THEORETICAL EXPLANATIONS AND EMPIRICAL EVIDENCE FOR THE RELATIONSHIP BETWEEN INCOME INEQUALITY AND POPULATION ORAL HEALTH

by

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Abstract

Background: Over 300 studies have examined the hypothesised negative impact of high income inequality on health outcomes. Oral health is integral to general health. Several studies have examined the association between income inequality and oral health outcomes. A gap exists in the understanding of the theoretical basis for the income inequality and oral health relationship. The literature on income inequality and oral health at the sub-national level is limited to the USA, Japan, and Brazil. Australian evidence on the association between income inequality and general health outcomes is limited and inconclusive, and there is none for oral health. To address these gaps, this thesis by publication answered the following two research questions:

Research Question (I): Which socio-epidemiologic theories can be used to explain the linkages between social inequalities and population oral health?

Research Question (II): Is area-level income inequality inversely associated with population oral health in the Australian context?

Methods: A scoping review identified different types of socio-epidemiologic theories used in the global literature on area-level social inequality and population oral health and analysed their extent of application. A population-based multilevel study used the data on oral health of 5,169 Australian dentate adults nested in 435 Local Government Areas (LGAs) from the 2013 National Dental Telephone Interview Survey (NDTIS-2013) to answer research question (II). Associations were tested between tertiles of LGA-level income inequality and oral health outcomes of inadequate dentition (presence of <21 teeth) and poor self-rated oral health after accounting for covariates. Additionally, the population-based study investigated variations in the tested associations according to tertiles of LGA-level mean household weekly income, as well as, the variations in the household income-oral health gradients according to tertiles of LGA-level income inequality.

Results: The scoping review found that there was limited explicit use of socio-epidemiologic theories in the analytical frameworks of selected studies. The use of psychosocial theory was dominant among all the socio-epidemiologic theories proposed to explain the association between income inequality and oral health outcomes. The population-based study found no associations between LGA-level income inequality and poor self-rated oral health after adjusting for covariates. Contrary to the hypothesis, LGA-level income inequality was inversely associated with inadequate dentition (OR: 0.64; 95% CI: 0.48, 0.87) at the individual level. However, this association was limited to LGAs with high mean income. Individuals with lower household income had poorer oral health, but the household income and inadequate dentition gradients varied according to LGA-level income inequality.

Conclusions: There is a lack of theoretical basis for the association between area-level income inequality and oral health. Increased and explicit testing of theoretical pathways within the analytical framework of studies on income inequality and oral health outcomes is required. Findings from the Australian population-based study do not support the positive associations between area-level income inequality and worse oral health as reported from the USA, Japan and Brazil. These variations are likely due to the contextual differences between Australia, and these contexts including its social and geographic characteristics and consequent implications on distribution of oral health resources.

Word count: 498/500 words

Thesis 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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Notes

Referencing style:

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). Chapters 5 and 6 of this thesis includes papers that are currently under peer-review in the journals Community Dentistry and Oral Epidemiology and Plos One. For consistency, the two manuscripts (Papers 3 and 4) are formatted using the Council of Scientific Editors (CSE) 8th Name-Year in this thesis, but are submitted to the journals following their respective referencing styles.

- Journal: Community Dentistry and Oral Epidemiology: (http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1600-0528/homepage/ForAuthors.html)
- Journal: PLOS One (http://journals.plos.org/plosone/s/submission-guidelines)

Appendices

Appendices submitted along with the publications to the journals are included at the end of Chapters 3 to 6. Appendices for the overall thesis are attached at the end of the thesis.

1. Introduction

Oral health is integral to general health and well-being. Despite being largely preventable, oral diseases affect half of the global population and negatively impact on both individuals and societies (Sheiham, 2005; IHME, 2016). Oral diseases are also more prevalent among individuals and populations with greater social disadvantage than their advantaged counterparts (Watt et al., 2016). The fundamental role of social conditions in determining the variations in oral health within and between societies signifies the importance of addressing social determinants of oral health (Phelan et al., 2010). The economic conditions of individuals and societies among other social determinants are widely recognised as factors that determine individual and population levels of health (Marmot, 2002; 2015).

Globally, high income inequality is well recognised as a social, economic and a political threat (Dabla-Norris et al., 2015). A vast amount of literature suggests that there is an inverse association between income inequality and population health. The hypothesised relationship is that societies with lower levels of income inequality are more likely to have better population health and lower rates of mortality on an average than societies with higher levels of income inequality (Pickett and Wilkinson, 2015). Neo-material, psychosocial, material and behavioural theoretical explanations tend to explain this relationship (Lynch et al., 2000; Marmot and Wilkinson, 2000). Despite a longstanding debate in the discipline of social epidemiology, there is a lack of consensus on which theory best explains how income inequality negatively impacts on population health.

