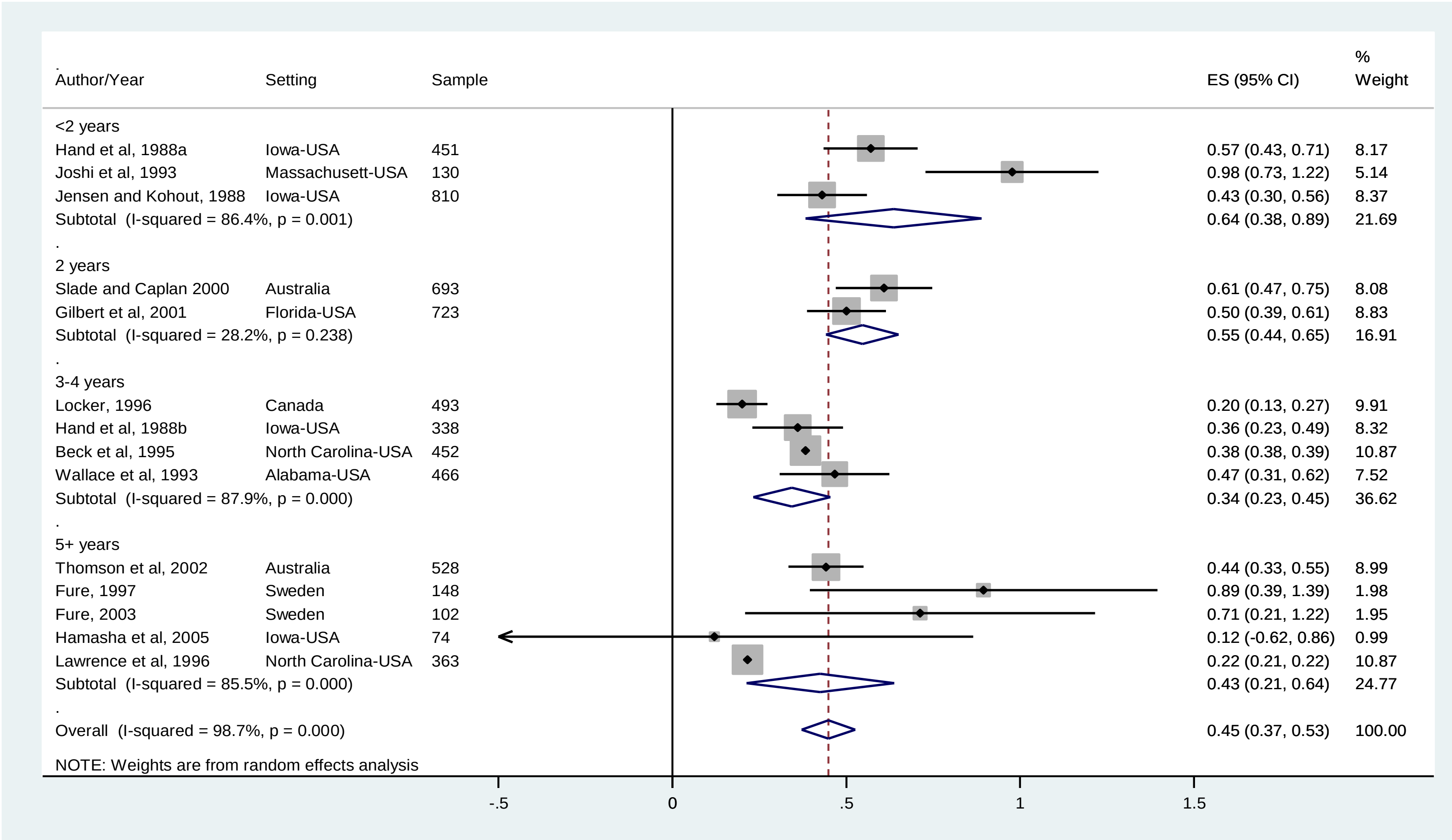

Figure 5-3 Annual root caries increment and 95% confidence interval by length of study

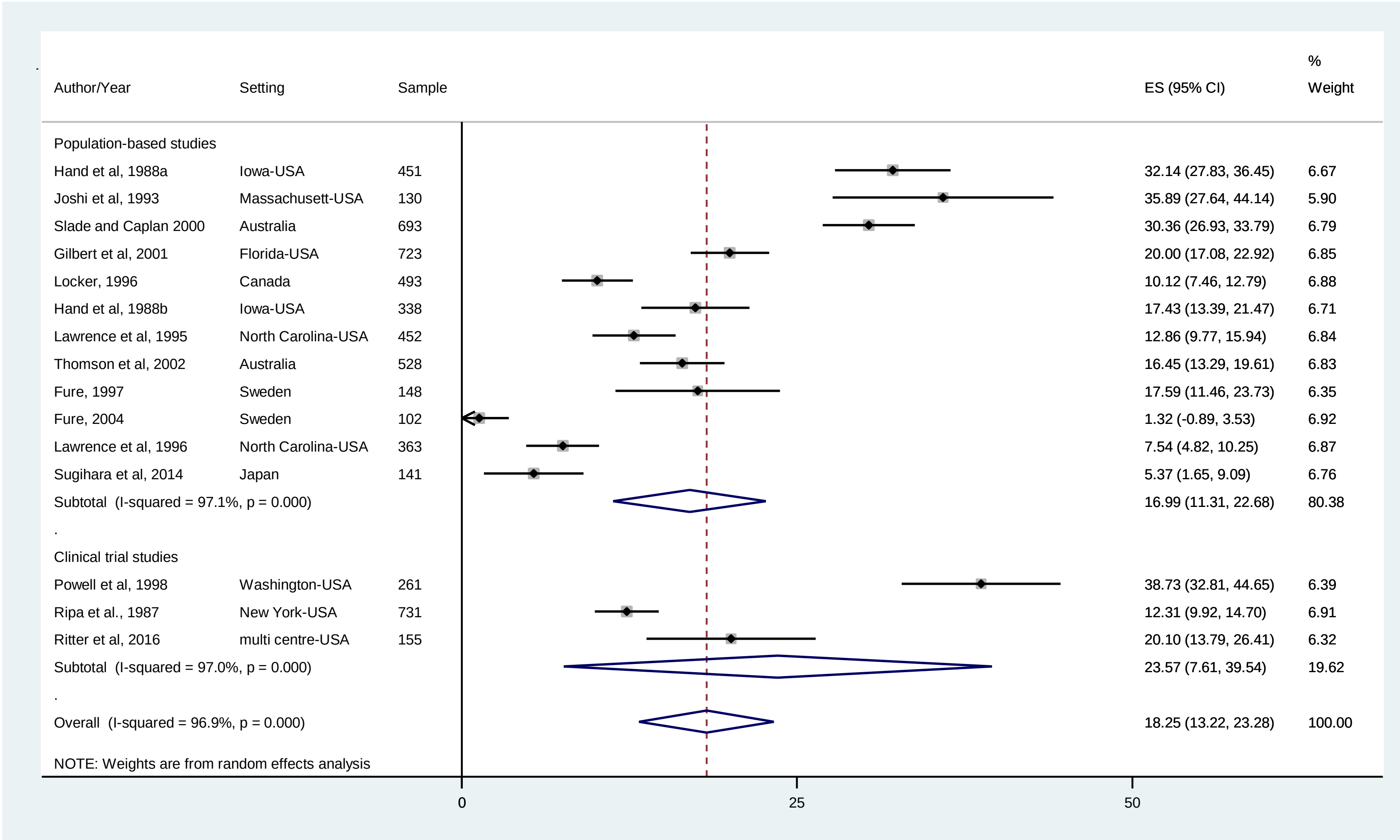

Figure 5-4 Annual root caries incidence and 95% confidence interval by type of study

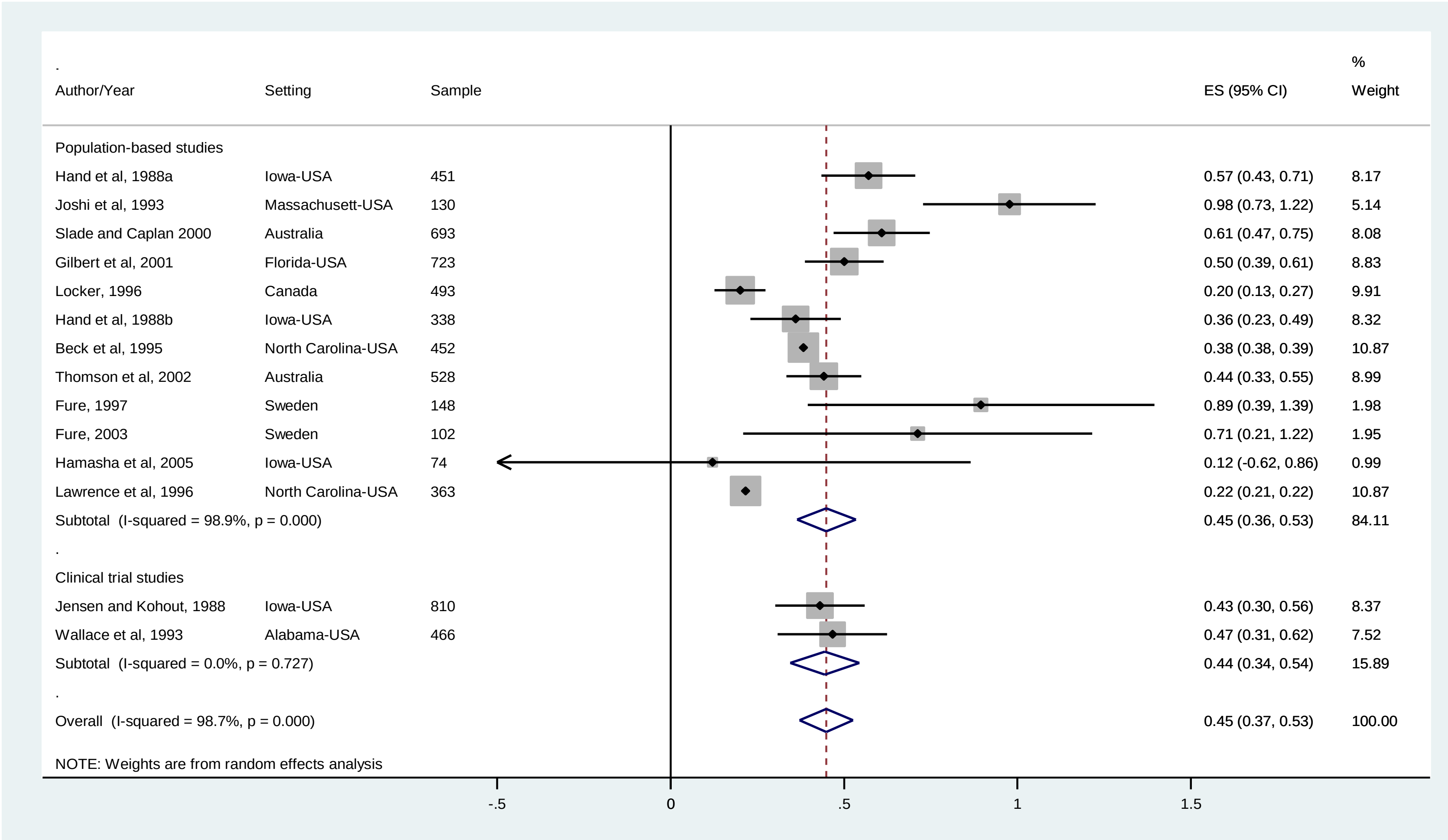

Figure 5-5 Annual root caries increment and 95% confidence interval by type of study

Table 5.1 presents the analysis of the meta-regression. During the univariate analysis, the variance of the root caries incidence estimate was explained by the length of the follow-up in the study (44.08%), baseline age (22.12%) and baseline root DFS (24.80%) respectively, while the variance of the root caries increment was explained by the length of the follow-up in the study (20.24%), root caries data adjustment (13.80%), source of participants (10.75%), baseline root DFS (2.83%) and number of exposed root surfaces (39.32%) respectively. In the multivariable analysis, all variables were not significant as the number of included studies reduced from 15 to 7 and 14 to 10 in the meta-analysis of root caries incidence and increment respectively.

Table 5.1 Association between study variables and estimated incidence and increment of root DFS

Variables	Root DFS incidence	Meta-regression			Root DFS increment	Meta-regression		
	%[CI]	Univariate P value	Adj R-squared	Multivariate P value	Mean[CI]	Univariate P value	Adj R-squared	Multivariate P value
Number of studies included (N)		15		7		14		10
Length of the studies								
<2 years	32.95[29.13-36.77]	reference	**44.08%**	reference	0.64[0.38-0.89]	reference	**20.24%**	reference
2 years	25.14[15.00-35.29]	0.34		0.21	0.55[0.44-0.65]	0.66		0.23
3-4 years	18.13[12.22-24.05]	**0.05**		0.12	0.34[0.23-0.45]	**0.07**		0.16
5+ years	9.4[3.32-15.48]	**0.007**		0.10	0.43[0.21-0.64]	**0.18**		0.03
Type of studies								
Population-based studies	16.99[11.31-22.68]	reference	0%	-	0.45[0.36-0.53]	reference	0%	-
Clinical trial studies	23.57[7.61-39.54]	0.40		-	0.44[0.34-0.54]	0.87		-
root caries data adjustment								
Crude	17.43[11.30-23.55]	reference	0%	-	0.56[0.42-0.71]	reference	**13.80%**	reference
Adjusted/net	20.51[13.21-27.81]	0.66		-	0.38[0.27-0.50]	**0.10**		0.23
Source of participants								
Random	16.50[10.40-22.59]	reference	0%	-	0.42[0.34-0.50]	reference	**10.75%**	reference
Not random	22.13[11.01-33.25]	0.39		-	0.69[0.16-1.23]	**0.15**		0.52
Age	-	**0.08**	**22.12%**	0.73	-	0.75	0%	-
Number of teeth	-	0.36	0%	-	-	0.44	0%	-
Baseline root DFS	-	**0.08**	**24.80%**	0.12	-	**0.18**	**2.83%**	0.07
Number of exposed root surfaces	-	0.99	0%	-	-	**0.04**	**39.32%**	0.12

DISCUSSION

This systematic review and meta-analysis demonstrated that the annual incidence and increment of the root caries were lower as the length of follow-up in a study increased. The annual root DFS incidence and increment from studies with less than 2 years follow-up were 32.95% and 0.64 root surfaces respectively while in the studies with longer than 5 years of follow-up, the cumulative annual root caries incidence and increment were 9.4% and 0.43 root surfaces respectively.

During the data extraction, it was recognised that root caries research differs in many facets. The population of interest among studies was different. Even after considering only the observational population-based and clinical trial studies, the way researchers presented root caries data varied. Root caries could be presented at the surface or tooth level as untreated root caries as well as treated or untreated root caries. Each of these measures could be presented in the root caries data adjustment process as the crude, adjusted or net incidence and increment. Some studies also chose to present root caries incidence and increment as a percentage of exposed root surfaces, expressing an attack rate corresponding to the root caries index introduced by Katz in 1980 (Katz, 1980). This diversity reduced the number of articles that could be pooled together if the strict inclusion criteria were applied. Furthermore, even in the population-based studies, the population of interest varied in relation to the baseline age or clinical characteristics of the study participants. Considering the diversity in root caries studies, the estimated root caries incidence and increments should be interpreted with caution.

In this analysis, we analysed the reports on root DF surfaces. When possible, the crude estimate was chosen for the analysis. Where the crude estimates were not presented, the preferred estimates were the adjusted estimates followed by the net estimates, following the recommendation made by Griffin et al. (Griffin et al., 2004). However, these differences in presenting the adjustment of root caries data (as crude, adjusted or net increments) result in a slightly different estimate of root caries (Griffin et al., 2004). Beck et al. (Beck, Lawrence and Koch, 1995) developed the adjusted caries estimate by multiplying the crude increment by the complement of the number of reversals divided by baseline frequency. They argued that when baseline caries prevalence increases, the probability of examiner reversals increases and the probability of examiner increments decreases. If Beck's adjustment was set as the gold standard, the deviation from the value was lower in the measurement using crude increment compared to the net increment. Beck et al. (Beck et al., 1995)[20] reported that compared to adjusted increment, crude root caries increment overestimated the value by 10% while the net root caries increment underestimate the value by 38%. Similarly, Slade and Caplan (Slade and Caplan, 2000) also reported an overestimated value of root caries by 21% when measured in crude increment compared to the adjusted increment, and an underestimated root caries value by 45% using the net increment.

The length of study follow-up was a source of heterogeneity in estimated root caries incidence and increment. About 44.08% and 20.24% study variance in root caries incidence and increment respectively, were explained by the length of follow-up in the study. The shorter durations seemed to reduce the sample bias due to attrition (Griffin et al., 2004), as people who drop out the study are usually the ones who tend to be ill (Hand, Hunt and Beck, 1988a) and develop more disease (Hand et al., 1988a; Lawrence et al., 1996). The longer studies may bias root caries results to relatively healthier elders, resembling a survivor bias. Providing the sub-analysis by length of follow-up, this study showed that root caries is still a problem even among healthier persons in studies of more than 5 years length.

Griffin et al. (Griffin et al., 2004) argued that a bias could also be caused by the annualisation of root caries incidence and increment by assuming that the outcomes measured were identically distributed for each year. However, many researchers (Griffin et al., 2004; Hand et al., 1988a; Hand, Hunt and Beck, 1988b) used this assumption, as there is insufficient research about the changes in the development of root caries year by year. Future research in this field could be of value in this area.

Further variance in estimates was explained by baseline age and baseline root DFS (22.12% and 24.80% respectively) for root caries incidence, and root caries data adjustment, source of participants, baseline root DFS and number of exposed roots (13.80%, 10.75%, 2.83% and 39.32% respectively) for root caries increment respectively. When considering all the variables in the multivariable model, the number of included articles reduced from 15 to 7 and 14 to 10 in the meta-analysis of root caries incidence and increment respectively as not all the included studies reported all the variables. All variables become non-significant in the multivariable analysis. This showed that the way researchers reported root caries studies differs, as well as showing the differences in the population of interest. Thus, there is still a need to perform root caries studies in a similar way. Future root caries research should address this issue to make the most of the advantage of pooled estimates of the disease.

CONCLUSION

Length of follow-up time is a factor influencing estimates of root caries incidence and increment. Longer follow-up was associated with lower estimates. This appeared to reflect a healthy participant or survivor bias. Root caries increased even among the healthier older adults.

Competing interests

The author(s) declare that they have no competing interests.

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Appendix 1.

SEARCH TERMS USED

Search terms in PUBMED:

‘root caries’ or ‘cervical caries’ or ‘root surface caries’	Progress* or Increment* or Incidence

((‘Root caries’ or ‘cervical caries’ or ‘root surface caries’)) and (progress* or increment* or incidence)

Results : 519

Search terms in EMBASE:

(Root or cervical) near/5 caries	Progress* or Increment* or Incidence

#1 and #2

Results : 218

Appendix 2.

JBI Critical Appraisal Checklist (MAStARI) for Cohort Studies

Reviewer : Date :

Author : Year: Record number :

	Answered with tick ☑ Question checklist	Yes	No	Unclear	Not Applicable
1	Is sample representative of people in the population as a whole?	☐	☐	☐	☐
2	Are the patients at a similar point in the course of their condition / illness?	☐	☐	☐	☐
3	Has bias been minimised in relation to selection of cases and of controls?	☐	☐	☐	☐
4	Are confounding factors identified and strategies to deal with them stated?	☐	☐	☐	☐
5	Are outcomes assessed using objective criteria?	☐	☐	☐	☐
6	Was follow up carried out over a sufficient time period?	☐	☐	☐	☐
7	Were the outcomes of people who withdrew described and included in the analysis?	☐	☐	☐	☐
8	Were outcomes measured in a reliable way?	☐	☐	☐	☐
9	Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal : no of 'Yes' (0–3): low quality ☐ (4-6): medium quality ☐ (7–9): high quality ☐

Include ☐ Exclude ☐ Seek further info ☐

Comments :

Appendix 3.

Details of included studies

Author/Year	Setting	Sample	Type of study	Length of study	RDFS annual incidence	RDFS annual SE incidence	RDFS incidence presentation	RDFS annual increment	RDFS annual SE increment	RDFS increment presentation
(Hand, Hunt and Beck, 1988a)	Iowa-USA	451	Population-based studies	<2 years	32.14%	2.20%	net	0.5700	0.0691	Net
(Joshi, Papas and Giunta, 1993)	Massachusetts-USA	130	Population-based studies	<2 years	35.89%	4.21%	crude	0.9762	0.1269	Crude
(Jensen and Kohout, 1988)	Iowa-USA	810	Clinical trial studies	<2 years	-	-	-	0.4300	0.0657	Crude
(Slade and Caplan, 2000)	Australia	693	Population-based studies	2 years	30.36%	1.75%	crude	0.6078	0.0707	Crude
(Gilbert et al., 2001)	Florida-USA	723	Population-based studies	2 years	20.00%	1.49%	adjusted	0.5000	0.0578	Adjusted
(Locker, 1996)	Canada	493	Population-based studies	3-4 years	10.12%	1.36%	crude	0.2000	0.0375	Net
(Hand, Hunt and Beck, 1988b)	Iowa-USA	338	Population-based studies	3-4 years	17.43%	2.06%	net	0.3600	0.0666	Net
(Lawrence, Hunt and Beck, 1995)	North Carolina-USA	452	Population-based studies	3-4 years	12.86%	1.57%	net	-	-	-
(Beck, Lawrence and Koch, 1995)	North Carolina-USA	452	Population-based studies	3-4 years	-	-	-	0.3828	0.0039	Crude
(Powell et al., 1998)	Washington-USA	261	Clinical trial studies	3-4 years	38.73%	3.02%	crude	-	-	-
(Ripa et al., 1987)	New York-USA	731	Clinical trial studies	3-4 years	12.31%	1.22%	crude	-	-	-
(Wallace, Retief and Bradley, 1993)	Alabama-USA	466	Clinical trial studies	3-4 years	-	-	-	0.4662	0.0803	Crude
(Ritter et al., 2016)	multi centre-USA	155	Clinical trial studies	3-4 years	20.10%	3.22%	crude	-	-	-
(Thomson et al., 2002)	Australia	528	Population-based studies	5+ years	16.45%	1.61%	crude	0.4420	0.0551	Adjusted
(Fure, 1997)	Sweden	148	Population-based studies	5+ years	17.59%	3.13%	crude	0.8945	0.2549	Crude
(Fure, 2003)	Sweden	102	Population-based studies	5+ years	-	-	-	0.7120	0.2568	Net
(Fure, 2004)	Sweden	102	Population-based studies	5+ years	1.32%	1.13%	crude	-	-	-
(Hamasha et al., 2005)	Iowa-USA	74	Population-based studies	5+ years	-	-	-	0.1200	0.3800	Net
(Lawrence et al., 1996)	North Carolina-USA	363	Population-based studies	5+ years	7.54%	1.39%	crude	0.2164	0.0039	Net
(Sugihara et al., 2014)	Japan	141	Population-based studies	5+ years	5.37%	1.9%	crude	0.12	-	Crude

[a] Received from the previous or baseline study

Appendix 3 (continued)

Details of included studies (continued)

Author/Year	Population	Source of sample	Important notes	Quality assessment	mean baseline age	baseline root DFS	no of teeth	no of exposed root surfaces
(Hand et al., 1988a)	Community dwelling older adults/ non-institutionalised older adults	Random	Teeth not dried, calculus not removed, no X-ray. All root restoration=filled caries,	6	71	2.35[a](Slade and Spencer, 1997)	18.8[a](Slade and Spencer, 1997)	29.83[a](Slade and Spencer, 1997)
(Joshi et al., 1993)	Healthy community dwelling resident	Volunteer	Third molar excluded, No X-ray	5	66.5	4.91	21.53	41.31
(Jensen and Kohout, 1988)	Non-fluoridated community dwelling	Volunteer	With X-ray	5	68.5	3.83	-	-
(Slade and Caplan, 2000)	Community dwelling	Random	Missing and crown not included, weighted	4	70.8	3.1	17.3	26.05
(Gilbert et al., 2001)	Elderly living in community	Random	All teeth including third molar, Weighted, No X-ray	6	61.5	-	22.0	-
(Locker, 1996)	community	Random	Third molar excluded, No X-ray	5	62.6[a](Locker and Leake, 1993)	3.6[a](Locker and Leake, 1993)	18.9[a](Locker and Leake, 1993)	-
(Hand et al., 1988b)	2 counties, Community dwelling older adults	Random	Different examiner	4	71	2.35	18.8	29.83
(Lawrence et al., 1995)	Non-institutionalised adults, Community dwelling	Random	Arrested caries were not scored, No X-ray, DF were Scored separately from cervical abrasion, All teeth including third molar, Missing was not counted	5	-	1.88	19.24	22.28
(Beck et al., 1995)	Community dwelling	Random	-	5	-	1.88	19.24	22.28
(Powell et al., 1998)	low income elderly	Volunteer	-	5	73	4.4	17.5	-
(Ripa et al., 1987)	Employee and spouses	Volunteer	-	5	53	-	14	-
(Wallace et al., 1993)	Non institutionalised adults	Random	-	5	67.3	3.6	23.5	46.1
(Ritter et al., 2016)	School clinic, community dental clinic and general community	Volunteer	Measured using ICDAS	5	52.42		-	16.99
(Thomson et al., 2002)	Community dwelling	Random	Missing and crown not included, weighted	5	69.42	3.17	17.24	26.05
(Fure, 1997)	Inhabitants	Random	With X-ray	5	62.23	-	19.43	64
(Fure, 2003)	Inhabitants	Random	With X-ray	6	62.23	-	21.8	64
(Fure, 2004)	Inhabitants, =elderly living in community	Random	With X-ray	5	62.23	-	21.8	64
(Hamasha et al., 2005)	Elderly living in community	Random	-	4	71	2.35	18.8	29.83
(Lawrence et al., 1996)	Community dwelling	Random	Arrested caries were not scored, categorise as sound. No X-ray, DF were Scored separately from cervical abrasion. Third molar included. Missing was not counted	6	-	2.3	20.2	21.5
(Sugihara et al., 2014)	Workers	Volunteer	Third molar excluded	4	-	0.55	27.3	3.38

[a] Received from the previous or baseline study

Appendix 4.

Details of excluded studies and the reason for exclusion

Title	Author/Year	Setting	Reason excluded	Other study related
Saliva, salivary micro-organisms, and oral health in the home-dwelling old elderly - A five-year longitudinal study	(Narhi, Kurki and Ainamo, 1999)	Helsinki-Finland	Outcome only root DS	
Prevalence and incidence of dental caries and related risk factors in 70- to 76-year-olds	(Johanson et al., 2009)	Sweden	Outcome only root DS	
A prediction model for root caries in an elderly population	(Sánchez-García et al., 2011)	Mexico	outcome only root DS	
Factors associated with root caries incidence in an elderly population	(Takano et al., 2003)	Japan	Outcome only root DS	
Incidence of tooth loss and dental caries in 60-, 70- and 80-year-old Swedish individuals	(Fure and Zickert, 1997)	Sweden	Has been reported in other study in more detail	Fure, 1997[15]
Five-year incidence of caries, salivary and microbial conditions in 60-, 70- and 80-year-old Swedish individuals	(Fure, 1998)	Sweden	Has been reported in other study in more detail	Fure, 1997[15]
Evaluation of a computer-based caries risk assessment program in an elderly group of individuals	(Hansel Petersson, Fure and Bratthall, 2003)	sweden	Has been reported in other study in more detail	Fure, 1997[15]
Tooth-surface-specific effects of xylitol: randomised trial results	(Ritter et al., 2013)	multi centre-USA	Has been reported in other study in more detail	Ritter et all, 2016[13]
Level of education and incidence of caries in the elderly: a 5-year follow-up study	(Siukosaari, Ainamo and Narhi, 2005)	Helsinki-Finland	Outcome only root DS, has been reported in other study in more detail	Narhi et al, 1999[23]
Three-year root caries increments: an analysis of teeth and surfaces at risk	(Leske and Ripa, 1989b)	New York-USA	Has been reported in other study in more detail	Ripa et al., 1987[11]
Three-year root caries increments: implications for clinical trials	(Leske and Ripa, 1989a)	New York-USA	Has been reported in other study in more detail	Ripa et al., 1987[11]
Incidence of root caries in older adults	(Wallace, Retief and Bradley, 1988)	Alabama	Has been reported in other study in more detail	Wallace et al, 1993[12]
The Dietary Approaches to Stop Hypertension Diet and New and Recurrent Root Caries Events in Men	(Kaye et al., 2015)	Boston, USA	Reported in tooth level	
Ten-year incidence of dental caries in adult and elderly Chinese	(Luan et al., 2000)	China	Reported in tooth level	
A 9-year longitudinal study of reported oral problems and dental and periodontal status in 70- and 79-year-old city cohorts in northern Sweden	(Nordstrom et al., 1998)	Sweden	Reported in tooth level, combined coronal and root caries	
A longitudinal study of the relationship between diet intake	(Yoshihara et al., 2009)	Japan	Reported in tooth level	

Title	Author/Year	Setting	Reason excluded	Other study related
and dental caries and periodontal disease in elderly Japanese subjects				
Comparison of a dentifrice containing 0.243% sodium fluoride, 0.3% triclosan, and 2.0% copolymer in a silica base, and a dentifrice containing 0.243% sodium fluoride in a silica base: a three-year clinical trial of root caries and dental crowns among adults	(Vered et al., 2009)	Israel	Not clear whether reported only D or DF, in surface or tooth level	
Effect of residence in a fluoridated community on the incidence of coronal and root caries in an older adult population	(Hunt, Eldredge and Beck, 1989)	Iowa	Has been reported in other study in more detail	Hand et al, 1988a(1)
Caries prevention in a community-dwelling older population	(Powell et al., 1999)	Washington-USA	Has been reported in other study in more detail	Powell et al, 1998(10)
Multifactorial modelling for root caries prediction	(Scheinin et al., 1992)	Finland	Root caries incident and increment values could not be extracted	
Multifactorial modelling for root caries prediction: 3-year follow-up results	(Scheinin et al., 1994)	Finland	Root caries incident and increment values could not be extracted	

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6 Chapter 6: Empirical study 2

6.1 Linkage of the Chapter to the body of research:

This Chapter addresses Aim 3 of this research. It provides an analysis of the four waves of South Australian Dental Longitudinal Study 1 data (SADLS1). It gives an estimation of root caries increment over 11-years of study among Australian older adults. The increment is an individual trend of root caries gathered through longitudinal data. The estimated increment was calculated using a multilevel longitudinal growth model. Time (in years) is used as a random factor in the model allowing for the modelling of variance between and within individuals. The intercepts are baseline root caries experience which is 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 changes. Further, the results also provide evidence of some oral health-related behaviours that are associated with the root caries increment.

6.2 Highlight

- This research found that root caries continued to increase even among healthier Australian older adults over 11-years of study.
- The annual increment of untreated root caries was 0.07 (SE=0.01) root surfaces, while treated or untreated root caries (root DFS) was 0.11 (SE=0.02) root surfaces.
- Irregular brushing, unfavorable dental visiting and tobacco smoking were risk factors for increasing untreated root caries, while irregular flossing and more frequent dental visit were associated with increased root DFS.

6.3 Future research direction

- Future research with more contemporary data adopting similar approach could be done to verify this finding.

- As this research found that root caries was an on-going problem within an individual even among healthier older adults, this research suggested that older adults still need to be targeted for root caries prevention programs.
- Prevention efforts should be focused on health behaviours.

6.4 Statement of authorship (empirical result 2)

Statement of Authorship

Title of Paper	Root surface caries among older Australians	
Publication Status	☐ Published ☑ Submitted for Publication	☐ Accepted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Hariyani N, Spencer J, Luzzi L, Do LG. Root surface caries among older Australians. Community Dentistry and Oral Epidemiology. 2017.	

Principal Author

Name of Principal Author (Candidate)	Ninuk Hariyani		
Contribution to the Paper	Initial conceptualization, preparing data request form, data preparation and analysis, presenting and discussing findings and writing the manuscript		
Overall percentage (%)	65%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	27-02-2018

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	A. John Spencer		
Contribution to the Paper	Provided intellectual contribution and revised the manuscript		
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Contribution to the Paper	Supervised the data analysis and interpretation. Provided intellectual contribution and revised the manuscript		
Signature		Date	27-02-2018

6.5 Empirical result 2

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 four oral examinations over 11-years and to examine behavioural factors associated with root caries.

***Methods**:* A secondary analysis was undertaken using data collected in four 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 four waves were included. The examinations were performed by trained and calibrated dentists. Baseline behavioural risk factors (tooth brushing frequency, flossing frequency, dental visiting pattern, reason for dental visiting and tobacco smoking status) and time in years across the four 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.

Key words: root caries, increment, older adults

INTRODUCTION

An increase in life expectancy and reduction in edentulousness among Australian adults have resulted in a substantial increase in the total number of natural teeth retained among Australian (Chalmers et al., 1999). 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 (Holm-Pedersen et al., 2005; Thomson et al., 2013).

Root caries is known to accumulate with age (Banting, 1984; Fure, 1997). 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 (Horowitz et al., 1975). 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 (Slade and Caplan, 1999). 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 three or more time points with two or more follow-up oral examinations (Fure, 2003; Hamasha et al., 2005; Lawrence et al., 1996; Thomson et al., 2002). Three or more time-points provides 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 (Joshi et al., 1994; Locker and Leake, 1993) and in incidence studies among the older adults (Locker, 1996; Phelan et al., 2004; Takano N, 2003). However, evidence on the relationship between behavioural factors and root caries is still conflicting and not all studies have confirmed the relationships (Beck, 1990; Beck, 1993; Ritter, Shugars and Bader, 2010). Moreover, the majority of longitudinal studies in root caries have been short-term research with 2- to 5-year periods of follow-up (Ritter et al., 2010).

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 (tooth brushing, 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.

MATERIALS AND METHODS

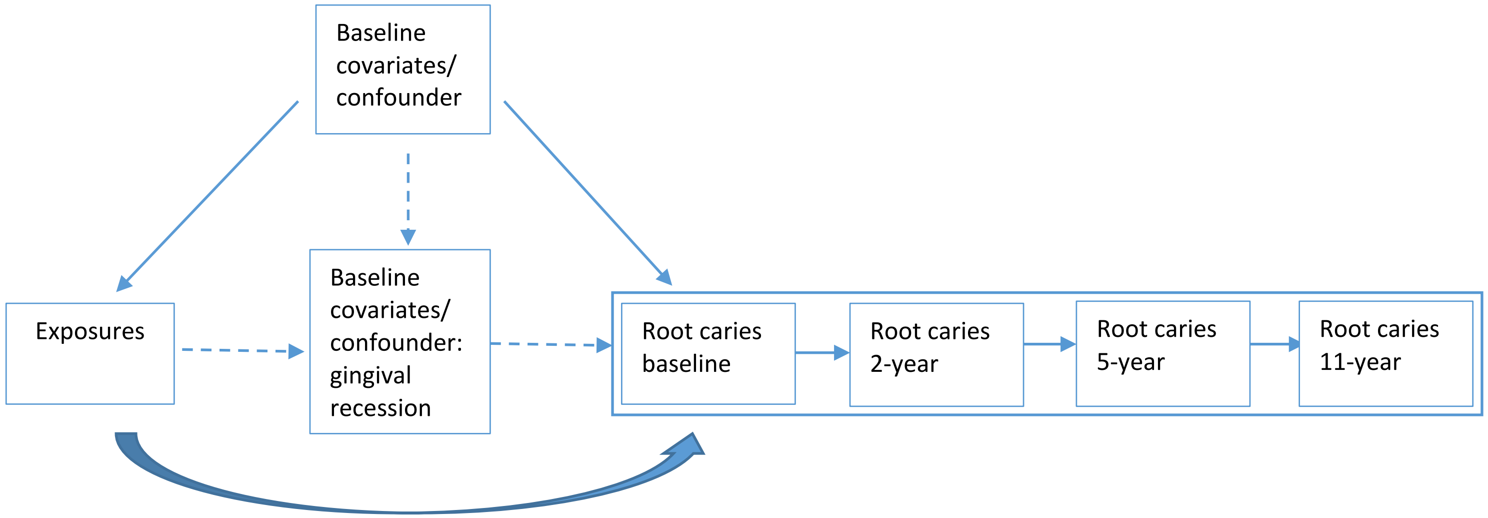
Study population and research design

The present study is based on four 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 (Slade and Spencer, 1995; Slade and Spencer, 1997; Thomson, 1999; Thomson et al., 2002). To summarise, 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 three age groups, two sexes and three locality categories; and six strata in Mt Gambier defined by three 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 2-year, 5-year and 11-year, 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 (Merchant and Pitiphat, 2002) (See Figure 1). DAG are a set of arrows drawn along a time line, characterising causal and temporal relationship between variables, and an aid to assess confounding (Merchant and Pitiphat, 2002). The outcome was root caries measured in four 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 four 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 (Vehkalahti, 1989), smoking (Chrysanthakopoulos, 2013), gingivitis (Chrysanthakopoulos, 2013) and age (Albandar and Kingman, 1999), 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 (Ritter et al., 2010). Further, the association of brushing frequency as an exposure and gingival recession was conflicting (Rajapakse et al., 2007). 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 tooth brushing 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 (Glymour, 2006), we believe that including gingival recession in the model would not generate a substantial bias. Ding and Miratrix in 2015 (Ding and Miratrix, 2015) 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 (Beck, 1998). Moreover, baseline root caries was used as an intercept in modelling the root caries increment.



- 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 socio-demographic 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 (Beck 1998)

Figure 6-1 Directed Acyclic Graph of root caries experience

Data collection

The oral examinations followed the United States National Institute of Dental Research (NIDR) protocol (National Institute of Dental Research, 1987). All examinations were conducted by one of four calibrated dentists, all of whom underwent three days of prior training and standardisation. Baseline examiners were trained and standardised by an international expert who had experience with the use of the protocol in surveys of older adults conducted in the USA. 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 one of the two calibrated examiners from the baseline examination who participated in all four waves of examinations. Baseline and all follow-up dental examinations were conducted under similar conditions. Mirrors and blunt NIDR probes were used under standardised illumination. Radiographs were not taken.

Root caries was recorded for all teeth and teeth roots present in the mouth, including third molars. Teeth were categorised 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 three quarters of the coronal structure missing, were coded separately as tooth roots.

For each tooth present, the status of four 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 cemento-enamel junction (CEJ) 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 three quarters of the coronal structure missing, it was coded as a retained sound or decayed root, and these codes were then inferred for the four root surfaces of the same tooth. The same procedure was applied in all oral examinations (baseline, 2nd, 5th, and 11th years 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).

Data management

At baseline, 913 dentate (have at least one 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 of 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 (WHO, 2007). Furthermore, we have included the number of sites with gingival recession as one 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 tooth brushing 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 less than 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 dichotomised into 60-69 years and ≥70 years. The level of education was dichotomised 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. By 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 categorised 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 categorised into normal gingiva (if there were no teeth with gingival bleeding after probing) and gingivitis (if at least one 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 1mm or more. The presence of gingival recession was only presented in the descriptive analysis to provide summary characteristics on gingival health.

Statistical analysis

The statistical analysis was performed in SAS-callable SUDAAN. Characteristics of the study participants in each waves, as well as the final dataset used which contained 358 dentate participants in all four 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 two categories, the Kruskal-Wallis 1-way ANOVA for a risk factor with three categories and Spearman's rho correlation for continuous risk factors, 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 (Hamasha et al., 2005), 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 two examinations, like the calculation of annual increment described in the previous study (Hamasha et al., 2005). However, the use of a multivariable multilevel growth model using a linear regression in this research provided a comparable estimate to the standard method.

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 AIC (Akaike Information Criterion) (Singer, 1998). Multi-level analysis using SAS ProcMixed was used to fit these models (Ha et al., 2016; Singer, 1998) 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 $P < 0.05$.

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.

RESULTS

Characteristics of the study participants

Table 6.1 shows the baseline characteristics of participants in each wave of oral examinations and participants in all four oral examination waves in the final dataset. During the 11 years of the study, 60.8% of study participants were lost of follow-up. As expected, the percentage of people age ≥ 70 years at baseline was reduced during the 11 year of study. In the final data set, there were only 31.6% participants aged 70+ years in the baseline while it was almost 50% at the baseline examination. The data in Table 6.1 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 less than 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.