Studies have also examined associations between income inequality and oral health outcomes. Evidence suggests that oral health at a population level is better in societies with lesser income inequality than those with higher income inequality both at the country level and sub-national level (Pattussi et al., 2001; Bernabe and Hobdell, 2010). Multilevel studies have shown that individuals in areas with higher income inequality have relatively worse oral health than those in less unequal areas (Celeste et al., 2009; Aida et al., 2011; Bernabe and Marcenes, 2011). However, the literature on income inequality and oral health is largely deficient on two fronts. First, there is a lack of clarity on the applicability and relevance of theoretical pathways proposed to explain the associations between income inequality and the outcomes of mortality and general morbidity on oral health outcomes. Second, the evidence at the sub-national level is available only from the U.S., Brazil and Japan. Reviews in general health have highlighted a geographic variation in the evidence on income inequality and health, particularly at the sub-national level both by context and the scale of examination (Lynch et al., 2004; Wilkinson and Pickett, 2006). This suggests that the associations between income inequality and oral health may differ contextually. To our knowledge there is no study in Australia that has tested an association between area-level income inequality and oral health, despite the concern with increasing income inequality (Fletcher and Guttmann, 2014; Fleming and Measham, 2015).

This thesis by publication addresses these deficiencies in a two-fold approach. First a theoretical component investigates the theoretical explanations for the relationship between income inequality and oral health. Second, the gap in evidence on income inequality and oral health in Australia is addressed through a population-based study.

1.1 Rationale

The pervasive nature of high income inequality on well-being of societies has important implications for reshaping the economic and political structure of societies to effect a re-distribution of income. In this context, while determinants of individual income may include an individual's education, skills and efforts as a characteristic of the social system, income inequality is determined by a society's history, politics and economics (Lynch et al., 2004).

Therefore, any evidence supporting the role of income inequality as a determinant of health status has important implications for action at a societal rather than individual level.

Determinants of oral health of individuals and societies are not entirely individual, and more and more studies show that societal factors determine the individual and population variations in oral health (Barbato and Peres, 2015). Research supporting the role of societal determinants in shaping the oral health of individuals and populations also builds a case for addressing the structural determinants of health. The combination of high prevalence of oral diseases, and the persistent nature of socioeconomic inequalities in oral health outcomes further reflects an urgent need to examine the structural determinants that systematically generate high levels of disease and its inequitable share according to socioeconomic positions (Watt et al., 2016; Kassebaum et al., 2017)

The literature in social oral epidemiology has lacked explicit attention to social theories (Baker and Gibson, 2014). The evidence on the association between income inequality and oral health also presents a lack of clarity on how socio-epidemiologic theories are applied. Understanding the theoretical pathways through which income inequality impacts on oral health is important to design relevant and effective interventions to reduce, and mitigate the detrimental impact of income inequality on oral health of individuals and population.

Considering the public health burden posed by oral diseases, and the increasing attention paid across societies to income inequality as a social and public health threat, it is timely and crucial to investigate the relationship between income inequality and population oral health.

1.2 Research approach and framework

The project included the following two research questions and corresponding hypotheses:

1.2.1 Research Question (I): Which socio-epidemiologic theories can be used to explain the linkages between social inequalities and population oral health?

Hypotheses:

a) There is a lack of explicit theoretical basis and clarification for the association between social inequalities and population oral health outcomes in the dental literature.
b) Socio-epidemiologic theories can be used to explain the relationship between social inequalities and population oral health outcomes if appropriate conceptual measures of inequalities and the pathophysiology of the outcomes are taken into account.

Aim:

To investigate the evidence on theoretical explanations of pathways and mechanisms through which social inequalities affects population oral health

Objectives:

i. To assess the availability of evidence on the association between area-level social inequality and population oral health according to social theories.
ii. To assess the extent to which the literature on this association is theoretically based
iii. To identify and categorise conceptual and measurement alternatives used in evidence to measure social class or socioeconomic inequalities according to the stratification and relational approaches.

iv. To identify and highlight any gaps in the literature.

Research approach:

A scoping review addressed the aims and objectives for research question (I). The review investigated the types of socio-epidemiologic theories used in the literature to explain the association between income inequality and oral health, and the extent of their integration into the analytical frameworks of primary studies.