Table 6.1 Background characteristics of study participants

Characteristic at baseline		Four waves of oral examinations				Final Dataset
		Baseline oral examinations	2-year follow-up examinations	5-year follow-up examinations	11-year follow-up examinations	
		%	%	%	%	%
Dentate respondents (N)		913	689	530	361	358
Socio-demographics						
Age	60-69 years	50.5	53.9	57.9	68.1	68.4
	>= 70 years	49.5	46.2	42.1	31.9	31.6
Gender	Male	59.0	59.1	57.6	54.2	53.9
	Female	41.0	40.9	42.5	45.8	46.1
Highest education	Trade/diploma or higher	40.2	40.9	42.9	45.1	45.4
	Senior high school or less	59.9	59.1	57.1	54.9	54.6
Residential place	Adelaide	61.3	60.2	58.5	57.2	57.3
	Mt Gambier	38.7	39.8	41.5	42.8	42.7
Private dental insurance	Yes	41.9	43.4	46.1	51.3	51.0
	No	58.1	56.6	53.9	48.7	49.0
Socio-economic						
Income	<$12,000	27.8	26.7	25.5	22.3	22.5
	$12,000-<$16,000	34.1	33.4	32.9	33.3	33.5
	>= $16,000	38.1	39.9	41.6	44.3	44.00
Clinical conditions						
Gingival status	Normal	38.0	38.8	37.0	36.8	36.9
	Gingivitis	62.0	61.2	63.0	63.2	63.1
Presence of gingival recession	Yes	97.5	98.0	98.3	97.8	97.8
	No	2.5	2.0	1.7	2.2	2.2
Number of sites with gingival recession (mean ± SD)		26.9 ± 17.0	26.6 ± 16.8	26.6 ± 16.5	24.6 ± 16.3	24.5 ± 16.3
Oral health related behavioural factors						
Frequency of brushing	Twice a day or more	61.8	63.6	64.7	66.9	67.3
	Less than twice a day	38.2	36.4	35.3	33.1	32.7
Frequency of flossing	Once a day or more	28.8	29.2	29.8	29.7	29.6
	Not every day	71.2	70.8	70.2	70.3	70.4
Dental visit	Last visit is Less than 1 year ago	61.6	64.6	68.0	70.8	70.6
	Last visit is more than 1 year ago	38.4	35.4	32.0	29.3	29.4
Reason of visit	Check-up	41.0	44.8	47.0	51.4	51.4
	Problem	59.0	55.3	53.0	48.6	48.6
Smoking	Never smoked	44.6	45.0	46.8	47.5	47.8
	Currently smoke and used to smoke	55.4	55.0	53.2	52.5	52.2

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, 2^{nd}, 5^{th}, and 11^{th} follow-up years respectively (Table 6.2). Table 6.2 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 brushed twice a day or more and who had their last dental visit less than 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 a 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), 5-year follow-up (mean±SD=1.35±2.61 vs mean±SD=0.75±1.56) and 11-year follow-up (mean±SD=1.21±2.56 vs mean±SD=0.74±2.24). Only the reason for the 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 a higher number of untreated root caries than women at the baseline and 11-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 a higher number of untreated root caries in the 11-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 less than 1 year ago, and check-up as a reason for a dental visit, were consistently associated with higher root DFS in all waves of oral examination.

Table 6.2 Bivariate analysis of root caries (root DS and root DFS) with the baseline explanatory variables

Characteristic in baseline		Untreated root caries (root DS)				Untreated/treated root caries (root DFS)			
		Baseline oral examinations	2-year follow-up examinations	5-year follow-up examinations	11-year follow-up examinations	Baseline oral examinations	2-year follow-up examinations	5-year follow-up examinations	11-year follow-up examinations
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Dentate and present at all examinations (N=358)		0.33 ± 0.88	0.37 ± 1.24	1.07 ± 2.19	0.98 ± 2.42	2.92 ± 3.28	3.37 ± 3.72	4.75 ± 4.52	4.02 ± 4.60
Socio-demographics									
Age	60-69 years	0.31 ± 0.86	0.40 ± 1.39	1.11 ± 2.20	0.76 ± 1.83	**2.69 ± 3.18**	**3.02 ± 3.53**	**4.32 ± 4.34**	**3.60 ± 3.71**
	>= 70 years	0.38 ± 0.94	0.29 ± 0.85	0.97 ± 2.18	1.48 ± 3.32	**3.40 ± 3.44**	**4.13 ± 4.02**	**5.69 ± 4.79**	**4.94 ± 6.02**
Gender	Male	**0.47 ± 1.07**	0.44 ± 1.42	1.23 ± 2.51	**1.43 ± 3.03**	3.06 ± 3.29	3.61 ± 3.76	4.83 ± 4.54	4.76 ± 5.55
	Female	**0.17 ± 0.56**	0.28 ± 0.99	0.88 ± 1.73	**0.46 ± 1.21**	2.75 ± 3.26	3.10 ± 3.67	4.66 ± 4.52	3.16 ± 2.92
Highest education	Trade/diploma or higher	0.33 ± 0.85	0.38 ± 1.12	1.28 ± 2.55	1.19 ± 2.83	2.97 ± 3.35	3.44 ± 3.92	4.97 ± 4.85	4.32 ± 4.78
	Senior high school or less	0.33 ± 0.92	0.35 ± 1.34	0.89 ± 1.83	0.82 ± 2.01	2.85 ± 3.22	3.30 ± 3.56	4.57 ± 4.25	3.76 ± 4.45
Residential place	Adelaide	0.24 ± 0.68	0.33 ± 0.98	0.97 ± 2.13	0.90 ± 2.35	3.05 ± 3.50	3.60± 3.98	4.91 ± 4.64	4.31 ±4.59
	Mt Gambier	0.45 ± 1.09	0.41 ± 1.52	1.20 ± 2.26	1.10 ± 2.51	2.73 ± 2.96	3.07 ± 3.33	4.55 ± 4.37	3.64 ± 4.60
Private dental insurance	Yes	0.29 ± 0.76	0.30 ± 1.05	1.04 ± 2.32	**0.94 ± 2.77**	2.77 ± 3.21	3.22 ± 3.67	4.57 ± 4.54	3.88 ± 4.64
	No	0.38 ± 1.01	0.41 ± 1.40	1.05 ± 2.00	**1.03 ±2.01**	3.09 ± 3.36	3.53 ± 3.80	4.89 ± 4.46	4.20 ± 4.59
Socio-economic									
Income	<$12,000	0.52 ± 1.35	0.37 ± 1.03	1.22 ± 2.31	0.90 ± 2.19	3.22 ± 3.36	3.77 ± 3.73	5.19 ± 4.72	3.90 ± 4.08
	$12,000-<$16,000	0.29 ± 0.64	0.30 ± 0.83	0.97 ± 1.69	0.89 ± 2.03	3.00 ± 3.38	3.20 ± 3.44	4.62 ± 4.32	3.90 ± 4.83
	>= $16,000	0.29 ± 0.79	0.45 ± 1.62	1.18 ± 2.61	1.12 ± 2.88	2.78 ± 3.19	3.24 ± 3.92	4.69 ± 4.72	4.43 ± 4.95
Clinical conditions									
Gingival status	Normal	0.41 ± 0.97	0.33 ± 1.44	0.85 ± 1.90	0.72 ± 1.73	3.34 ± 3.46	3.65 ± 3.77	4.59 ± 4.27	3.54 ± 4.36
	Gingivitis	0.26 ± 0.72	0.34 ± 1.04	1.20 ± 2.34	1.20 ± 2.83	2.70 ± 3.18	3.22 ± 3.78	4.84 ± 4.73	4.33 ± 4.85
Number of sites with gingival recession (mean ± SD=24.52 ± 16.31)		0.33 ± 0.88	0.37 ± 1.24	**1.07 ± 2.19**	0.98 ± 2.42	**2.92 ± 3.28**	**3.37 ± 3.72**	**4.75 ± 4.52**	**4.02 ± 4.60**
Oral health related behavioural factors									
Frequency of brushing	Twice a day or more	**0.22 ± 0.68**	0.27 ± 0.85	0.99 ± 1.95	0.88 ± 2.42	3.00 ± 3.27	3.56 ± 3.81	**5.02 ± 4.50**	**4.21 ± 4.36**
	Less than twice a day	**0.55 ± 1.18**	0.57 ± 1.79	1.22 ± 2.62	1.19 ± 2.41	2.74 ± 3.30	2.98 ± 3.51	**4.20 ± 4.52**	**3.63 ± 5.05**
Frequency of flossing	Once a day or more	0.25 ± 0.75	0.44 ± 1.66	0.91± 2.06	1.12 ± 3.10	3.16 ± 3.37	3.59 ± 3.54	5.32 ± 4.62	4.45 ± 4.69
	Not every day	0.37 ± 0.93	0.33 ± 1.02	1.13 ± 2.24	0.92 ± 2.07	2.81 ± 3.24	3.28 ± 3.80	4.52 ± 4.47	3.84 ± 4.56
Dental visit	Last visit is less than 1 year ago	**0.26 ± 0.74**	0.36 ± 1.31	1.04 ± 2.21	1.12 ± 2.71	**3.27 ± 3.38**	**3.81 ± 3.94**	**5.15 ± 4.50**	**4.71 ± 5.03**
	Last visit is more than 1 year ago	**0.50 ± 1.15**	0.39 ± 1.08	1.15 ± 2.16	0.68 ± 1.50	**2.02 ± 2.85**	**2.30 ± 2.88**	**3.80 ± 4.46**	**2.36 ± 2.77**
Reason of visit	Check-up	**0.17 ± 0.54**	**0.27 ± 0.96**	**0.89 ± 1.94**	**1.02 ± 2.76**	**3.55 ± 3.52**	**4.08 ± 4.05**	**5.48 ± 4.72**	**4.71 ± 4.61**
	Problem	**0.49 ± 1.12**	**0.47 ± 1.48**	**1.26 ± 2.42**	**0.94 ± 2.00**	**2.24 ± 2.86**	**2.63 ± 3.19**	**3.98 ± 4.17**	**3.29 ± 4.49**
Smoking	Never smoked	**0.16 ± 0.49**	0.25 ± 0.76	**0.75 ± 1.56**	**0.74 ± 2.24**	2.63 ± 3.09	3.06 ± 3.18	4.44 ± 3.97	3.73 ± 4.35
	Currently smoke and used to smoke	**0.49 ± 1.11**	0.48 ± 1.55	**1.35 ± 2.61**	**1.21 ± 2.56**	3.18 ± 3.43	3.66 ± 4.14	5.04 ± 4.97	4.29 ± 4.81

Numbers in bold indicate that bivariate associations between mean root DS and risk factors from baseline were statistically significant at P <0.05 level. Bivariate analysis was conducted using the Mann-Whitney U test for risk factors with two categories, the Kruskal-Wallis 1-way ANOVA for a risk factor with three categories and Spearman's rho correlation for a continuous risk factor as all distributions were not normal.

The increment and associated behavioural factors of root caries

Models for the untreated root caries are presented in Table 6.3. The null model shows that untreated root caries increased by 0.07 surfaces annually. There was a strong positive covariance between intercept and slope (E=0.03, p=0.01), indicating that participants with the highest baseline untreated root caries had the steepest increase in untreated root caries. The annual increment of 0.07 surfaces 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 a number of sites with gingival recession were associated with root DS increment. We also observed a 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 6.4 presents models for the treated or untreated root caries (root DFS). The null model shows 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 the last dental visit being less than 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 a number of sites with gingival recession were associated with root DFS increment. A full model with interactions showed bigger DIC and AIC than the final model, so these are not presented.

Table 6.3 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**	**<0.01**	**0.60**	**0.18**	**<0.01**	0.01	0.26	0.97
Annual increment		**0.07**	**0.01**	**<0.01**	**0.07**	**0.01**	**<0.01**	**0.07**	**0.01**	**<0.01**
Socio-demographics										
Age	60-69 years (ref. >= 70 years)				0.09	0.12	0.50	0.02	0.12	0.87
Gender	Female (ref. Male)				-0.18	0.12	0.12	0.06	0.13	0.67
Highest education	Senior high school or less (ref. Trade/diploma or higher)				-0.13	0.12	0.29	-0.15	0.12	0.23
Residential place	Adelaide (ref. Mt Gambier)				-0.15	0.12	0.22	-0.13	0.12	0.27
Private dental insurance	No (ref. Yes)				0.02	0.13	0.89	-0.02	0.13	0.88
Socio-economic										
Income	<$12,000 (ref. >= $16,000)				0.08	0.16	0.65	0.02	0.17	0.92
	$12,000-<$16,000 (ref. >= $16,000)				-0.14	0.14	0.31	-0.19	0.14	0.17
Clinical conditions										
Gingival status	Gingivitis (ref. Normal)				-0.02	0.12	0.87	-0.03	0.12	0.77
No of sites with gingival recession					**0.01**	**0.003**	**<0.01**	**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**	**0.04**
Flossing frequency	Not every day (ref. Once a day or more)							0.09	0.13	0.47
Dental visit	Last visit is less than 1 year ago (ref. Last visit is more than 1 year ago)							0.16	0.14	0.25
Reason of visit	Problems (ref. Check-up)							**0.30**	**0.13**	**0.03**
Smoking	Currently smoke and used to smoke (ref. Never smoke)							**0.33**	**0.12**	**<0.01**
Deviance statistics										
Variability between intercepts		0			0			0		
Covariance between intercept and slope		0.03	0.01	0.01	0.02	0.02	0.19	0.02	0.02	0.32
Variability between slopes		0.02	0.004	<0.01	0.03	0.005	<0.01	0.03	0.005	<0.01
Residual		2.10	0.09	<0.01	2.11	0.10	<0.01	2.09	0.10	<0.01
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; *Statistically significant estimates Mixed model using SAS Proc Mixed, p<0.05; Reference model: with intercept and time only as the random factors; E, estimate; SE, Standard error of estimates.

AIC: Akaike Information Criterion (smaller is better), DIC: Deviance Information Criteria = -2RLL (smaller is better)

Table 6.4 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**	**<0.01**	**3.33**	**0.57**	**<0.01**	**2.03**	**0.81**	**0.01**
Annual increment		**0.10**	**0.02**	**<0.01**	**0.11**	**0.02**	**<0.01**	**0.11**	**0.02**	**<0.01**
Socio-demographics										
Age	60-69 years (ref. >= 70 years)				-0.39	0.39	0.32	-0.42	0.38	0.27
Gender	Female (ref. Male)				-0.14	0.37	0.71	-0.07	0.40	0.87
Highest education	Senior high school or less (ref. Trade/diploma or higher)				-0.30	0.38	0.42	-0.39	0.37	0.30
Residential place	Adelaide (ref. Mt Gambier)				0.57	0.37	0.12	0.50	0.36	0.17
Private dental insurance	No (ref. Yes)				-0.002	0.40	1.00	0.26	0.39	0.51
Socio-economic										
Income	<$12,000 (ref. >= $16,000)				0.38	0.51	0.46	0.30	0.50	0.55
	$12,000-<$16,000 (ref. >= $16,000)				0.20	0.44	0.65	0.30	0.43	0.48
Clinical conditions										
Gingival status	Gingivitis (ref. Normal)				-0.008	0.37	0.98	-0.11	0.36	0.77
No of sites with gingival recession					**0.10**	**0.01**	**<0.01**	**0.10**	**0.01**	**<0.01**
Oral health related behavioural factors										
Brushing frequency	Less than twice a day (ref. Twice a day or more)							-0.08	0.37	0.83
Flossing frequency	Not every day (ref. Once a day or more)							**0.81**	**0.39**	**0.04**
Dental visit	Last visit is less than 1 year ago (ref. Last visit is more than 1 year ago)							**1.22**	**0.44**	**<0.01**
Reason of visit	Problems (ref. Check-up)							-0.78	0.40	0.06
Smoking	Currently smoke and used to smoke (ref. Never smoke)							0.47	0.37	0.21
Deviance statistics										
Variability between intercepts		9.52	0.96	<0.01	6.87	0.86	<0.01	6.33	0.83	<0.01
Covariance between intercept and slope		-0.11	0.08	0.18	-0.03	0.08	0.69	-0.04	0.08	0.59
Variability between slopes		0.07	0.01	<0.01	0.08	0.01	<0.01	0.08	0.01	<0.01
Residual		5.69	0.30	<0.01	5.84	0.34	<0.01	5.86	0.34	<0.01
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; *Statistically significant estimates Mixed model using SAS Proc Mixed, p<0.05; Reference model: with intercept and time only as the random factors; E, estimate; SE, Standard error of estimates.

AIC: Akaike Information Criterion (smaller is better), DIC: Deviance Information Criteria = -2RLL (smaller is better)

DISCUSSION

This study reports 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 indices does not mean that 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 takes 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 three points of oral examination. Future analysis with more contemporary data is needed to confirm the findings. However, our findings in annualised root DS and root DFS increments were comparable to those reported in an Iowan study with similar length of follow-up (Hamasha et al., 2005).

Longitudinal studies always face a problem with attrition of the participants (Slade and Caplan, 1999), 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 (Deeg, 2002). The attrition in this study was slightly higher than the longitudinal studies of root caries of the same length conducted in Sweden (Fure, 2003), but much lower than that observed in Iowa (Hamasha et al., 2005). Previous studies (Slade, Gansky and Spencer, 1997; Thomson et al., 2002) have revealed that people who are lost to follow-up are those with higher root caries at baseline (Slade et al., 1997) and those with a higher number of chronic medical conditions (Thomson et al., 2002). Thus, these results for root caries increment in this analysis are biased toward 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) (Hariyani et al., 2017). 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 tooth brushing, visiting a dentist only for a problem, and smoking were risk factors for a higher increase in untreated root caries; while not flossing every day and frequent dental visiting (last dental visit less than 1 year ago) were risk factors for a higher increase of 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 etiologic agents in dental caries (Sheiham and James, 2015). Tooth brushing could mechanically remove plaque and together with fluoridated toothpaste could assist in altering the balance between demineralisation and remineralisation, having a preventive effect on root caries. The finding that infrequent brushing was risk factor for untreated root caries is consistent with previous studies (Gokalp and Dogan, 2012; Hariyani et al., 2017; Vehkalahti and Paunio, 1988). A meta-analysis estimating the effect of tooth brushing 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 (Kumar, Tadakamadla and Johnson, 2016), even though this effect could not be separated from the potential contribution of fluoride in the toothpaste used in the tooth brushing activity (Tinanoff, 2017).

Smoking was related to the elevation of *mutans streptococci* and *lactobacilli* in saliva, which are associated with the initiation and progression of dental caries (Sakki and Knuuttila, 1996). Also smoking contributes to a lower buffering capacity of saliva, weakening a protective factor against dental caries (Wikner and Söder, 1994). Our finding that smoking was a risk factor for root caries was supported in some previous studies (Hariyani et al., 2017; Phelan et al., 2004) while some other studies did not find any association (Gilbert et al., 2001; Locker, 1996).

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-ups 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 (Crocombe et al., 2012). 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 for 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. (Walls, Silver and Steele, 2000) found that up to 55% of restorations placed by United Kingdom 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 a 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 (Sambunjak, 2011; Vernon and Seacat, 2017), the correct use of flossing could remove food trapped in the interproximal contact area between teeth, which could further 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 (Banting, 1986) 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 (Burt, Ismail and Eklund, 1986). Dentists who observe gingival recession in their older adult patients often encourage more cleaning including tooth brushing 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 tooth brushing frequency, and root caries. We found that gingival recession was significantly associated with both increased root DS and root DFS suggesting this approach was appropriate.

This research found that some behavioural risk factors such as infrequent tooth brushing, visiting a dentist only for a problem and smoking were associated with untreated root caries, thus changing these behaviours should be routinely promoted among older adults. However, it is understandable that the ability to carry out daily living activities, and that the cognitive function diminishes with ageing (Plassman et al., 2008), 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 a longitudinal study with more than three 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 (Phillips and Clancy, 1972). 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 it does 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 (Slade and Caplan, 1999) as the reason for tooth extraction generally remains unknown.

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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7 Chapter 7: Empirical study 3

7.1 Linkage of the Chapter to the body of research:

This Chapter addresses Aim 4 of this research. It provides a comparative analysis of root caries experience in two generations of older Australians two decades apart. This analysis tests the ‘failure of success’ or ‘more teeth, more disease’ theory in regards to root caries among Australian older adults. The data used come from SADLS1 (the generation born before 1931) and SADLS2 (a generation born before 1953). These two generations are hereafter called the previous and current generation respectively.

7.2 Highlight

- This research found that the current generation of Australian older adults retained more natural teeth than the previous generation.
- Even though the current generation had more exposed root surfaces, in general, it experienced lower level of root caries than the previous generation. The findings showed that the current generation is a relatively more successful generation for oral health compared to the generation born two decades earlier.
- This findings do not support the ‘failure of success’ or ‘more teeth, more disease’ theories. The findings showed that even though the current generation preserved more teeth into older age, with more accumulated sites of gingival recession, the generation presented less root caries.
- Risk indicators found for untreated root caries and treated or untreated root caries were relatively different. Thus, providing root caries in different measurements (as root DS, root FS and root DFS) will extend our understanding of the different risk indicators of root caries beyond those provided by the root DFS measurement.
- Gingival recession, irregular brushing, an unfavourable reason for dental visiting, and smoking were the risk indicators for untreated root caries, while age, gingival recession and time since the last dental visit were the risk indicators for treated root caries.

- An increased exposure to water fluoridation might have been an explanation for the differences of root caries cases across the generations.

7.3 Future research direction

- As this research showed that the 'failure of success' or 'more teeth, more disease' theories were not supported for root caries, it seems that public health programs in Australia were providing the right direction in preventing root caries. Water fluoridation and behavioral interventions for modifiable indicators (e.g., smoking) should be continued to reduce root caries.
- Future research using the longitudinal study components is needed to further test whether more teeth retained translates into more disease or not; as well as to test whether or not the risk factors for developing root caries are the same across generations.