1.2.2 Research Question (II): Is area-level income inequality inversely associated with population oral health in the Australian context?

Hypothesis:

Areas with higher income inequality will have poorer oral health, on average, than areas with lower levels of income inequality within Australia.

Aim:

To test if area-level income inequality is associated with oral health outcomes among Australian adults after accounting for individual level association between income and oral health.

Objectives:

i. To test associations between income inequality and oral health outcomes at the individual level after accounting for both area-level and individual-level confounders.
ii. To test the associations between income inequality and oral health according to area-level mean income.

iii. To compare the associations between household income and oral health outcomes under different levels of income inequality.

Research approach: The objectives of the research question (II) were addressed in two steps. First, a detailed theoretical assessment informed the differences in analysing oral health outcomes at the individual and population levels. This assessment focused on the methodological and policy implications related to the level of analysis of the outcome. Second, based on the information generated from the theoretical assessment, a population-based multilevel study on national level oral health data on Australian adults tested the associations between area-level income inequality and oral health outcomes at the individual level.

1.3 Structure of the thesis

The format of this Ph.D. is a thesis by publication. Both published and submitted papers are included as chapters. Additional chapters to describe the overall research include introduction (current chapter), review of literature, and thesis conclusion. Each chapter by publication includes its brief rationale and the conclusion for the chapter that links back to the thesis. This thesis addresses the two research questions collectively through four publications.

Research Question (I): Which socio-epidemiologic theories can be used to explain the linkages between social inequalities and population oral health?

Paper 1: The role of theories in explaining the association between social inequalities and population oral health: a scoping review protocol

Paper 2: Theoretical basis and explanation for the relationship between area-level social inequalities and population oral health outcomes – A scoping review

Research Question (II): Is area-level income inequality inversely associated with population oral health in the Australian context?

Paper 3: Investigating societal determinants of oral health – opportunities and challenges in multilevel studies

Paper 4: Area-level income inequality and oral health among Australian adults – A population-based multilevel study

The thesis includes seven chapters in total. The overall structure of thesis is as follows:

Chapter 1: Introduction to overall thesis (current chapter).

Chapter 2: The review of literature on income inequality and population oral health.

Chapter 3: Methodology to evaluate the evidence on theoretical explanations of pathways and mechanisms through which social inequalities affects population oral health. This chapter includes the first publication that is a scoping review protocol published in the Journal *JBI Database of Systematic Reviews & Implementation Reports.*

Chapter 4: This chapter reports the findings of the scoping review and is published in the Journal *SSM Population Health.*

Chapter 5: This chapter includes the theoretical assessment of aspects critical to testing the association between income inequality and oral health at a population level compared to individual level. The chapter also reviews the methodological aspects related to testing association between income inequality and oral health outcomes as an example of investigation of societal determinants of oral health. This chapter is prepared as a publication and is currently under review in the Journal *Community Dentistry and Oral Epidemiology.*

Chapter 6: Chapter 6 reports findings from the investigation on the association between area-level income inequality and oral health among Australian adults. This chapter is prepared in a publication format and has been submitted for publication in the Journal *Plos One.*

Chapter 7: This chapter presents the overall conclusion for the thesis that includes a summary of research findings, strengths and limitations of the research, possible research and policy implications and my final remarks on drawing conclusions from the findings.

1.4 Research outputs from this thesis

This thesis has led to following research outputs:

i) Singh, A., Harford, J., Watt, R.G., & Peres, M.A. (2014). Role of theories in explaining the association between social inequalities and population oral health – Protocol of a Scoping Review. (Poster presentation at the *8th Annual Florey International Postgraduate Research Conference*, 25th September 2014, Adelaide, Australia).

ii) Singh, A., Harford, J., Watt, R.G., & Peres, M.A. (2015). The role of theories in explaining the association between social inequalities and population oral health: a scoping review protocol. *JBI Database of Systematic Reviews & Implementation Reports*, 13, 11.

iii) Singh, A., Harford, J., Schuch, H.S., Watt, R.G., & Peres, M.A. (2015). Theories on social inequalities and oral health: a scoping review. (Oral presentation at the *55th Annual Scientific Meeting of the IADR Australia & New Zealand Division*, Dunedin, New Zealand, 24-26 August 2015).

iv) Singh, A., Harford, J., Schuch, H.S., Watt, R.G., & Peres, M.A. (2016). Theoretical basis and explanation for the relationship between area-level social inequalities and population oral health outcomes – A scoping review. *SSM - Population Health*, 2, 451-462.