7.4 Statement of authorship (empirical result 3)

Statement of Authorship

Title of Paper	The prevalence and severity of root caries across Australian generations
Publication Status	☐ Published ☐ Accepted for Publication ☑ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
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Principal Author

Name of Principal Author (Candidate)	Niniuk Hariyani		
Contribution to the Paper	Initial conceptualization, preparing data request form, do data entry and cleaning, data preparation and analysis, presenting and discussing findings and writing the manuscript		
Overall percentage (%)	85%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	27-02-2018

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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7.5 Empirical result 3

ABSTRACT

Background: The 'failure of success' theory predicts that as subsequent generations of older adults retain more teeth those additional teeth will experience more oral disease such as root caries. The theory in relation to root caries has never been tested in a cross-generational study. This study aims to compare root caries across generations of South Australian older adults to test the theory and explore root caries risk indicators.

Methods: Data were from the baseline of two South Australian studies separated by 22 years. In both studies stratified random samples of people aged 60+ years from Adelaide and Mount Gambier were recruited. Dental examinations were performed by trained and calibrated dentists. One of the dental examiners from the earlier study was the gold standard examiner in the second study. Risk indicators included behavioural factors, clinical oral conditions, socio-demographic and socio-economic status. Root caries was assessed as untreated root caries (RDS), treated root caries (RFS) and treated or untreated root caries (RDFS), and was presented as the prevalence and summed count. Multivariable models for Poisson and negative binomial distributions were used to estimate prevalence ratios (PR) and mean ratios (MR) respectively and their 95% confidence intervals (95%CI).

Results: The current generation of South Australian older adults has significantly lower RDS (PR[95% CI]=0.65[0.47-0.89]; MR[95% CI]=0.51[0.35-0.73]) and RDFS (PR[95% CI]= 0.84[0.71-0.99]; MR[95% CI]=0.76[0.65-0.90]) than the previous generation. The RFS in the previous and current generation was similar. Gingival recession, irregular brushing, dental visiting for a problem, and smoking were the indicators for RDS, while age, gingival recession, tooth brushing frequency, time since last dental visit and reason for visiting were the indicators for RFS or RDFS.

Conclusions: These results do not support the 'failure of success' theory in relation to root caries among South Australian older adults. Despite the higher number of teeth retained, the current generation of older adults has less root caries than the previous generation. Behavioural factors remain the indicators of root caries across the generations.

Key words: root caries, across generation, 'failure of success'

INTRODUCTION

Root caries has become a subject of interest among researchers in dentistry across the last several decades. It was predicted that the burden of root caries would become more apparent as the life expectancy increased and tooth loss in older adults decreased (Banting, 1984; Reinhardt and Douglass, 1989). With the increased number of teeth retained, more teeth would be at risk of developing root caries. This presumption, congruent with the 'failure of success' theory raised by Gruenberg in 1977 (Gruenberg, 1977), was part of the 'more teeth, more disease'(Joshi et al., 1996) theories accepted in dentistry. Cross-sectional data have confirmed that the more teeth retained, the more caries and periodontal disease encountered (Joshi et al., 1996; Nicolau, Srisilapana and Marcenes, 2000). It is predicted that the current generation with more teeth will also have more root caries, which will have implications for the burden of oral diseases in the future. However, the 'failure of success' or 'more teeth, more disease' theories have not yet been tested using data across two different generations.

Furthermore, as there are many changes across generations such as exposure to fluoridated water or use of fluoridated toothpaste as part of improved oral hygiene, and an increased awareness of the dangers of smoking, it is possible that the indicators for root caries will differ across generations. Thus, this study aims to test the 'failure of success' or the 'more teeth, more disease' theories related to root caries using two cross-sectional studies of South Australian older adults, and to explore the possible indicators for root caries across the generations.

MATERIALS AND METHODS

Study population and research design

The first South Australian Dental Longitudinal Study commenced in 1991/1992 (SADLS1). SADLS1 consisted of three strata of older adults 60+ years old from both Adelaide, the capital city of South Australia, and Mount Gambier, a regional city in the south-east of the state. A recent Intergenerational Change in Oral Health in Australia Study (SADLS2) was conducted to measure the disease among a current generation of Australian older adults 60+ years in the same locations 22 years later. A comparison of root caries prevalence and severity among the current and the previous generation of Australian older adults was made by comparing the results of the two studies. Drawing participants from the same background population allowed comparison of the two cohorts with minimal confounding. SADLS1 and SADLS2's participants represented the generation of older adults born before 1931 and 1953, which hereafter will be called the previous and current generations respectively.

SADLS1 and SADLS2 both adopted a longitudinal study design. This article presents the analysis of only the baseline data. The details of the recruitment procedures of SADLS1 have been published previously (Slade and Spencer, 1997). SADLS2 adopted a similar strategy design, using a stratified random sample of persons aged 60+ years selected from the Australian Electoral Roll, which is a compulsory register for Australian citizens.

Data collection and management

Each SADLS contained both a social survey (interview or mailed questionnaire) and oral examination at baseline. A participating dental examiner in SADLS1 was retained as the gold standard examiner in SADLS2 for the oral examinations. SADLS1 and SADLS2 adopted different rules in handling a condition where a caries lesion involved both the coronal and root surfaces. SADLS1 used the 'half rule' while SADLS2 used 'one millimetre rule'. With the 'half rule', root caries lesion was only recorded if more than half of the lesion was located in the root surface, while in the 'one millimetre rule', root caries were recorded if the lesion extended at least one millimetre to the root surface. In the oral examination, all teeth and retained roots present in the mouth, including the third molars, were examined for root caries. Teeth were categorised as present if more than a quarter of the natural or restored coronal tooth structure was present, otherwise it was coded separately as retained roots.

For each tooth present, the status of four root surfaces was recorded. Root caries was recorded by differentiating root surfaces which were decayed, filled or sound. To be recorded 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 cemento-enamel junction were recorded as unexposed. In the coding scheme, examiners differentiated recurrent/secondary decay from primary decay, as well as filled unsatisfactorily from filled satisfactory. No distinction was made between caries-related and non-caries related root restorations**.** Each retained root was coded as retained root decayed or sound, which then was translated as the status of the four root surfaces of the same retained root. The same procedure was applied in both SADLS1 and SADLS2. The outcome presented in this article is the prevalence and the severity of root caries, with each measurement in three different formats: root decayed surfaces (RDS); root filled surfaces (RFS); and, root decayed and filled surfaces (RDFS).

Risk indicators were collected through a self-reported social survey (interview in SADLS1 and questionnaire in SADLS2) and oral examination during the baseline. Risk indicators included socio-demographic status (age, sex, highest school/tertiary qualification, residential place and private insurance), socio-economic status (household income), clinical condition (number of teeth and the number of exposed root surfaces) and oral health-related behaviours. Oral health related behaviours were tooth brushing frequency (twice a day or more vs less than twice a day), flossing frequency (once a day or more vs not every day), dental visiting (last visit was less than 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). Age was dichotomised into 60-69 years and ≥70 years. The level of education was dichotomised into trade/diploma or higher and senior high school or less. Residential location was divided into living in Adelaide and Mount Gambier, which also represents the access of the study participants to water fluoridation. Adelaide, the capital city of South Australia, has had water fluoridated since 1971, while the rural city of Mount Gambier's water was not fluoridated until 2010. Private dental insurance was categorised as having private insurance or not.

Socio-economic status was measured by household income (categorised as low, medium and high income). Income was collected in different dollar value categories due to the data collection being 22 years apart. Household income was categorised into three almost equal groups based on the distribution of income in each study. For SADLS1, <$12,000, $12,000-<$16,000, and >=$16,000 were categorised as relatively low, medium and high income respectively while for SADLS2, <$20,000, $20,000-<$40,000, and >=$40,000 were categorised as low, medium and high income respectively.

In the multivariable analysis gingival recession was expressed as a count of the number of surfaces with recession of 1 mm or more, while the number of teeth was presented as the total count of teeth and teeth roots presents in the mouth.

Statistical analysis

The statistical analysis was performed in SAS-callable SUDAAN. Background characteristics and clinical conditions of the two generations were described using prevalence and means. Indicators of root caries prevalence and severity for each generation were examined using bivariate and multivariable analyses. For root caries prevalence (RDS, RFS and RDFS prevalence), bivariate analysis was conducted using chi-square for categorical predictors and logistic regression for the continuous predictors. For root caries severities (mean RDS, RFS and RDFS), bivariate analysis was conducted using the Mann-Whitney U test for the predictors with two categories, the Kruskal-Wallis 1-way ANOVA for a predictor with three categories and Spearman's rho correlation for continuous predictor as all distributions were not normal. Separate multivariable models for each generation were performed using Proc Genmod (SAS Institute Inc., 2010) to check the risk indicators of root caries prevalence and severity in each generation. Finally, the multivariable Poisson and negative binomial models of both the previous and current generations were performed using Proc Genmod to test for differences between the prevalence and severity of root caries across the generations respectively as well as differences in risk indicators. A variance inflation factor was used to check the multi-collinearity. As there was no evidence of multi-collinearity, all of the indicators were included in the multivariable analysis. For models across the generations, a minimally adjusted model (adjusted only by generation, age and sex) and full model (adjusted with all possible indicators) were estimated for each outcome measurement. The best model was a model presenting the lowest DIC (Deviance Information Criteria) and AIC (Akaike Information Criterion) (Beal, 2007). All analysis was unweighted. The statistical significance of the associations was evaluated at $P < 0.05$.

Ethical review

Both SADLS1 and SADLS2 received ethical approval from the University of Adelaide Human Research Ethics Committee. In addition, SADLS2 also received ethical approval from the South Australia Health Human Research Ethics Committee. The participants in both the studies provided written informed consent for the self-reported social survey and the oral examination.

RESULTS

A total of 913 and 486 dentate respondents underwent an oral examination in SADLS1 and SADLS2 respectively. Table 7.1 presents characteristics of dentate people surveyed in both SADLS1 and SADLS2, comparing those who participated in the oral examination with those who did not. The characteristics of older adults who were dentally examined and those not examined were not significantly different, except that in the SADLS1 those examined were more likely to have higher education, while in SADLS2 those examined were younger and more likely to have made a dental visit within the previous year. Compared to those in SADLS1, participants who were examined in SADLS2 were more likely to live in Mount Gambier (51.9% compared to 38.7%) and to hold private dental insurance (61.6% compared to 41.9%).

The clinical oral examination (Table 7.1) indicates that the current generation retained significantly more teeth than the previous generation (mean [95% CI] = 21.6[21.0-22.3] compared to mean [95% CI] = 16.3[15.8-16.8] respectively). The prevalence and the mean number of sites with gingival recession in the current generation were also higher (% [95% CI] = 99.4[98.7-100] vs 97.5[96.5-98.5] and mean number of sites [95% CI] = 38.3[36.3-40.1] vs 26.9[25.8-28.0] respectively). However, the prevalence of root caries was lower in the current generation. The prevalence and the severity of untreated root caries were significantly lower in the current generation than the previous generation (% [95% CI] = 16.5[13.2-19.8] vs 27.3[24.4-30.2] and mean count [95% CI] = 0.41[0.27-0.56] vs 0.95[0.74-1.17] respectively), while the mean of treated root caries (RFS) in the current generation was slightly higher, but not significantly different from the previous generation (mean count [95% CI] = 2.87[2.49-3.26] vs 2.54 [2.32-2.76] respectively). The mean of treated and untreated root caries (RDFS) was still lower in the current generation than that of the previous generation (mean count [95% CI] = 3.29[2.88-3.70] vs 3.49 [3.20-3.79] respectively). The findings from the bivariate analysis of the prevalence and severity of root caries with risk indicators are presented in Table 7.2 and 7.3 respectively.

Table 7.1 Background characteristic and clinical conditions of SADLS1 and SADLS2 dentate participants (comparing participants coming/not coming to the oral examination in each generational study)

Background characteristic and clinical condition		SADLS1 participants examined	SADLS1 participants non-examined	SADLS2 participants examined	SADLS2 participants non-examined
Number of Participants		913	294	486	185
Background characteristic		%[95% CI]	%[95% CI]	%[95% CI]	%[95% CI]
Socio-demographic					
Age	60-69 years	50.5[47.2-53.7]	42.3[36.6-48.0]	**54.4[49.9-58.9]**	**37.8[30.6-44.9]**
	>= 70 years	49.5[46.3-52.8]	57.7[52.0-63.4]	**45.6[41.1-50.1]**	**62.2[55.1-69.4]**
Sex	Male	59.0[55.8-62.2]	50.7[44.9-56.4]	53.5[49.0-58.0]	51.6[44.3-59.0]
	Female	41.0[37.8-44.2]	49.3[43.6-55.1]	46.5[42.0-51.0]	48.4[41.0-55.7]
Highest school/Tertiary qualification	Trade/diploma or higher	**40.2[37.0-43.3]**	**28.2[23.1-33.4]**	46.1[41.5-50.8]	43.3[35.6-51.0]
	Senior high school or less	**59.8[56.7-63.0]**	**71.8[66.6-76.9]**	53.9[49.2-58.5]	56.7[49.0-64.4]
Residential place*	Adelaide	61.3[58.2-64.5]	53.4[47.7-59.1]	48.1[43.7-52.6]	56.2[49.0-63.4]
	Mt Gambier	38.7[35.5-41.8]	46.6[40.9-52.3]	51.9[47.4-56.3]	43.8[36.6-51.0]
Private dental insurance*	Yes	41.9[38.7-45.2]	41.9[36.1-47.6]	61.6[57.2-66.0]	57.5[50.2-64.9]
	No	58.1[54.8-61.3]	58.1[52.4-63.9]	38.4[34.0-42.8]	42.5[35.1-49.8]
Socio-economic					
Income	Low	27.8[24.8-30.8]	34.8[28.9-40.7]	34.8[30.1-39.5]	43.9[35.5-52.2]
	Medium	34.1[30.9-37.3]	28.9[23.2-34.5]	27.8[23.4-32.2]	22.3[15.3-29.3]
	High	38.1[34.8-41.3]	36.4[30.4-42.3]	37.3[32.6-42.1]	33.8[25.9-41.8]
Oral health behaviours					
Frequency of brushing	Twice a day or more	61.8[58.6-65.0]	58.2[52.5-63.8]	68.7[64.6-72.9]	57.3[50.1-64.5]
	Less than twice a day	38.2[35.0-41.4]	41.8[36.2-47.5]	31.3[27.1-35.4]	42.7[35.5-49.9]
Frequency of flossing	Once or more a day	28.8[25.8-31.7]	21.8[17.0-26.5]	33.1[28.9-37.3]	37.8[30.8-44.9]
	Not every day	71.2[68.3-74.2]	78.2[73.5-83.0]	66.9[62.7-71.1]	62.2[55.1-69.2]
Dental Visit	Last visit is less than 1 year ago	61.6[58.5-64.8]	55.2[49.4-61.0]	**68.8[64.7-72.9]**	**55.6[48.2-62.9]**
	Last visit is more than 1 year ago	38.4[35.2-41.5]	44.8[39.0-50.6]	**31.2[27.1-35.3]**	**44.4[37.1-51.8]**
Reason of visit	Check-up	41.0[37.8-44.2]	37.0[31.4-42.6]	44.0[39.6-48.5]	37.3[30.3-44.3]
	Problem	59.0[56.0-62.2]	63.0[57.4-68.6]	56.0[51.5-60.4]	62.7[55.7-69.7]
Smoking	Never smoke	44.6[41.4-47.9]	46.3[40.5-52.0]	52.5[48.0-56.9]	49.7[42.5-57.0]
	Currently smoke and used to smoke	55.4[52.1-58.6]	53.7[48.0-59.5]	47.5[43.1-52.0]	50.3[43.0-57.5]
clinical condition		Values are mean[95% CI] or %[95% CI]	-	Values are mean[95% CI] or %[95% CI]	-
Number of teeth (all teeth and teeth roots present)*		16.3[15.8-16.8]		21.6[21.0-22.3]	
Presence of gingival recession *		97.5[96.5-98.5]	-	99.4[98.7-100]	-
Number of surfaces with gingival recession*		26.9[25.8-28.0]	-	38.3[36.3-40.1]	-
RDS Prevalence*		27.3[24.4-30.2]	-	16.5[13.2-19.8]	-
Mean RDS*		0.95[0.74-1.17]	-	0.41[0.27-0.56]	-
RFS Prevalence		61.2[58.1-64.4]	-	60.1[55.7-64.5]	-
Mean RFS		2.54[2.32-2.76]	-	2.87[2.49-3.26]	-
RDFS Prevalence		72.1[69.2-75.0]	-	65.8[61.6-70.1]	-
Mean RDFS		3.49[3.20-3.79]	-	3.29[2.88-3.70]	-

Bold: significant different between examined and not-examined dentate participants in each study;

* significant different among examined dental participant across generational study;

SADLS: South Australia Dental Longitudinal Study. SADLS1 baseline was conducted in 1991-1992. SADLS2 baseline was conducted in 2011-2012. CI: 95% Confidence Interval

Table 7.2 Bivariate analysis of root caries prevalence with some predictors amongst older South Australians born before 1931 (previous generation/in SADLS1) and those born before 1953 (current generation/in SADLS2)

Risk Indicator		Root caries prevalence in two generations of Australians					
		RDS Prevalence %[CI]		RFS Prevalence %[CI]		RDFS Prevalence %[CI]	
		Previous generation	Current Generation	Previous generation	Current generation	Previous generation	Current generation
Socio-demographic							
Age	60-69 years	**22.6[18.7-26.4]**	12.4[8.35-16.5]	59.0[54.5-63.5]	55.4[49.3-61.5]	**68.8[64.5-73.0]**	60.5[54.5-66.5]
	>= 70 years	**32.1[27.8-36.4]**	21.3[15.8-26.8]	63.5[59.0-68.0]	65.7[59.4-72.1]	**75.4[71.5-79.4]**	72.2[66.2-78.2]
Sex	Male	**33.4[29.4-37.4]**	18.4[13.6-23.2]	61.8[57.7-65.9]	**54.5[48.4-60.7]**	74.4[70.7-78.1]	62.0[56.0-68.0]
	Female	**18.4[14.5-22.4]**	14.0[9.37-18.6]	60.4[55.4-65.4]	**67.1[60.9-73.3]**	68.7[64.0-73.4]	70.7[64.7-76.8]
Highest school/Tertiary qualification	Trade/diploma or higher	29.3[24.6-34.0]	13.3[8.59-18.0]	62.5[57.5-67.5]	55.2[48.3-62.1]	72.1[67.4-76.7]	61.1[54.3-67.8]
	Senior high school or less	25.9[22.2-29.6]	19.0[14.0-24.0]	60.3[56.2-64.4]	63.7[57.5-70.0]	72.1[68.3-75.8]	70.0[64.2-75.9]
Residential place	Adelaide	26.3[22.6-29.9]	12.4[8.14-16.6]	63.4[59.4-67.4]	57.7[51.3-64.1]	73.8[70.1-77.4]	61.5[55.3-67.8]
	Mt Gambier	28.9[24.1-33.6]	20.2[15.2-25.2]	57.8[52.6-63.0]	62.3[56.3-68.3]	69.4[64.6-74.2]	69.8[64.1-75.5]
Private dental insurance	Yes	**23.7[19.4-28.0]**	**12.2[8.45-16.0]**	**65.8[61.0-70.6]**	60.0[54.4-65.6]	72.6[68.1-77.1]	64.6[58.9-69.9]
	No	**30.0[26.1-34.0]**	**23.4[17.2-29.5]**	**57.6[53.4-61.8]**	59.8[52.6-66.9]	71.5[67.6-75.4]	67.9[61.1-74.7]
Socio-economic							
Income	low	31.1[25.2-37.0]	20.1[13.4-26.9]	**58.8[52.5-65.1]**	63.3[55.2-71.4]	72.3[66.5-78.0]	70.5[62.8-78.2]
	Medium	29.5[24.2-34.7]	18.9[11.5-26.3]	**56.2[50.4-61.9]**	67.6[58.7-76.4]	71.2[66.0-76.5]	70.3[61.6-78.9]
	high	23.6[19.0-28.3]	12.1[6.8-17.4]	**66.3[61.1-71.4]**	51.0[42.9-59.1]	72.7[67.8-77.6]	59.1[51.1-67.0]
Oral health behaviours							
Frequency of brushing	Twice a day or more	**19.5[16.3-22.8]**	15.0[11.1-18.8]	**65.0[61.1-69.0]**	**66.2[61.1-71.3]**	71.6[67.8-75.3]	**70.4[65.4-75.3]**
	Less than twice a day	**39.7[34.5-448]**	19.7[13.3-26.1]	**55.5[50.2-60.7]**	**46.7[38.7-54.7]**	73.0[68.3-77.7]	**55.9[47.9-63.9]**
Frequency of flossing	Once a day or more	28.2[22.8-33.7]	18.6[12.6-24.7]	**68.3[62.7-74.0]**	67.1[59.7-74.4]	77.1[72.0-82.2]	70.8[63.7-77.9]
	Not every day	26.8[23.4-30.2]	15.4[11.4-19.3]	**58.6[54.8-62.4]**	56.6[51.2-62.0]	70.1[66.6-73.6]	63.4[58.1-68.6]
Dental visit	Last visit is less than 1 year ago	**23.3[19.7-26.8]**	14.4[10.6-18.2]	**72.3[68.5-76.0]**	**65.8[60.6-70.9]**	**77.3[73.8-80.8]**	69.4[64.4-74.3]
	Last visit is more than 1 year ago	**33.3[28.4-38.3]**	20.5[14.0-27.0]	**44.3[39.0-49.5]**	**47.7[39.6-55.7]**	**63.8[58.7-68.9]**	58.3[50.3-66.2]
Reason of visit	Check-up	**17.5[13.6-21.3]**	**8.88[5.04-12.7]**	**78.8[74.6-82.9]**	66.8[60.5-73.2]	**80.4[76.3-84.4]**	68.2[61.9-74.5]
	Problem	**34.2[30.2-38.2]**	**22.4[17.4-27.4]**	**49.0[44.7-53.2]**	54.8[48.8-60.7]	**66.2[62.1-70.2]**	64.0[58.2-69.7]
Smoking	Never smoked	**19.4[15.6-23.3]**	13.3[9.13-17.5]	59.7[54.9-64.5]	60.8[54.8-66.8]	**68.8[64.3-73.3]**	63.1[57.2-69.1]
	Currently smoke or used to smoke	**33.7[29.5-37.8]**	19.9[14.7-25.1]	62.4[58.1-66.6]	59.3[52.9-65.7]	**74.7[70.8-78.5]**	68.8[62.8-74.8]
Risk Indicator		RDS Prevalence OR estimate[CI]		RFS Prevalence OR estimate[CI]		RDFS Prevalence OR estimate[CI]	
		Previous generation	Current Generation	Previous generation	Current generation	Previous generation	Current generation
Clinical conditions							
Exposed root surfaces[a]		1.01[1.00-1.01]	**1.02[1.01-1.03]**	**1.04[1.03-1.05]**	**1.02[1.01-1.03]**	**1.04[1.03-1.06]**	**1.03[1.02-1.04]**
Number of teeth		**0.96[0.94-0.98]**	**0.95[0.92-0.98]**	**1.07[1.05-1.09]**	1.02[0.99-1.04]	**1.04[1.02-1.06]**	1.00[0.97-1.02]

[a] Number of surfaces with gingival recession; **Bold**: risk indicator was significant in each study; 95% CI: 95% Confidence Interval; DS: Decayed Surfaces; FS: Filled Surfaces; DFS: Decayed Filled Surfaces; bivariate analysis was conducted using chi-square for categorical predictors and logistic regression for the continuous predictors; OR: Odd Ratio.

Table 7.3 Bivariate analysis of the severity of root caries with some predictors amongst older South Australians born before 1931 (previous generation/in SADLS1) and those born before 1953 (current generation/in SADLS2)

Risk Indicator		The severity of root caries in two generations of Australians					
		RDS Mean[CI]		RFS Mean[CI]		RDFS Mean[CI]	
		Previous generation	Current generation	Previous generation	Current generation	Previous generation	Current generation
Socio-demographic							
Age	60-69 years	0.76[0.47-1.06]	0.26[0.12-0.40]	2.27[1.99-2.55]	2.41[1.96-2.86]	**3.03[2.64-3.42]**	**2.67[2.20-3.13]**
	>= 70 years	1.15[0.83-1.47]	0.60[0.32-0.87]	2.82[2.48-3.16]	3.38[2.72-4.04]	**3.97[3.53-4.40]**	**3.98[3.26-4.70]**
Sex	Male	**1.30[0.95-1.65]**	0.51[0.27-0.74]	2.67[2.37-2.97]	2.70[2.12-3.27]	**3.97[3.54-4.41]**	3.20[2.58-3.83]
	Female	**0.45[0.29-0.62]**	0.31[0.14-0.47]	2.35[2.03-2.66]	3.12[2.60-3.64]	**2.80[2.46-3.15]**	3.43[2.89-3.97]
Highest school/Tertiary qualification	Trade/diploma or higher	0.93[0.61-1.25]	0.47[0.17-0.78]	2.74[2.38-3.10]	2.99[2.29-3.69]	3.67[3.20-4.14]	3.46[2.70-4.22]
	Senior high school or less	0.98[0.68-1.27]	0.38[0.25-0.51]	2.41[2.13-2.68]	2.90[2.41-3.38]	3.39[3.01-3.77]	3.28[2.78-3.78]
Residential place	Adelaide	0.85[0.59-1.11]	0.34[0.11-0.58]	2.73[2.44-3.03]	2.60[2.04-3.15]	3.58[3.21-3.96]	2.94[2.34-3.54]
	Mt Gambier	1.12[0.74-1.50]	0.48[0.30-0.65]	2.24[1.92-2.55]	3.13[2.60-3.66]	3.35[2.88-3.83]	3.61[3.05-4.17]
Private dental insurance	Yes	0.66[0.42-0.90]	0.26[0.16-0.36]	2.86[2.50-3.22]	2.98[2.45-3.50]	3.52[3.09-3.96]	3.23[2.69-3.78]
	No	1.18[0.84-1.51]	0.67[0.33-1.01]	2.32[2.04-2.59]	2.76[2.20-3.32]	3.49[3.09-3.90]	3.42[2.79-4.06]
Socio-economic							
Income	Low	1.24[0.76-1.71]	0.52[0.29-0.74]	2.37[1.95-2.80]	2.98[2.29-3.67]	3.61[3.01-4.20]	3.50[2.75-4.24]
	Medium	0.97[0.55-1.39]	0.48[0.02-0.93]	2.42[2.05-2.79]	2.86[2.21-3.52]	3.39[2.86-3.92]	3.34[2.56-4.12]
	High	0.77[0.47-1.07]*	0.25[0.12-0.38]	2.75[2.36-3.13]	2.67[1.98-3.36]	3.52[3.04-3.99]	2.92[2.22-3.62]
Oral health behaviours							
Frequency of brushing	Twice a day or more	**0.54[0.39-0.69]**	0.40[0.20-0.59]	**2.80[2.51-3.10]**	3.20[2.75-3.66]	3.35[3.03-3.67]	3.60[3.10-4.09]
	Less than twice a day	**1.61[1.11-2.12]**	0.45[0.26-0.63]	**2.13[1.80-2.45]**	2.16[1.45-2.86]	3.74[3.17-4.31]	2.61[1.87-3.34]
Frequency of flossing	Once a day or more	0.77[0.50-1.05]	0.39[0.21-0.56]	2.74[2.34-3.14]	**3.68[2.95-4.42]**	3.51[3.04-3.98]	4.07[3.29-4.85]
	Not every day	1.02[0.74-1.31]	0.42[0.23-0.62]	2.47[2.20-2.73]	**2.47[2.03-2.91]**	3.49[3.12-3.86]	2.90[2.43-3.37]
Dental visit	Last visit is less than 1 year ago	**0.51[0.40-0.61]**	0.31[0.20-0.42]	**3.24[2.94-3.54]**	**3.40[2.88-3.91]**	3.75[3.43-4.06]	**3.71[3.18-4.25]**
	Last visit is more than 1 year ago	**1.66[1.13-2.20]**	0.63[0.23-1.03]	**1.44[1.17-1.72]**	**1.73[1.29-2.17]**	3.10[2.53-3.68]	**2.36[1.79-2.93]**
Reason of visit	Check-up	**0.31[0.22-0.41]**	0.22[0.09-0.36]	**3.87[3.47-4.27]**	3.29[2.73-3.84]	**4.19[3.77-4.60]**	3.51[2.92-4.10]
	Problem	**1.35[1.01-1.69]**	0.56[0.32-0.79]	**1.61[1.40-1.83]**	2.55[2.02-3.08]	**2.96[2.57-3.35]**	3.11[2.55-3.68]
Smoking	Never smoked	**0.59[0.34-0.85]**	0.29[0.14-0.45]	2.34[2.04-2.65]	2.89[2.32-3.46]	**2.94[2.55-3.32]**	3.18[2.59-3.77]
	Currently smoke or used to smoke	**1.25[0.92-1.58]**	0.55[0.30-0.80]	2.70[2.39-3.01]	2.86[2.34-3.37]	**3.95[3.52-4.38]**	3.40[2.83-3.98]
Risk Indicator		RDS Correlation coefficient		RFS Correlation coefficient		RDFS Correlation coefficient	
		Previous generation	Current generation	Previous generation	Current generation	Previous generation	Current generation
Clinical conditions							
Exposed root surfaces[a]		**0.16**	0.04	**0.37**	**0.30**	0.40	**0.29**
Number of teeth		-0.05	**-0.16**	**0.23**	0.08	0.14	0.02

[a] Number of surfaces with gingival recession; **Bold**: risk indicator was significant in each study; 95% CI: 95% Confidence Interval; DS: Decayed Surfaces; FS: Filled Surfaces; DFS: Decayed Filled Surfaces; bivariate analysis was conducted using the Mann-Whitney U test for the predictors with two categories, the Kruskal-Wallis 1-way ANOVA for a predictor with three categories and Spearman's rho correlation for continuous predictor as all distributions were not normal.

While there were some differences in the indicators for root caries between the generations, the direction of associations was mostly the same. Having private dental insurance and visiting a dentist for a check-up were related to a lower RDS prevalence in all generations. More frequent brushing and dental visiting were related to higher RFS, while increased age was associated with higher RDFS in both generations. The multivariable analysis of root caries in each generation is presented in the Appendix. The multivariable analysis across generations is presented in Tables 7.4 and 7.5.

Table 7.4 Multivariable analysis of root caries prevalence in older South Australians across generations (SADLS1 and SADLS2)

Risk Indicator	Root caries prevalence					
	Minimally adjusted model RDS	Full model RDS	Minimally adjusted model RFS	Full model RFS	Minimally adjusted model RDFS	Full model RDFS
	Prevalence PR[95% CI]	Prevalence PR[95% CI]	Prevalence PR[95% CI]	Prevalence PR[95% CI]	Prevalence PR[95% CI]	Prevalence PR[95% CI]
Generation						
Current generations (ref. generation 20 years ago)	**0.62[0.48-0.80]**	**0.65[0.47-0.89]**	0.98[0.85-1.14]	0.84[0.70-1.01]	0.92[0.80-1.05]	**0.84[0.71-0.99]**
Socio-demographic						
Age						
60-69 years (ref. >= 70 years)	**0.70[0.56-0.88]**	0.87[0.68-1.11]	0.89[0.78-1.02]	0.91[0.78-1.07]	0.89[0.78-1.01]	0.93[0.80-1.07]
Sex						
Female (ref. Male)	**0.62[0.49-0.79]**	0.82[0.61-1.10]	1.07[0.93-1.22]	1.01[0.86-1.20]	1.00[0.88-1.14]	1.00[0.85-1.17]
Highest school/Tertiary qualification						
Senior high school or less (ref. Trade/diploma or higher)		0.91[0.71-1.16]		1.03[0.88-1.21]		1.03[0.89-1.19]
Residential place						
Adelaide (ref. Mt Gambier)		0.95[0.74-1.20]		0.98[0.84-1.14]		0.99[0.86-1.14]
Private dental insurance						
No (ref. Yes)		0.92[0.70-1.21]		1.04[0.87-1.23]		1.02[0.87-1.19]
Socio-economic						
Income*						
low (ref. high)		1.29[0.95-1.77]		1.04[0.85-1.27]		1.06[0.88-1.28]
medium (ref. high)		1.16[0.85-1.57]		1.03[0.85-1.25]		1.05[0.88-1.26]
Clinical conditions						
Exposed root surfaces[a]		**1.01[1.01-1.02]**		1.01[1.00-1.01]		1.01[1.00-1.01]
Number of teeth		**0.96[0.94-0.98]**		1.01[0.99-1.02]		1.00[0.99-1.01]
Oral health behaviours						
Frequency of brushing						
Less than twice a day (ref. Twice a day or more)		**1.54[1.20-1.96]**		0.89[0.75-1.05]		0.99[0.86-1.16]
Frequency of flossing						
Not every day (ref. Once a day or more)		0.86[0.67-1.12]		0.99[0.84-1.16]		0.99[0.85-1.15]
Dental visit						
Last visit is less than 1 year ago (ref. Last visit is more than 1 year ago)		1.14[0.88-1.49]		**1.37[1.13-1.67]**		1.16[0.98-1.38]
Reason of visit						
Problem (ref. Check-up)		**1.81[1.32-2.48]**		**0.81[0.68-0.98]**		0.92[0.77-1.09]
Smoking						
Currently smoke or used to smoke (ref. Never smoked)		**1.36[1.03-1.79]**		1.01[0.86-1.19]		1.05[0.91-1.22]
Model comparison						
AIC	1558.2	1313.3	2529.9	2133.9	2634.4	2265.9
DIC	1579.1	1394.7	2550.8	2215.2	2655.3	2347.3

[a] Number of surfaces with gingival recession; PR: Prevalence Ratio; Log Poisson Regression model; 95% CI: 95% Confidence Interval; DS: Decayed Surfaces; FS: Filled Surfaces; DFS: Decayed Filled Surfaces; AIC: Akaike Information Criterion (smaller is better), DIC: Deviance Information Criteria = -2RLL (smaller is better). **Bold**: Significant

Table 7.5 Multivariable analysis of the severity of root caries in older South Australians across generations (SADLS1 and SADLS2)

Risk Indicator	The severity of root caries					
	Minimally adjusted model RDS MR[95% CI]	Full model RDS MR[95% CI]	Minimally adjusted model RFS MR[95% CI]	Full model RFS MR[95% CI]	Minimally adjusted model RDFS MR[95% CI]	Full model RDFS MR[95% CI]
Generation						
Current generations (ref. generation 20 years ago)	**0.48[0.34-0.66]**	**0.51[0.35-0.73]**	1.13[0.96-1.33]	0.83[0.69-1.00]	0.96[0.83-1.11]	**0.76[0.65-0.90]**
Socio-demographic						
Age						
60-69 years (ref. >= 70 years)	**0.62[0.46-0.83]**	0.74[0.54-1.00]	**0.77[0.66-0.90]**	**0.80[0.68-0.94]**	**0.75[0.65-0.86]**	**0.82[0.70-0.95]**
Sex						
Female (ref. Male)	**0.44[0.32-0.59]**	**0.62[0.43-0.89]**	1.01[0.86-1.19]	0.98[0.82-1.17]	**0.85[0.74-0.98]**	0.90[0.77-1.06]
Highest school/Tertiary qualification						
Senior high school or less (ref. Trade/diploma or higher)		0.74[0.53-1.03]		0.93[0.79-1.10]		0.93[0.80-1.07]
Residential place						
Adelaide (ref. Mt Gambier)		0.84[0.62-1.13]		0.91[0.77-1.07]		0.92[0.80-1.07]
Private dental insurance						
No (ref. Yes)		1.05[0.72-1.52]		0.96[0.81-1.15]		1.05[0.89-1.24]
Socio-economic						
Income*						
low (ref. high)		**1.56[1.03-2.34]**		1.09[0.88-1.35]		1.09[0.91-1.32]
medium (ref. high)		1.10[0.75-1.62]		1.10[0.90-1.35]		1.05[0.87-1.26]
Clinical conditions						
Exposed root surfaces[a]		**1.03[1.02-1.04]**		**1.02[1.02-1.03]**		**1.03[1.02-1.03]**
Number of teeth		**0.94[0.92-0.96]**		1.01[1.00-1.02]		0.99[0.98-1.00]
Oral health behaviours						
Frequency of brushing						
Less than twice a day (ref. Twice a day or more)		**1.53[1.10-2.11]**		**0.80[0.68-0.95]**		0.97[0.83-1.13]
Frequency of flossing						
Not every day (ref. Once a day or more)		1.07[0.76-1.50]		0.99[0.84-1.18]		1.05[0.90-1.23]
Dental visit						
Last visit is less than 1 year ago (ref. Last visit is more than 1 year ago)		0.78[0.55-1.10]		**1.64[1.35-1.99]**		**1.27[1.07-1.52]**
Reason of visit						
Problem (ref. Check-up)		**2.40[1.65-3.51]**		**0.70[0.59-0.85]**		0.84[0.71-1.00]
Smoking						
Currently smoke or used to smoke (ref. Never smoked)		**1.50[1.08-2.08]**		1.01[0.86-1.20]		1.09[0.94-1.27]
Model comparison						
AIC	2682.1	2230.0	5822.0	4827.3	6482.4	5451.6
DIC	2708.3	2316.4	5848.2	4913.7	6508.6	5538.0

[a] Number of surfaces with gingival recession; MR: Mean Ratio; Log Negative binomial regression model; 95% CI: 95% Confidence Interval; DS: Decayed Surfaces; FS: Filled Surfaces; DFS: Decayed Filled Surfaces; AIC: Akaike Information Criterion (smaller is better), DIC: Deviance Information Criteria = -2RLL (smaller is better). **Bold**: Significant

The AIC and DIC of the full models are lower than the minimally adjusted model for all root caries measurements, showing the better fit of models after being adjusted for all indicators. In the root caries full models, the current generation had a lower untreated root caries (RDS prevalence PR [95% CI] =0.65[0.47-0.89] and mean RDS (MR [95% CI] = 0.51[0.35-0.73]) and untreated or treated root caries (RDFS prevalence PR [95% CI] = 0.84[0.71-0.99] and mean RDFS (MR [95% CI] = 0.76[0.65-0.90]) than the previous generation. The RFS did not differ across the generations. None of the socio-demographic factors included in the full model were indicators for root caries prevalence. Being female was an indicator for having a lower mean of untreated root caries (MR [95% CI] = 0.62[0.43-0.89]) while lower income was an indicator for having a higher mean of RDS (MR [95% CI] = 1.56[1.03-2.34]). Younger age was associated with lower mean of RFS (MR [95% CI] = 0.80[0.68-0.94]) and RDFS (MR [95% CI] = 0.82[0.70-0.95]). A higher number of sites with gingival recession was associated with higher RDS prevalence and with the severity of root caries in all types of measurement (RDS, RFS and RDFS), while a higher number of teeth was associated with a lower prevalence and severity of RDS only. Among the oral health-related behaviours included in the full model, brushing less than twice a day, visiting a dentist only for a problem, and smoking were associated with a higher RDS prevalence (PR [95% CI] = 1.54[1.20-1.96], 1.81[1.32-2.48] and 1.36[1.03-1.79] respectively) and mean RDS (MR [95% CI] = 1.53[1.10-2.11], 2.40[1.65-3.51] and 1.50[1.08-2.08] respectively). Visiting a dentist in the previous year was related with higher RFS prevalence and the mean of RFS and RDFS. Brushing less than twice a day was an indicator for a lower mean number of treated root caries (MR [95% CI] = 0.80[0.68-0.95]), while visiting a dentist only for a problem was an indicator for lower prevalence and lower severity of treated root caries (PR [95% CI] = 0.81[0.68-0.98] and MR [95% CI] = 0.70[0.59-0.85] respectively). Visiting a dentist in the previous year was an indicator for having a higher mean of RDFS (MR [95% CI] = 1.27[1.07-1.52]).

DISCUSSION

This research shows that the current generation of Australian older adults have retained more teeth than the previous generation, and despite the increase in sites with gingival recession compared to the previous generation, the current generation has less root caries. The 'half rule' applied in the SADLS1 oral examinations tended to under-estimate root caries. Therefore, the difference in the rule of handling a condition where a caries lesion involved both the coronal and root surfaces applied in SADLS1 and SADLS2 did not affect the conclusion that the current generation had lower root caries than the previous generation.

Our findings do not support the ‘failure of success’ or ‘more teeth, more disease’ theory in relation to root caries. The finding that the number of teeth was significantly higher among the current generation substantiated the downward trend of edentulousness and upward retention of teeth in older adults in Australia (Slade and Sanders, 2007). There was an increase in sites with gingival recession, but most of those sites remained root caries free.

When the ‘more teeth, more disease’ theory was assessed (Joshi et al., 1996), Joshi reported that in contrast to other oral conditions, the number of teeth/surfaces with untreated caries (both coronal and root caries) was lower as the number of teeth increased. They argued that this phenomenon was caused by tooth extraction. Teeth that were extracted had higher rates of caries, reducing the number of teeth with disease. However, by comparing the root caries in two generations and controlling for the number of teeth, we showed that the reduction in root caries in this cross-generational study was a result of successful ageing.

Our findings showed that despite the increase in the number of sites with gingival recession, the root surface caries was lower in the current generation, demonstrating that it is possible to avoid or postpone the onset of root caries cases and keep the majority of exposed root caries free. It is likely that water fluoridation plays a role in this finding. People living in the Adelaide region have benefited more from water fluoridation than those living in Mount Gambier, whose water was only fluoridated almost 40 years later. Prevalence of RDFS in Adelaide declined from 74% to 62% but did not change (69%) in Mount Gambier, and the severity of RDFS decreased from 3.58 to 2.94 in Adelaide, but increased from 3.35 to 3.61 in Mount Gambier. However, these changes were not statistically significant. Water fluoridation has been found to be a significant predictor for lower root caries in some previous studies (Burt, Ismail and Eklund, 1986; Stamm, Banting and Imrey, 1990), but not in another study (Rihs, de Sousa Mda and Wada, 2008). However, even though the magnitude of root caries is not as high as predicted, root caries is still a dental problem in the current generation of Australian older adults 60+ years old. Almost two-thirds of older adults still showed RDFS while almost 17% had untreated root caries.

Some socio-demographic, clinical and oral health-related behaviours were found as indicators for root caries. Younger age was related to lower mean of root caries, supporting the previous understanding that root caries increased in older age (Banting, 1984). As RDFS is a cumulative index and as root caries was related to exposed root surfaces whose prevalence increased with ageing, it is understandable that older people exhibit more root caries. Being male and having a lower income were indicators for higher RDS, also consistent with the previous research (Hariyani et al., 2017; Ritter et al., 2012).

In terms of clinical indicators, an increased number of surfaces with gingival recession was related to the mean increase of root caries in all kinds of measurements. Research has consistently shown this association (Hariyani et al.,, 2017; Lawrence, Hunt and Beck, 1995). Gingival recession puts the exposed root in contact with the oral environment, increasing the risk of developing root caries. Having more teeth was significantly related to lower untreated root caries in this study, supporting previous research (Beck, Kohout and Hunt, 1988; Fure and Zickert, 1990).

The behavioural indicators for RDS and RFS or RDFS were quite different. It is important to first note that a measurement in root caries fillings was problematic. All root surfaces with a filling are usually recorded as filled surfaces despite uncertainty as to why a filling has been placed. Walls et al. (Walls, Silver and Steele, 2000) undertook a prospective study among United Kingdom dentists and reported that 45% of restorations were placed because of decay, while 55% were done for other reasons. Accordingly, including all the filled root surfaces could overestimate root caries. Therefore, we provided RDS, RFS and RDFS measurements to acknowledge this problem and to provide more detailed assessment. Less frequent tooth brushing, dental visiting for a problem, and smoking were indicators for untreated root caries, while frequent tooth brushing, frequent dental visiting and visiting a dentist for a check-up were indicators for treated root caries. As tooth brushing can remove plaque, and usually involves fluoridated toothpaste, tooth brushing could have a preventive effect for root caries, supporting previous research (Hariyani et al., 2017; Vehkalahti and Paunio, 1988). Smoking could contribute to a lower buffering capacity of saliva (Wikner and Söder, 1994) while at the same time being related to the increased number of *mutans streptococci* and *lactobacilli (Sakki and Knuuttila, 1996)*, which made it as a risk for root caries. However, this association was still inconclusive (Ritter, Shugars and Bader, 2010). Compared to those who visited a dentist for a check-up, people who visited a dentist for a problem had a higher risk of having untreated root caries and a lower risk of having root fillings. Furthermore, those who reported more frequent dental visits had more root fillings. These facts may suggest that people who visit a dentist more frequently are more likely to have a problem detected early enough for restorative intervention and possibly more likely to be able to afford restoration over extraction. Alternatively, more frequent dental visiting may provide more opportunities for decisions to fill root surfaces for reasons other than root caries. The association of more frequent brushing with more filled root surfaces may indicate a clustering of oral health behaviours, with people who brush regularly usually being routine dental attenders (Lopez and Baelum, 2007). Research on the clustering of behaviours as a risk for root caries warrants a future investigation.

There are some strengths in this study. To our knowledge, this is the first study testing the 'failure of success' or 'more teeth, more disease' theories in root caries cases across generations. The 22-year gap between the two studies provided an opportune time to assess the different generations of older adults 60+ years old, as there would be little intersection in participants in the studies. Furthermore, the high number of participants pooled from the studies could increase the study power in terms of the estimates. However, not knowing the root caries history of missing teeth, not using radiographs and conducting examinations under field condition could underestimate root caries. Furthermore, as unweighted analysis was performed, these results cannot be generalised to Australian older adults. As this study involves two cross-sectional samples of older adults, we were unable to investigate whether more teeth retained in middle-aged individuals in the current generation will translate into more disease in their older age; as well as being unable to directly investigate whether the ongoing incidence and risk of root caries through to old age is the same across generations. To be able to answer these questions, longitudinal data are needed. The availability of our longitudinal data from these two cohorts will provide an opportunity to examine these issues in future research.

CONCLUSIONS

The findings of this study do not support the 'failure of success' theory in relation to root caries among South Australian older adults. The current generation of South Australian older adults demonstrated successful ageing, presenting more teeth at risk, but less root caries compared to the previous generation. However, root caries is still a dental problem in many of the current generation of Australian older adults.

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Appendix 1 Multivariable analysis of root caries prevalence with explanatory factors among South Australian elders born before 1931 (previous generation/in SADLS1) and those born before 1953 (current generation/in SADLS2)

Risk Indicator	Root caries prevalence					
	RDS Prevalence PR[95% CI]		RFS Prevalence PR[95% CI]		RDFS Prevalence PR[95% CI]	
	Previous generation	Current generation	Previous generation	Current generation	Previous generation	Current generation
Sociodemographic						
Age						
60-69 years (ref. >= 70 years)	0.88[0.71-1.10]	0.89[0.59-1.35]	0.93[0.81-1.07]	0.96[0.77-1.20]	0.94[0.84-1.06]	0.95[0.78-1.17]
Sex						
Female (ref. Male)	0.81[0.61-1.07]	0.82[0.54-1.24]	0.98[0.84-1.15]	1.10[0.88-1.37]	0.98[0.86-1.12]	1.07[0.87-1.30]
Highest school/Tertiary qualification						
Senior high school or less (ref. Trade/diploma or higher)	0.85[0.68-1.06]	1.14[0.77-1.69]	0.99[0.86-1.14]	1.13[0.91-1.40]	1.00[0.89-1.12]	1.11[0.91-1.35]
Residential place						
Adelaide (ref. Mt Gambier)	0.99[0.80-1.24]	0.80[0.54-1.18]	1.00[0.87-1.15]	0.98[0.79-1.21]	1.02[0.91-1.15]	0.94[0.78-1.15]
Private dental insurance						
No (ref. Yes)	0.90[0.70-1.15]	1.01[0.67-1.52]	1.05[0.90-1.22]	1.03[0.81-1.31]	1.02[0.90-1.16]	1.02[0.82-1.26]
Socioeconomic						
Income*						
low (ref. high)	1.30[0.97-1.72]	1.32[0.79-2.19]	0.95[0.79-1.14]	1.27[0.97-1.66]	1.00[0.86-1.17]	1.19[0.93-1.52]
medium (ref. high)	1.16[0.88-1.51]	1.13[0.66-1.94]	0.93[0.79-1.10]	1.31[0.99-1.73]	1.01[0.88-1.16]	1.16[0.90-1.50]
Clinical conditions						
Exposed root surfaces[a]	1.01[1.00-1.02]	**1.02[1.01-1.03]**	1.01[1.00-1.01]	1.01[1.00-1.01]	1.01[1.00-1.01]	1.01[1.00-1.01]
Number of teeth	**0.97[0.95-0.99]**	**0.94[0.91-0.97]**	1.01[1.00-1.02]	0.99[0.97-1.01]	1.00[0.99-1.01]	0.99[0.97-1.00]
Oral health behaviours						
Frequency of brushing						
Less than twice a day (ref. Twice a day or more)	**1.60[1.28-1.98]**	1.28[0.87-1.90]	0.90[0.78-1.04]	0.81[0.63-1.04]	1.02[0.91-1.15]	0.91[0.73-1.13]
Frequency of flossing						
Not every day (ref. Once a day or more)	0.91[0.72-1.15]	0.76[0.51-1.13]	1.00[0.87-1.16]	0.97[0.78-1.21]	1.00[0.89-1.13]	0.99[0.81-1.21]
Dental visit						
Last visit is less than 1 year ago (ref. Last visit is more than 1 year ago)	1.09[0.86-1.40]	1.19[0.78-1.82]	**1.39[1.16-1.65]**	1.20[0.91-1.59]	1.14[0.99-1.31]	1.14[0.89-1.46]
Reason of visit						
Problem (ref. Check-up)	**1.65[1.25-2.19]**	**2.44[1.47-4.06]**	**0.80[0.68-0.94]**	0.83[0.65-1.07]	0.91[0.79-1.05]	0.91[0.72-1.14]
Smoking						
Currently smoke or used to smoke (ref. Never smoked)	**1.39[1.08-1.78]**	1.17[0.77-1.76]	1.03[0.89-1.19]	0.92[0.74-1.14]	1.06[0.94-1.20]	1.01[0.83-1.23]

[a] Number of surfaces with gingival recession; PR: Prevalence Ratio; Log Poisson Regression model; 95% CI: 95% Confidence Interval; DS: Decayed Surfaces; FS: Filled Surfaces; DFS: Decayed Filled Surfaces. **Bold**: Significant

Appendix 2. Multivariable analysis of the severity of root caries with explanatory factors among South Australian elders born before 1931 (previous generation/in SADLS1) and those born before 1953 (current generation/in SADLS2)

Risk Indicator	The severity of root caries					
	RDS MR[95% CI]		RFS MR[95% CI]		RDFS MR[95% CI]	
	Previous generation	Current generation	Previous generation	Current generation	Previous generation	Current generation
Socio-demographic						
Age						
60-69 years (ref. >= 70 years)	0.85[0.61-1.19]	0.56[0.26-1.21]	**0.81[0.67-0.97]**	0.90[0.64-1.26]	**0.84[0.72-0.99]**	0.83[0.61-1.14]
Sex						
Female (ref. Male)	**0.64[0.41-0.98]**	0.58[0.27-1.25]	0.96[0.78-1.20]	1.14[0.83-1.56]	0.88[0.72-1.07]	1.05[0.78-1.41]
Highest school/Tertiary qualification						
Senior high school or less (ref. Trade/diploma or higher)	0.72[0.49-1.05]	0.87[0.43-1.75]	0.86[0.71-1.04]	1.10[0.81-1.49]	0.90[0.76-1.07]	1.00[0.75-1.33]
Residential place						
Adelaide (ref. Mt Gambier)	0.75[0.53-1.06]	1.09[0.54-2.17]	0.98[0.81-1.18]	0.79[0.57-1.08]	0.97[0.82-1.14]	0.84[0.63-1.12]
Private dental insurance						
No (ref. Yes)	0.99[0.64-1.51]	1.34[0.64-2.81]	0.93[0.76-1.15]	1.00[0.71-1.40]	1.01[0.84-1.22]	1.09[0.80-1.49]
Socio-economic						
Income*						
low (ref. high)	1.45[0.92-2.31]	1.71[0.71-4.11]	1.01[0.79-1.29]	1.24[0.84-1.84]	1.04[0.83-1.29]	1.18[0.82-1.70]
medium (ref. high)	1.01[0.66-1.56]	1.08[0.43-2.73]	1.15[0.91-1.44]	1.03[0.69-1.55]	1.04[0.85-1.27]	1.08[0.74-1.57]
Clinical conditions						
Exposed root surfaces[a]	**1.03[1.02-1.04]**	**1.03[1.01-1.05]**	**1.03[1.02-1.03]**	**1.02[1.01-1.03]**	**1.03[1.02-1.03]**	**1.02[1.01-1.03]**
Number of teeth	**0.95[0.92-0.98]**	**0.91[0.86-0.97]**	1.01[1.00-1.03]	1.00[0..97-1.02]	0.99[0.98-1.01]	0.98[0.96-1.00]
Oral health behaviours						
Frequency of brushing						
Less than twice a day (ref. Twice a day or more)	**1.77[1.23-2.53]**	1.10[0.52-2.37]	0.84[0.69-1.01]	**0.70[0.49-0.98]**	1.05[0.88-1.25]	0.74[0.54-1.02]
Frequency of flossing						
Not every day (ref. Once a day or more)	1.18[0.81-1.73]	1.01[0.47-2.16]	1.15[0.94-1.40]	0.78[0.56-1.08]	1.19[1.00-1.43]	0.86[0.63-1.16]
Dental visit						
Last visit is less than 1 year ago (ref. Last visit is more than 1 year ago)	0.68[0.46-1.01]	1.16[0.51-2.66]	**1.60[1.28-1.99]**	1.47[0.99-2.19]	1.17[0.96-1.43]	1.35[0.94-1.95]
Reason of visit						
Problem (ref. Check-up)	**2.36[1.52-3.68]**	**2.54[1.15-5.59]**	**0.61[0.49-0.75]**	0.93[0.65-1.34]	**0.76[0.63-0.93]**	0.99[0.71-1.38]
Smoking						
Currently smoke or used to smoke (ref. Never smoked)	1.44[0.99-2.12]	1.56[0.78-3.12]	1.07[0.87-1.30]	0.86[0.63-1.17]	1.15[0.96-1.38]	0.93[0.70-1.24]

[a] Number of surfaces with gingival recession; MR: Mean Ratio; Log Negative binomial regression model; 95% CI: 95% Confidence Interval; DS: Decayed Surfaces; FS: Filled Surfaces; DFS: Decayed Filled Surfaces. **Bold**: Significant

8 Chapter 8: General discussion and conclusion

This Chapter presents an overview of the study, a summary of the main findings, overall discussion of the study, strengths and limitations, implications of the findings for public health and research, and the overall conclusions.

8.1 Overview of study and summary of findings

The purpose of this study was to investigate root caries's distribution and its risk factors in the contemporary population of Australian older adults. Root caries has recently come to the attention of dental research circle and policy makers. A reason for this attention was a dental public health success in improving population oral health, particularly in maintaining the natural dentition in the current generation (as a result of increased life expectancy and the decrease in tooth loss). However, this success may put the older adults at higher risk of developing gingival recession (as a result of ageing and periodontal disease). It has been argued that these conditions could lead to a possible increase in root caries in the current generation, as the exposed root will be in contact with the oral environment. Thus, it has been predicted that with the increased number of teeth retained by older adults, root caries will be a prominent problem in the current generations compared to the previous generation (Reinhardt and Douglass, 1989). This presumption, congruent with the 'failure of success' theory raised by Gruenberg (1977), was part of the 'more teeth, more disease' theory accepted in the dentistry (Joshi et al., 1996). These theories have been checked in a cross-sectional study (Joshi et al., 1996), but never evaluated in a comparative analysis across different generations. Thus, in particular, this study aimed to test the 'failure of success' or the 'more teeth, more disease' theories in relation to root caries among Australian older adults across the generations.

This study applied different approaches to address its aims. There were two hypotheses checked. It was hypothesised that the patterns of population distribution and the population risk profiles of root caries are not different across generations of older adults. In general, the findings of this study showed that root caries was a problem among general and older Australian adults. However, the problem was less in the current generation, despite the increased number of teeth and sites with gingival recession, therefore rejecting the first hypothesis. Furthermore, there is no difference in risk indicators for root caries across generations, therefore supporting the second hypothesis.

Beside those two main findings, the study also showed that there was much variation in methodology in root caries research around the world, which needs to be addressed in future research to be able to get the most advantage out of meta-analysis estimates. This study also showed that root caries increased continuously even among healthier older adults, and the increase was independent of the age of the participants.

8.2 Strengths of this study

The present study has a number of strengths, including the high quality of the primary data and the sophisticated approaches and statistical techniques used. Concerning the data, all three sets of data used in this study (NSAOH, SADLS1 and SADLS2) came from well-designed population-based studies with relatively large sample sizes. The NSAOH was a national survey collecting oral health data among general Australians 15+ years old. SADLS1 and SADLS2 were comprehensive longitudinal studies of the oral health of Australian older adults 60+ years old, conducted 22 years apart. This provided a strength of this study, in having good statistical power to address the aims. As has been shown in the literature review in Chapter 2, there was significant heterogeneity in the methods of data collection and analysis of root caries data around the world. The oral examinations in all of the studies presented in this study involved the same 'gold standard' examiner, thus improving consistency across studies. All of the examiners also undertook a comprehensive training before the examinations were conducted.

Furthermore, this study adopted contemporary analytical techniques such as a systematic review with meta-analysis and meta-regression, as well as a multi-level longitudinal growth modelling technique to address the research aims. This was another strength of the study. A combination of a systematic review with meta-analysis and meta-regression is categorised as an approach that provides a high level of evidence from a body of studies. The application of this approach in root caries data conducted in this research was among the few research projects in the field (Griffin et al., 2004; Leake, 2001). A combination of a systematic review with meta-analysis and meta-regression is theoretically appropriate for addressing Aim 2 of this thesis quantifying the problem of root caries progression (in terms of the incidence and increment) from previously reported studies around the world. This was required as heterogeneity was identified across studies included in the systematic review. Thus, the evaluation of reasons for the heterogeneity among studies using the meta-regression was insightful. In addition, the use of a multi-level longitudinal growth model is innovative in the oral health literature. Searches conducted on the scientific literature confirmed the innovative character of using this approach: the researcher identified only two relevant papers that actually used a multi-level longitudinal growth model (also known as mixed effect model) in presenting the caries progression (Bernabé et al., 2016; Ha et al., 2016). Neither of those studies was conducted with root caries data. In addition to being innovative, the use of this method is theoretically appropriate for addressing Aim 3 of this thesis (to quantify the longitudinal root caries increment), as this method took into account the fact that repeated measures on the same individual are correlated as well as variance between individuals. Furthermore, by allowing time and the intercept (baseline root caries experience) to be random factors, the estimated annual increment of root caries has been adjusted for between-individual variations in baseline caries experience, and overtime changes within individual. Thus, this model took into account the different possibilities in the susceptibility of each individual for developing root caries both in baseline and over-time changes.

To the best as can be ascertained, this study is the first study to use the comparative analysis across generations to test the ‘failure of success’ or the ‘more teeth, more disease’ theories. The SADLS1 and SADLS2, conducted 22 years apart, was an excellent opportunity to conduct a cross-generational comparison of the root caries given minimum intersection in participants between both studies.

8.3 Limitations of this study

Some limitations of this study deserve attention. As all the analysis was secondary data analysis, availability of variables analysed depended on the data that had already been collected. All the explanatory variables were self-reported, and there was no way to control the social desirability bias in participant responses in this study. Furthermore, the oral examinations were conducted in field conditions, and radiographs were not taken. This might contribute to an underestimation of root caries. However, this limitation did not affect the comparative analysis across generations. With filled root caries data, no distinction was made between caries-related and non-caries related root restorations. Walls et al. (2000) undertook a prospective study among general dental practitioners in the United Kingdom and reported that 45% of restorations were undertaken because of decay, while 55% were carried out to treat cervical wear/sensitivity. Accordingly, the inclusion of all root fillings will over estimates root caries. To mitigate this problem, in this study, root caries were presented in the root DS, root FS as well as root DFS formats. However, the root caries findings may also be slightly under estimated as the missing teeth were not included. A slightly under estimation of root caries could also happen through the decision to record arrested cavitated root caries lesion as sound root, given that root caries progression is an intermittent process.

The root caries estimates found in the meta-analysis should also be interpreted with caution given high degree of heterogeneity. However, the use of sub-set analysis study and the use of meta-regression to assess sources of heterogeneity were the recommended ways to limit the problem (Petticrew and Roberts, 2008).

8.4 General discussion of the results

This study provided population estimates of root caries experience in Australia using the NSAOH 2004-06 data, which provides estimates that were representative for all of Australia's states and territories (empirical study 1 in Chapter 4). The root DFS prevalence among general Australian adults 15+ years old (25.3%) was comparable to that reported among adults 21+ years old in Denmark where 26% had root DFS (Christensen et al., 2015). The root DFS prevalence among Australian adults 60+ years old (62%) was slightly lower from 63% prevalence of root DFS reported among older adults 65+ years old in the Iowa study 15 years earlier (Beck, 1990). The prevalence of untreated root caries among general Australians 15+ years old in this study (6.7%) was slightly lower than that reported in the United States, where 9.8% participants aged 20+ years were reported being affected with one or more untreated root caries lesion (Kim et al., 2012). The prevalence of untreated root caries among Australian older adults 60+ years old was lower than among adults aged 50+ and 60+ years in Canada and Germany, respectively, where some 27% had untreated root caries (Locker and Leake, 1993; Mack et al., 2004). The lower root caries prevalence among Australian adults could reflect lower root caries activity, better access to dental services or a combination. However, this could also be caused by the different age of participants or a different decision in presenting root caries cases across studies. Risk indicators found were similar in both the general Australian adult and the Australian older adult populations.

Two studies were conducted to investigate the development of root caries. The first study adopted a combination of a systematic review, meta-analysis and meta-regression methods (presented in Chapter 5), while the other study was an empirical study adopting a multi-level longitudinal growth analysis (empirical study 2 in Chapter 6). Meta-analysis of root caries studies around the world was conducted following a systematic review to provide estimates of root DFS incidence and increment, while meta-regression was used to assess the heterogeneity of studies included. Sub-analysis due to the length and type of study was also conducted. The systematic review and meta-regression showed that root caries studies across the world were diverse, supporting a previous study (Banting, 1986). There is still a lack of consistency in reporting among the studies undertaken and the wide spectrum of the population group investigated. Considering the observed heterogeneity, the result of the meta-analysis should be interpreted with caution. Furthermore, future research should address this concern by conducting root caries research in a similar way to take most advantage of the pooled estimates of the disease. This research found that despite the type of studies, the length of studies influenced the root caries development estimates. It showed that the annual root DFS incidence and increment from studies around the world that were less than two years in length were 32.95% and 0.64 root surfaces respectively, while in the studies which were five years or longer, the annual root DFS incidence and increment were 9.4% and 0.43 respectively. This discrepancy was likely a result of survival bias observed in longitudinal studies of older adults. The estimates from the longer studies were biased to relatively healthier persons remaining for the whole length of study. There is evidence of progression of root caries even among healthier persons.

The results from the systematic review and meta-analysis study also reveal that the research in root caries was very diverse, particularly regarding the population of interest, the measurement applied, as well as the methods in reporting the root caries data. The decision to present root caries data as a simple prevalence and severity in this study by using the DFS index and not the root caries index (Katz, 1996) seems reasonable so as to allow an international comparison following the WHO recommendations (WHO, 2007). Furthermore, the number of surfaces with gingival recession is also used as a predictor in all models.

From the empirical study 2 modelling the root caries increment, it was found that the root DS and root DFS increased by 0.07 and 0.11 surfaces annually, respectively, among Australian older adults over the 11 years of the study. The longitudinal growth analysis also demonstrated that the increase was independent on the age of the participants at the baseline of the study. There was an attrition of the study participants during the 11 years of the study period. People who were lost to follow-up in this study were those with higher root caries at baseline (Slade, Gansky and Spencer, 1997) and those with a higher number of chronic medical conditions (Thomson et al., 2002). Thus, it showed that root caries is still increasing even among older healthier adults, and this supports the previous findings from the combination of the systematic review, meta-analysis and meta-regression study. Findings from these two Chapters showed that the development of root caries continues throughout life; and this also shows that older adults in a community would benefit from preventive programs.

The cross-generational study comparing root caries prevalence from the baselines of SADLS1 and SADLS2 was presented in the empirical study 3 in Chapter 7. It found that after controlling for the number of retained teeth and sites with gingival recession in the two different generations, the current generation of older Australian adults experienced a significantly less root caries compared to the previous generation. Hence, the findings did not support the ‘failure of success’ or ‘more teeth, more disease’ theories in regards to root caries. It should be noted that different rules were applied in SADL1 and SADLS2 in regard to the coding of a lesion when a lesion involved both the coronal and root surfaces. In SADLS 1, the root caries lesion was coded only if more than a half of the lesion was located in root surfaces (‘half rule’). While in SADLS2, the root caries lesion was coded if the lesion extended at least one millimetre to the root surfaces (‘one millimetre rule’). The ‘half rule’ tends to underestimate root caries. Therefore, this difference did not affect the conclusion that the current generation had less root caries than the previous generation. It is likely that water fluoridation played a role in the reduction of root caries across generations. Even though the differences are not statistically significant, people living in the Adelaide region where water has been fluoridated since 1971 seemed to have benefited from water fluoridation than those who lived in Mount Gambier, whose water was only fluoridated almost forty years later. Prevalence of root DFS in Adelaide declined, but did not change in Mount Gambier, and the severity of root DFS decreased in Adelaide, but increased in Mount Gambier. A report from a United States study also showed a significant decrease in the prevalence of root caries among American older adults 65+ years old between 1988–1994 and 1999–2004 (Dye et al., 2007). However, we could not make a comparison on risk indicators, as they were not reported in the study by Dye et al (2007).

In relation to the risk indicators for root caries, in general, the indicators found were similar across all the results. These indicators were relatively different between untreated root caries (root DS) and root caries that includes treated root caries (root FS or root DFS).

Being older, being male, having lower socio-economic status, brushing teeth infrequently, having poor oral hygiene, visiting a dentist only for a problem and smoking were associated with untreated root caries. Further, being older, living in the metropolitan area, visiting a dentist frequently (last dental visit less than one year ago), visiting a dentist for a check-up and smoking were associated with treated root caries. An increased number of surfaces with gingival recession was associated with an increase in root DS, root FS, and root DFS. In terms of flossing, the findings were inconclusive. More flossing was associated with more root FS and root DFS in one finding, but more flossing was also associated with lower DFS in another finding.

The finding that smoking and older age was associated with more root caries, both measured as root DS and root DFS, is consistent with the results of other studies (Banting, Ellen and Fillery, 1980; Bharateesh and Kokila, 2014; Locker and Leake, 1993; Phelan et al., 2004). Some part of this association could be explained through gingival recession, while another explanation could the direct effect of smoking on root caries. Gingival recession increased across age (Albandar and Kingman, 1999; Khocht et al., 1993; Müller, Stadermann and Heinecke, 2002; Pradeep et al., 2012; Serino et al., 1994; Tugnait and Clerehugh, 2001) and was higher in smokers than non-smokers (Chrysanthakopoulos, 2010; Pradeep et al., 2012). Gingival recession exposed the root surfaces to the oral environment, and increased their risk of developing root caries (Lawrence, Hunt and Beck, 1995). Moreover, smoking could contribute to a lower of the buffering capacity of saliva (Wikner and Söder, 1994), while at the same time it could be related to an increased number of *mutans streptococci* and *lactobacilli* (Sakki and Knuuttila, 1996), which become a risk for root caries.

Being male increased the risk of untreated root caries, probably due to generally high-risk behaviours and low utilisation of health services among men (Pinkhasov et al., 2010). Previous research has demonstrated that a routine check-up could be an effective way of promoting good oral health and avoiding disease, as dentists can monitor dental health, suggest preventive treatment or detect disease in the early stages. It also supports our finding that visiting a dentist only for a problem was associated with an increase in untreated root caries.

Poor oral hygiene and infrequent tooth brushing were associated with higher untreated root caries, as supported in a previous study (Vehkalahti and Paunio, 1988). Sugar embedded in dental plaque is a well-known etiologic agent in dental caries (Sheiham and James, 2015). Tooth brushing mechanically removes plaque. Fluoridated toothpaste acts in altering the balance between demineralisation and remineralisation, thus creating a preventive effect against root caries. Our findings also reveal that root caries is socially patterned. People in a lower socio-economic position bear more of the root caries burden. Low socio-economic position has been found associated with less healthy behaviours and limited access to dental services, either treatment or preventive services. A combination of these factors could increase the risk of having untreated root caries lesions.

When root caries measurements include root caries fillings (root caries was measured as root FS or root DFS), it seems that the behaviour related to treatment or dental visits is important. People who visit a dentist frequently (last dental visit less than one year ago) and those visiting a dentist for a check-up had an increase in treated root caries. Filled root surfaces were not differentiated between root caries-related or non-caries-related fillings. These filled root surfaces reflect a treatment decision by the dentist. When treated root caries was included, people living in the metropolitan area showed higher root caries experience. This finding could reflect a previously report showing that people living in the Australian non-metropolitan area were less likely to have been using dental services in the previous 12 months (Brennan, Spencer and Szuster, 1998).

The findings gathered from the cross-sectional and longitudinal analyses in this study were consistent, supporting much of the previous research worldwide. The consistent evidence from the different study types and analyses based on the triangulation approach improved the credibility and robustness of the evidence found (Lawlor, Tilling and Davey Smith, 2017).

8.5 Study implications

8.5.1 Implication for dental public health

This study findings did not support the ‘failure of success’ or ‘more teeth, more disease’ theories in relation to root caries across older adult generations in South Australia. This study showed that across 22 years, the new generation retained more natural teeth, had more gingival recession but less root caries than the previous generation. This indicated a success in preventing root caries. This success might have been a combination of effective population-based programs such as the expansion of water fluoridation and/or the increased adoption of healthy behaviours by individuals. However, despite the success in the reduction in root caries, a significant percentage of Australian older adults still have root caries. Health professionals and policy-makers should use this knowledge to make suggestions and decisions for patients or communities to create better conditions for achieving better oral health for the next generation of older adults.

Preventive efforts should targeting health behaviours especially among disadvantaged population groups, as well as continuing the upstream approach of water fluoridation programs.

8.5.2 Implication for future research

This study showed that studies in root caries around the world are diverse. The diversity includes using different types of root caries measurements, populations of interest, as well as the way researchers presented root caries data. To take the most advantage of a pooled estimate and to provide more robust evidence from a future meta-analysis, there is a need to perform root caries research in a more consistent way.

On the other hand, in the case of diverse research, triangulation was a good method to gather evidence. Triangulation is the practice of obtaining more reliable answers to research questions through integrating results from several different approaches, where each approach has different key sources of potential bias that are unrelated to each other (Lawlor et al., 2017). While findings from the studies pointed to the same direction, triangulation provided better evidence than individual study. This study applied the triangulation method to contribute to the understanding of root caries. Future research is needed to confirm the findings.

8.6 Conclusions

This study examined root caries's distribution and its risk indicators in the contemporary population of Australian older adults, with a particular focus on comparative analysis across generations. It has provided high quality evidence that root caries remains a dental public health problem among Australian adults. However, despite having more teeth and more exposed root surfaces, the current Australian older adult generation has significantly less root caries compared to the previous generation. Thus, the findings of this study do not support the 'failure of success' or 'more teeth, more disease' theories in relation to root caries among Australian older adults. The profiles of risk indicators for root caries has remained stable across the generations.

The specific conclusions are:

1. Root caries (root DFS) affected 25% of Australian adults 15+ years old. This prevalence was as high as 62% among Australian older adults 60+ years old.

2. Past root caries research was diverse in terms of measurements used, populations being investigated, or the ways in which researchers presented the root caries data. This diversity influenced the consistency of the results identified.
3. In order to make the most advantage of a root caries pooled estimate in a future meta-analysis, there is a need for a more uniform approach in conducting and reporting root caries research.
4. The study succeeded in applying a triangulation method in investigating root caries and its risk indicators. By doing so, the study found that root caries increased across age continuously, even among healthier adults. This increase was independent of the starting age of the participants.
5. By applying the triangulation method, this study found that risk indicators for root caries were similar across generations.
6. The risk indicators were different between untreated root caries (root DS), and treatment-related root caries (root FS and root DFS). Risk indicators for untreated root caries (root DS) included age, gender, socio-economic status, tooth brushing frequency, oral hygiene status, reason of dental visit, and smoking. Risk indicators for treated root caries (root FS) and untreated and treated root caries (root DFS) included age, place of living, the latest dental visit, reason for dental visit, and smoking.
7. The current generation of South Australian older adults retained more natural teeth and experienced more gingival recession than the previous generation. However, this current generation had a less root caries, thus rejecting the ‘failure of success’ or ‘more teeth, more disease’ theories.
8. However, a significant proportion of the South Australian current generation still experience root caries; 16.5% and 66% had untreated root caries (root DS) and treated or untreated root caries (root DFS) respectively.
9. A combination of water fluoridation and an increased adoption of a healthy lifestyle including oral health behaviour, it is possible to further reduce root caries disease for the next generation.

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Thesis Appendices

Appendix 1. Ethics approvals for the SADLS2

Appendix 1.1. Ethical approval from the University of Adelaide

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY

LEVEL 7, 115 GRENFELL STREET
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CRICOS Provider Number 00123M

8 July 2015

Dr J Harford
School of Dentistry

Dear Dr Harford

ETHICS APPROVAL No: **H-2012-010**

PROJECT TITLE: **Intergenerational change in oral health in Australia**

Thank you for your request dated 28.05.2015 and 11.06.2015 for an extension to the approved project. The request for extension has been reviewed by the Low Risk Human Research Ethics Review Group (Faculty of Health Sciences) and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants.

The ethics expiry date for this project is: **31 March 2018**.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled *Annual Report on Project Status* is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/ethics/human/guidelines/reporting. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the Information Sheet and the signed Consent Form to retain. It is also a condition of approval that you **immediately report** anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol; and
- the project is discontinued before the expected date of completion.

Please refer to the following ethics approval document for any additional conditions that may apply to this project.

Yours sincerely,

Sabine Schreiber
Secretary, Human Research Ethics Committee
Office of Research Ethics, Compliance and Integrity

Appendix 1.2. Ethical approval from the Australian government

Government of South Australia
SA Health

SA Health Human Research Ethics Committee
Level 10, Citi-Centre Building
11 Hindmarsh Square
ADELAIDE SA 5000
Telephone: (08) 8226 6367
Facsimile: (08) 8226 7088

Dr Jane Harford
Australian Research Centre for Population Oral Health
The University of Adelaide
ADELAIDE SA 5005

Dear Dr Harford,

HREC reference number: HREC/13/SAH/28

Project title: Intergenerational Change in Oral Health in Australia

RE: HREC Application – Final Approval

Thank you for responding to the conditions of approval granted by the SA Health SA Health HREC in relation to the above project.

I am pleased to advise that your application has been granted full ethics approval and meets the requirements of the *National Statement on Ethical Conduct in Human Research*, subject to the following:

- The research must be conducted in accordance with the 'National Statement on Ethical Conduct in Human Research.'
- A progress report, at least annually, must be provided to the HREC.
- When the project is completed, a final report must be provided to the HREC.
- The HREC must be notified of any complaints by participants or of adverse events involving participants.
- The HREC must be notified immediately of any unforeseen events that might affect ethical acceptability of the project.
- Any proposed changes to the original proposal must be submitted to and approved by the HREC before they are implemented.
- If the project is discontinued before its completion, the HREC must be advised immediately and provided with reasons for discontinuing the project.

HREC approval is valid for 3 years from the date of this letter.

Should you have any queries about the HREC's consideration of your project please contact Lauren Perry, Executive Officer of the HREC, on (08) 8226 6431 or hrec@health.sa.gov.au

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You are reminded that this letter constitutes ethical approval only. You must not commence this research project at a SA Health site until separate authorisation from the Chief Executive or delegate of that site has been obtained via the completion of a Site Specific Assessment form. Please contact David van der Hoek via email at ResearchGovernance@health.sa.gov.au to discuss this process further.

The HREC wishes you every success in your research.

Yours sincerely

Andrew Alston
DEPUTY CHAIRPERSON
HUMAN RESEARCH ETHICS COMMITTEE

6/5/13

Appendix 2. Conference abstracts and poster presentations

Appendix 2.1. Transdisciplinary Measurement and Evaluation Research Group (TMERG) meeting, University of Adelaide (Abstract for oral presentation)

TMERG
Transdisciplinary Measurement and Evaluation Research Group

Seminar

Time Trend and Associated Behavioural Factors of Root Caries among Australian – a Multi-level Growth Model

Dr Ninuk Hariyani
PhD Candidate, Adelaide Dental School – UofA
Lecturer in dental public health, Faculty of Dentistry, Airlangga University, Indonesia

PhD Candidate, Adelaide Dental School, UofA
Master of Public Health, The University of Adelaide
Doctor of Dental Surgery, Airlangga University, Indonesia

Date/Time: **Friday, 20 October 2017 - 11.00am – 12.00pm**
Venue: **Kevin Marjoribanks SMaRTE Classroom** (Level 8, Nexus Building)

Please register at **http://education.adelaide.edu.au/research/seminars/**

Abstract:
Root caries has increased as a clinical problem in recent decades. However, the time trend of root caries has not been quantified. The aims of this study were to quantify 11-year trends of root caries experience in elders and to examine behavioural factors associated with root caries.

Methods:
A secondary analysis was undertaken using data collected in four 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 four waves were included. The examinations were performed by trained and calibrated dentists. Baseline behavioural factors (tooth brushing frequency, flossing frequency, dental visiting pattern, reason for dental visiting and tobacco smoking status) and time in years across the four waves were the main exposures. Baseline clinical oral conditions (gingival condition and gingival recession), demographic and socio-economic status 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 linear regression analysis was used to get an estimate for the time trend and associated oral health related behavior adjusting for all the covariates.

Appendix 2.2. 57th Annual Scientific Meeting of IADR Australian & New Zealand Division, Adelaide (Abstract for oral presentation)

CONTROL ID: 2813971

TITLE: Root Caries Incidence and Increment in the Population – A systematic review and meta-analysis of longitudinal studies

Objectives: Meta-analysis of root caries incidence and increment studies are rare. Two previous meta-analysis reported different estimates due to variations in inclusion criteria. More recent publications have also become available. This research aims to do a systematic review and meta-analysis of root caries incidence and increment with meta-regression to analyze the possible sources of heterogeneity.

Methods: A systematic review was conducted for publications in PUBMED and EMBASE. The inclusion criteria include longitudinal studies published in English language prior to 2017, observational population-based and clinical trial studies which presented data on root caries incidence and increment. The selected literature was independently reviewed by 2 authors based on the inclusion exclusion criteria for this systematic review. Data adjustment were performed by two authors independently for consistency checking. A pooled incidence and increment of root caries using decayed, filled root surfaces (DFS) were estimated. Additionally, a meta-regression analysis was performed separately by length of follow-up (<2 years; 2 years; 3-4 years and 5+years).

Results: Among 737 articles, 21 articles were included in the meta-analysis, 16 and 15 articles in the meta-analysis of incidence and increments respectively. For all included studies, the annualised root caries incidence and increment were 18.35% [CI=13.56%-23-14%] and 0.45 [CI=0.37-0.52] root DFS respectively. Length of follow-up time influenced the estimates. The annual root DFS incidence and increment from studies that less than 2 years were 32.95% [CI=29.13%-36.77] and 0.64 [CI=0.38-0.89] root surfaces respectively. In the studies with 5+ years follow-up, the cumulative annualised root caries incidence and increment were 9.4% [CI=3.32%-15.48%] and 0.43 [CI=0.21-0.64] root surfaces respectively. Type of studies (population-based vs clinical trials) did not influence the estimates.

Conclusions: Length of follow-up time is a factor influencing estimates of root caries incidence and increment. Root caries increased continuously in the older adults.

AUTHORS (FIRST NAME INITIAL LAST NAME): N. Hariyani[1, 2], D. Setyowati[3, 2], A. J. Spencer[1], L. Luzzi[1], L. G. Do[1]

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PRESENTER: Ninuk Hariyani

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PREFERRED PRESENTATION TYPE: Oral

Support: No

Support Funding Agency/Grant Number: (none)

AWARDS:

TABLE TITLE: (No Tables)

(no table selected)

(No Image Selected)

Declaration of Helsinki of the World Medical Association Compliance: Declaration of Helsinki of the World Medical Association Compliance

Financial Interest Disclosure - Account create: Ninuk Hariyani: No Answer. | Dini Setyowati: No Answer. | A Spencer: No Answer. | Liana Luzzi: No Answer. | Loc Do: No Answer.

First Publishing/Presentation : First Publising/Presentation Confirmation

Permission to Publish: Permission to Publish

Pre-Registration: Pre-Registration

Appendix 2.3. The 11th Annual Florey Postgraduate Research Conference (Poster)

The prevalence and severity of root caries across Australian generations

THE UNIVERSITY of ADELAIDE

Ninuk Hariyani[1,2], John Spencer[1], Liana Luzzi[1], Jane Harford[3], Haiping Tan[1], Gloria Mejia[4], Kaye Roberts-Thomson[1], Loc Do[1]
[1] Australian Research Centre for Population Oral Health, School of Dentistry, University of Adelaide, South Australia, Australia
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[4] School of Health Sciences, University of South Australia, Australia

Introduction

- Increase in life expectancy and better dental prevention and care resulted in older adults retaining teeth for longer.
- However, retained teeth are more likely to have exposed roots due to gingival recession that may increase risk of developing root caries.
- This presumption congruent with the "Failure of success" theory[1], the "More teeth more disease" theory[2] and opposed the "Compression for morbidity" theory[3].
- However, the theories have not yet been tested using data in different generations.
- Furthermore, there are inter-generation variations can lead to different factors influencing root caries experience.

Aim

- To test the "Failure of success" and the "Compression of morbidity" theories for root caries experience.
- To explore putative risk factors for root caries experience across generations.

Methods

- Two South Australian Dental Longitudinal Study (SADLS) 1 and 2 conducted among Australian elders 60+ years in 1990s and 2010s.
- The studies were conducted using the same methods of sampling and data collection allowing for cross-cohort comparison.
- SADLS1 and SADLS2's participants will represent the generation born before 1931 and 1953 which later called as the previous and current generations respectively.
- **Outcome**: root caries prevalence and severity of:
  - Decayed roots (DS)
  - Filled roots (FS)
  - Decayed or filled root (DFS)
- **Predicted factors**: age, sex, highest education, residential place and private insurance, household income, number of teeth, number of exposed root surfaces, tooth brushing frequency, flossing frequency, dental visit pattern, reason of visit and smoking status.
- Statistical Analysis in SAS 9.4
- The multivariable models of both the previous and current generations were performed using Proc Genmod.

Results

Table 1. Characteristics of SADLS 1 and SADLS 2 dentate participants

clinical condition	SADLS 1 participants (previous generations)	SADLS 2 participants (current generations)
Number of Participants	913	486
	(mean[95% CI])	(mean[95% CI])
Number of teeth (all teeth and teeth roots present)*	16.3[15.8-16.8]	↑ 21.6[21.0-22.3]
Number of surfaces with gingival recession*	26.9[25.8-28.0]	↑ 38.3[36.3-40.1]
Root DS*	0.95[0.74-1.17]	↓ 0.41[0.27-0.56]
Root FS	2.54[2.32-2.76]	2.87[2.49-3.26]
Root DFS	3.49[3.20-3.79]	3.29[2.88-3.70]

Table 2. Multivariable analysis of root caries

Risk Indicator	Root caries outcome					
	Root DS Prevalence PR[95% CI]	Root DS MR[95% CI]	Root FS Prevalence PR[95% CI]	Root FS MR[95% CI]	Root DFS Prevalence PR[95% CI]	Root DFS MR[95% CI]
Generation						
Current generations (ref. generation 22 years ago)	**0.65 [0.47-0.89]**	**0.51 [0.35-0.73]**	0.84 [0.70-1.01]	0.83 [0.69-1.00]	**0.84 [0.71-0.99]**	**0.76 [0.65-0.90]**
Age						
60-69 years (ref. >= 70 years)	0.87 [0.68-1.11]	0.74 [0.54-1.00]	0.91 [0.78-1.07]	**0.80 [0.68-0.94]**	0.93 [0.80-1.07]	**0.82 [0.70-0.95]**
Sex						
Female (ref. Male)	0.82 [0.61-1.10]	**0.62 [0.43-0.89]**	1.01 [0.86-1.20]	0.98 [0.82-1.17]	1.00 [0.85-1.17]	0.90 [0.77-1.06]
Income						
low (ref. high)	1.29 [0.95-1.77]	**1.56 [1.03-2.34]**	1.04 [0.85-1.27]	1.09 [0.88-1.35]	1.06 [0.88-1.28]	1.09 [0.91-1.32]
Clinical conditions						
Exposed root surfaces	**1.01 [1.01-1.02]**	**1.03 [1.02-1.04]**	1.01 [1.00-1.01]	**1.02 [1.02-1.03]**	1.01 [1.00-1.01]	**1.03 [1.02-1.03]**
Number of teeth	**0.96 [0.94-0.98]**	**0.94 [0.92-0.96]**	1.01 [0.99-1.02]	1.01 [1.00-1.02]	1.00 [0.99-1.01]	0.99 [0.98-1.00]
Frequency of brushing						
<2 times/a day (ref. 2+ times/a day)	**1.54 [1.20-1.96]**	**1.53 [1.10-2.11]**	0.89 [0.75-1.05]	**0.80 [0.68-0.95]**	0.99 [0.86-1.16]	0.97 [0.83-1.13]
Dental visit						
Last visit <1 year (ref. Last visit 1+ year ago)	1.14 [0.88-1.49]	0.78 [0.55-1.10]	**1.37 [1.13-1.67]**	**1.64 [1.35-1.99]**	1.16 [0.99-1.36]	**1.27 [1.07-1.52]**
Reason of visit						
Problem (ref. Check-up)	**1.81 [1.32-2.48]**	**2.40 [1.65-3.51]**	**0.81 [0.68-0.96]**	**0.70 [0.59-0.85]**	0.92 [0.77-1.09]	0.84 [0.71-1.00]
Smoking						
Current or former smokers (ref. Never smoker)	**1.36 [1.03-1.79]**	**1.50 [1.08-2.08]**	1.01 [0.88-1.19]	1.01 [0.86-1.20]	1.05 [0.91-1.22]	1.09 [0.94-1.27]

- After controlling for the number of teeth and gingival recession, the current generation of Australian adults has significantly lower root caries experience.
- Gingival recession, brushing less than twice a day, unfavourable reason of dental visit and smoking were predictors for untreated root caries.
- More frequent visit and visiting for check-up were predictors for the increase of filled root caries.

Discussion

- Our finding did not support the "Failure of success" theory/the "More teeth more disease" theory in relation to root caries.
- Despite a significant increase in retained teeth and gingival recession, the current generation experienced lower rate of root caries experience.
- The "Compression of morbidity" theory was applicable in root caries cases in Australia.
- More frequent brushing with fluoridated toothpaste is an important preventive measure for dental caries.
- Smoking was a significant risk factor for root caries experience.
- The current generations seems adopted more healthier behavior.

Limitation

- Unable to conclude whether more teeth retained in middle age in the current generation will translate into more disease in the older age.
- Unable to conclude whether the risk of developing root caries the same across generations.

Conclusion

- The "Failure of success" theory has not been proven in relation to root caries experience.
- Current generation of Australian elders preserves more teeth but has lower root caries cases than the previous generation.
- Predictors for root caries were remain the same across generations.

Acknowlegements

- SADLS 1 baseline study was supported by the National Health and Medical Research Council (NHMRC) Grant No #910557.
- SADLS 2 baseline study was supported by the National Health and Medical Research Council (NHMRC) Grant No #1011589.
- Indonesian Government – DG-RSTHE Scholarship
- Australian Research Centre for Population Oral Health, The University of Adelaide

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2. Joshi A, Douglass C, Feldman H, Mitchell P, Jette A. Consequences of Success: Do More Teeth Translate into More Disease and Utilization? Journal of Public Health Dentistry. 1996;56(4):190-7.
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Appendix 2.4. Research day, Adelaide Dental School. Adelaide Health & Medical Sciences. Adelaide (Abstract for oral presentation)

2017 Adelaide Dental School Research Day

THE UNIVERSITY *of* ADELAIDE

Registration Form **Closing Date Monday 19th June 2017**

APPLICANT DETAILS

Title: Dr **Name: Ninuk Hariyani**

Email address: ninuk.hariyani@adelaide.edu.au

Phone: 0883132556

Position: PhD student **School: Adelaide Dental school**

If student, please indicate your current position and provide relevant details:

☐ **Honours Student** **Year of completion:**

☒ **HDR Student** **Year of candidature commencement: 2014**

☐ **Master** **Year of candidature commencement:**

RESEARCH DAY DETAILS

Are you submitting an abstract?

☐ YES ☐ NO

☒ **Oral** ☐ **Poster**

Would you like to be considered for the Colgate Competition? ☒ YES ☐ NO

If Yes, then you must present an Oral presentation at the ADS Research Day

Title of Presentation: Root Caries Incidence and Increment in the Population – A systematic review and meta-analysis of longitudinal studies

Abstract:

(Up to 250 words including aims, methods, results and conclusion to be included)

Introduction: Meta-analysis of root caries incidence and increment studies are rare. Two previous meta-analysis reported different estimates due to variations in inclusion criteria. More recent publications have also become available. **Methods:** A systematic review was conducted for publications in PUBMED and EMBASE. The inclusion criteria include longitudinal studies published in English language prior to 2017, observational population-based and clinical trial studies which presented data on root caries incidence and increment. The selected literature was independently reviewed by 2 authors based on the inclusion exclusion criteria for this meta-analysis. Data adjustment were performed by two authors independently for consistency checking. A pooled incidence and increment of root caries using decayed, filled root surfaces (DFS) were estimated. Additionally, a meta-regression analysis was performed separately by length of follow-up (<2 years; 2 years; 3-4 years and 5+years). **Results:** For all included studies, the annualised root caries incidence and increment were 19.23% and 0.44 root DFS respectively. Length of follow-up time influenced the estimates. The annual root DFS incidence and increment from studies that less than 2 years were 33% and 0.59 root surfaces respectively. In the studies with 5+ years follow-up, the cumulative annualised root caries incidence and increment were 10.47% and 0.43 root surfaces respectively. Type of studies (population-based vs clinical trials) did not influence the estimates. **Conclusions:** Length of follow-up time is a factor influencing estimates of root caries incidence and increment. Root caries increased continuously in the older adults.

DECLARATION

I declare that to the best of my knowledge and belief, the information supplied in this registration is correct and complete.

Applicant's signature:	**Date:** 15 June 2017

Page **1** of **2**

Appendix 2.5. IADR San Francisco (Abstract for oral presentation)

CONTROL ID: 2627647

TITLE: Time Trend and Associated Behavioural Factors of Untreated Root Caries

AUTHORS (FIRST NAME INITIAL LAST NAME): N. Hariyani[1, 2], A. Spencer[1], L. Luzzi[1], L. G. Do[1]

AUTHORS/INSTITUTIONS: N. Hariyani, A. Spencer, L. Luzzi, L.G. Do, ARCPOH School of Dentistry, The University of Adelaide, Adelaide, South Australia, AUSTRALIA|N. Hariyani, Department of Dental Public Health, Faculty of Dental Medicine Airlangga University, Surabaya, East Java, INDONESIA|

PREFERRED PRESENTATION TYPE: Oral

CURRENT SCIENTIFIC GROUPS & NETWORKS: Behavioral, Epidemiologic and Health Services Research

ABSTRACT BODY:

Objectives: Root caries is known to increase across time. However, the time trend of untreated root caries has never been quantified. The aims of this study were to quantify 11-year trends of untreated root caries experience in elders and to examine behavioural factors associated with untreated 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 1991/92. The study group consisted of a stratified random sample of people aged 60+ years at baseline. 358 participants with complete oral examinations in all four waves were included. The examinations were performed by trained and calibrated dentists. Data of behavioural factors (tooth brushing frequency, flossing frequency, dental visiting pattern, reason for dental visiting and tobacco smoking status) was gathered through baseline interviews. Behavioural factors and time in year were the main exposures. Baseline clinical oral conditions (gingival condition and gingival recession), demographic and socioeconomic status served as covariates. Root caries was measured as mean number of untreated root decayed surfaces (root-DS) at each wave of examination. Bivariate and multivariable analyses for repeated data were conducted. Multivariable Generalized Estimating Equations for negative binomial distribution was used to estimate rate ratio (RR) and their 95% confidence intervals (95%CI) for the time trend and covariates.

Results: Findings from the multivariable models indicated that the annualized rate of developing new root-DS was 1.09 (CI=1.05-1.13), which was significant. Irregular brushing and unfavourable dental visiting behaviours were risk factors for untreated root caries ((RR[CI]=1.51 [1.02-2.22]) and (RR[CI]=1.64 [1.10-2.45]) respectively). Smokers had significantly higher root caries (RR[CI]=1.55 [1.03-2.34]) than never-smokers.

Conclusions: Untreated root caries increased across time. Irregular brushing, unfavourable dental visiting and tobacco smoking were risk factors for increasing root caries. Change in these behaviours should be routinely promoted among elders.

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TABLE FOOTER: (No Tables)

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KEYWORDS: root caries trend, decayed root surfaces, Australian population.

Support Funding Agency/Grant Number - Abstracts: SADLS 1 was supported by the National Health and Medical Research Council and the US National Institute of Dental Research. Grant No. RO1-DE09588.

Financial Interest Disclosure: None

AWARDS: IADR Award-IADR Colgate Research in Prevention Travel Award |IADR Award-IADR Lion Dental Research Award for Junior Investigators |IADR Group/Network Award-IADR BEHSR Outstanding Student Abstract Award|IADR Group/Network Award-IADR BEHSR Lois Cohen International Travel Award

Group Author Abstracts - Abstract:

Session Chair Volunteers - Abstracts: Not Interested

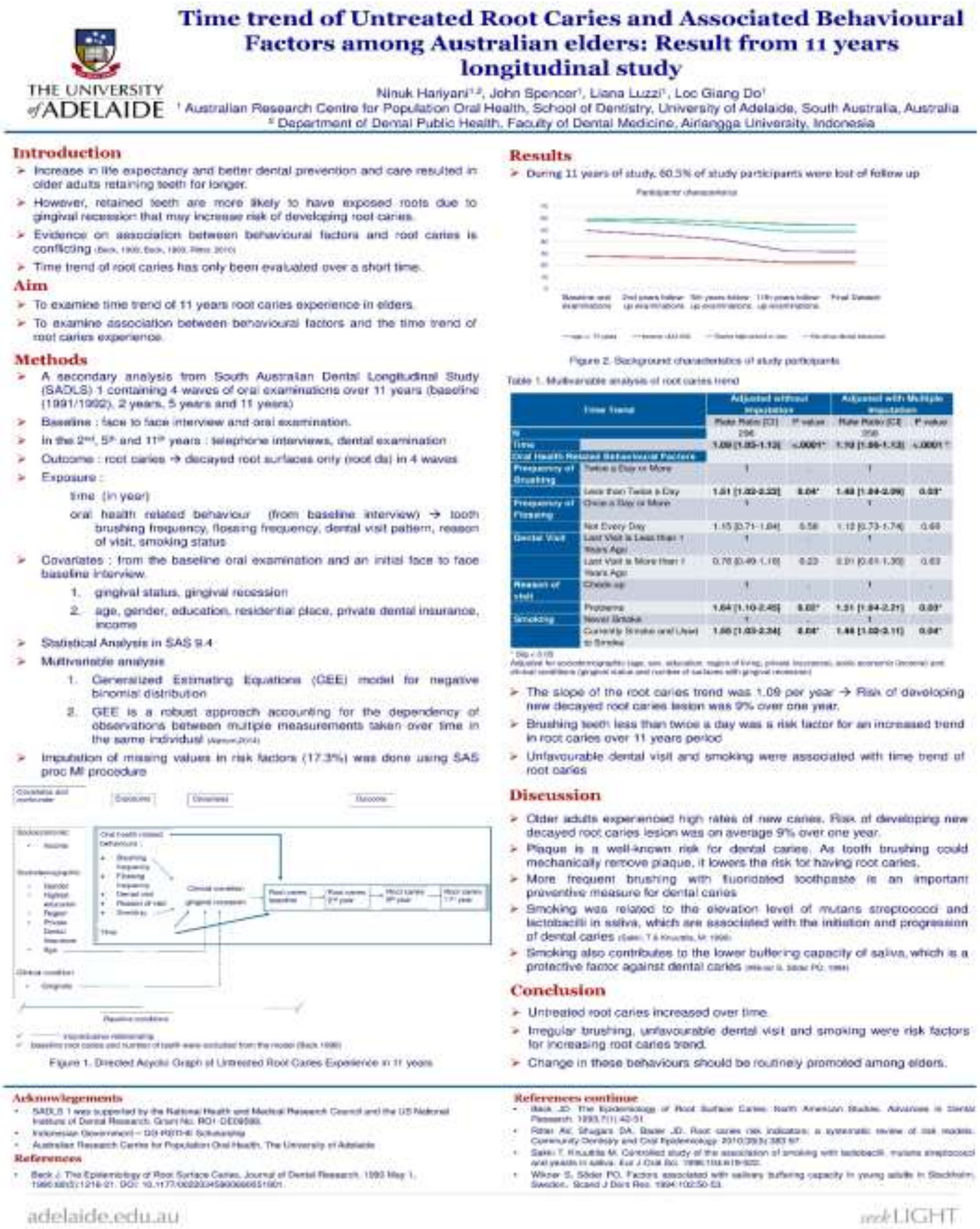
Special Scheduling Needs - Abstracts:

Student Status - Abstracts: PhD Student (after professional degree)

Student Other Designation - Abstracts:

Abstract Submission - Track Selection: Not Applicable

Appendix 2.6. The 10th Annual Florey Postgraduate Research Conference (Poster)



Appendix 2.7. Research day, Adelaide Dental School. Adelaide Convention Centre. Adelaide (Abstract for oral presentation)

RESEARCH DAY 2016
SUBMISSION OF ABSTRACT

Poster ☐ Oral Presentation √

Title of presentation:

Age trend of untreated Root Caries and Associated Behavioural Factors among Australian elders: Result from 11 years longitudinal study

Authors & Affiliations (list affiliation in brackets after name):

Ninuk H (ARCPOH The University of Adelaide; Faculty of Dentistry-Airlangga University)

A John Spencer (ARCPOH The University of Adelaide)

Liana Luzzi (ARCPOH The University of Adelaide)

Loc G Do (ARCPOH The University of Adelaide)

Presenter is: **Ninuk H** ~~Staff/Affiliate /~~ PhD Student ~~/ Masters Student / DClinDent Student / Hons Student~~

Abstract:

Objectives: Root caries is known to increase with age. However, factors associated with the age trend of untreated root caries have rarely been studied. The aims of this study were to examine 11-year trend of untreated root caries experience in elders and to examine behavioural factors associated with the time trend.
Methods: A secondary analysis was undertaken using 4 waves of South Australian Dental Longitudinal Study 1 data. The study group consisted of a stratified random sample of people aged 60+ years at baseline. 358 participants with complete oral examinations at all four waves were included in analysis. The examinations were performed by trained and calibrated dentists. Data of behavioural factors (tooth brushing frequency, flossing frequency, dental visit pattern, reason of visit and smoking status) was gathered through baseline interview. Behavioural factors and time are the main exposures. Baseline clinical oral condition (gingival condition and gingival recession), sociodemographic and socioeconomic status served as covariates. Root caries was measured using mean number of untreated root caries (root DS) at each wave of examination. Bivariate and multivariate analyses for repeated data were conducted to explore associations between variables. Multivariate Generalized Estimating Equations for Negative binomial distribution was used to estimate rate ratio (RR) and their 95% confidence intervals (95%CI) for the age trend and covariates.
Results: Multivariate model reported that the risk of developing new decayed root caries lesion was 1.09/a year. Irregular brushing and unfavourable dental visiting behaviours were risk factors for untreated root caries ((RR[CI]=1.51 [1.02-2.22]) and (RR[CI]=1.64 [1.10-2.45]) respectively). Smokers had significantly higher root caries (RR[CI]=1.55 [1.03-2.34]) than never-smokers.
Conclusions: Untreated root caries increased with age. Irregular brushing, unfavourable dental visit and smoking were risk factors for increasing root caries trend. Changing in these behaviours should be routinely promoted among elders.

Key words: root caries trend, decayed root surfaces, Australian population

Appendix 2.8. 55th Annual Scientific Meeting of the IADR ANZ Division. Dunedin Public Art Gallery, Dunedin, New Zealand (Abstract for oral presentation)

CONTROL ID: 2327221
TITLE: Root Caries Experience among Australians Adults
AUTHORS (FIRST NAME INITIAL LAST NAME): N. Hariyani[1, 2], A. J. Spencer[1], L. Luzzi[1], L. Do[1]
AUTHORS/INSTITUTIONS: N. Hariyani, A.J. Spencer, L. Luzzi, L. Do, ARCPOH, the University of Adelaide, Adelaide, South Australia, AUSTRALIA|N. Hariyani, Department of Dental Public Health, Airlangga University, Surabaya, East Java, INDONESIA|
Group Author Abstracts:
ABSTRACT BODY:
Objectives: Increase in life expectancy and reduction in tooth loss in contemporary Australian adults may increase the population-level risk for having root caries. The aims of this study were: 1. to describe root caries experience in Australian adults. 2. to evaluate association of root caries with socio-demographic and socioeconomic indicators, clinical, and behavioural factors.
Methods: A secondary analysis was undertaken using data from National Survey of Adult Oral Health 2004-2006. The study group consisted of 5,505 persons aged 15-91 years randomly selected by a stratified, multi-stage probability sampling method. Study participants underwent an oral examination, performed by trained and standardized dentists, to determine root caries (defined as prevalence, decayed or filled root surfaces (root DFS) and decayed root surfaces (root DS)), oral hygiene and gingival condition. Questionnaires were administered to collect data on age, sex, education, region, income, toothbrushing, flossing, dental visiting pattern and smoking. Multivariable models were generated, accounted for the complex sampling design, to estimate prevalence ratios (PR) and rate ratio (RR) and their 95% confidence intervals (95%CI).
Results: The root caries prevalence was 25.3%(SE=0.09) with severity in root DFS and root DS was 0.87(SE=0.04) and 0.15(SE=0.01) respectively. Prevalence and severity of root caries significantly increased with older age. The high-income group had significantly lower root caries prevalence (PR[CI]=0.78[0.64-0.95]), mean root DFS (RR[CI]=0.68[0.52-0.89]) and mean root DS (RR[CI]=0.23[0.13-0.42]) than the low-income group. Smokers had significantly higher root caries prevalence (PR[CI]=1.32[1.16-1.50]), mean root DFS (RR[CI]=1.57[1.32-1.85]) and mean root DS (RR[CI]=2.44[1.53-3.88]) than never-smokers.
Conclusions: Root caries has been found affecting a significant proportion of Australian adults. Those from lower socio-economic position and smokers presented a significantly higher prevalence and severity of root caries.
TABLE TITLE: (No Tables)
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TABLE FOOTER: (No Tables)
(No Image Selected)
Financial Interest Disclosure: NONE