v) Singh, A., Harford, J. & Peres, M.A. (2016). Testing associations between area level social inequality and population oral health within Australia – similar, yet different. (Oral presentation at the 2016 *SA Population Health Conference*, 22nd October 2016, Adelaide, Australia).

vi) Singh, A. (2017). The conundrum of analytical unit when testing the income inequality hypothesis. (Oral presentation at the Behavioral, Epidemiological and Health Services Research Group (BEHSR) Epi-forum at the *IADR/AADR/CADR General Session & Exhibition*, San Francisco, California, USA - March 21, 2017).

vii) Singh, A., Harford, J., Antunes, J.L.F. & Peres, M.A. (2017). Associations between area income inequality and oral health within Australia. (Oral presentation at the *IADR/AADR/CADR General Session & Exhibition*, San Francisco, California, USA - March 22-25, 2017).

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2. Literature Review

Outline of the Literature Review chapter

This section summarises the literature on the relationship between income inequality and population oral health. This Literature Review aims to highlight the gaps in the literature in the relationship between income inequality and population oral health. The review sets the background by establishing the current global emphasis on income inequality as a concern for social well-being and health. The review then specifically leads into the literature with an observation of an association between area-level income inequality and population health at national and sub-national levels. Different types of explanations that are proposed to explain how income inequality may impact on health outcomes are then elaborated. A contrast between socio-epidemiologic theories, that aims to provide the sociological and epidemiological basis for the association between income inequality and health will be highlighted against the alternative explanations that position the association as an artefactual presentation. Next, this section will summarise some key theoretical and methodological aspects critical to the literature on income inequality and health. The global evidence on the associations between income inequality and oral health outcomes will then be reviewed, finally leading into a summary of the Literature Review.

2.1. Income inequality: a social and health concern

According to the Dictionary of Economics, income is defined as the 'flow of returns over a period of time derived from the ownership of *factors of production*.' The factors of production include land, labour, and capital (Pass et al., 1988). The distribution of income has historically gained attention as a topic of discussion among scholars and philosophers across multiple academic disciplines including history, sociology, economics, political sciences, anthropology, political economy and more recently in the field of epidemiology. Inequality or the lack of equality means the state of not being equal. Increasing income inequalities within and between countries has become a global concern as a range of detrimental consequences on social and economic indicators such as inequality of opportunity, negative impacts on economic growth and its sustainability, negative impacts on labour productivity, under-investment in education, and political instability and conflict (Wilkinson and Pickett, 2009; Piketty, 2014; Dabla-Norris et al., 2015). The United Nations lists reducing inequality between and within countries as the tenth goal among seventeen Sustainable Development Goals (SDG) recognising the social and economic threats posed by rising income inequality in societies across the world (UN, 2016).

The relationship between income inequality and poor health has played a central role in the widespread concern about income inequality (Lynch et al., 2004; De Maio, 2012; Muntaner et al., 2012). The idea that income inequality negatively impacts on health and well-being provides an important counter-narrative to the conventional economic wisdom that inequality is necessary and beneficial for economic growth (Wilkinson, 1996; Kawachi and Kennedy, 2002; Muntaner et al., 2012; Piketty, 2014). Wilkinson and Pickett (2009) demonstrated a positive relationship between country-level income inequality and an index of social and health problems including lower rates of life expectancy, maths and literacy, trust, social mobility and higher rates of infant mortality, homicides, imprisonment, teenage births, obesity and mental illness, in rich countries.

2.2. Income inequality and population health: Evolution of the idea and summary of findings

This section summarises the evolution of research on the association between income inequality and population health. The interest in income inequality as a determinant of health arose from the quest to explain why the association between income and health disappeared at high levels of income. This section first highlights the link between three important papers that mark this transition and led to the development of research on the association between income inequality and population health (Preston, 1975; Rodgers, 1979; Wilkinson, 1992). Then the findings from reviews of the evidence on income inequality and general health outcomes will be summarised (Judge et al., 1998b; Wagstaff and Doorslaer, 2000; Macinko et al., 2003; Subramanian et al., 2003; Lynch et al., 2004; Kondo et al., 2009; Wilkinson and Pickett, 2006).

Evolution of the idea

The examination of cross-sectional relationships between rates of national life expectancy and average national income during two decades (1930s and 1960s) of the twentieth century showed an asymptotic curvilinear relationship (Preston, 1975). This non-linear relationship was a likely reflection of diminishing returns in life expectancy to increases in income; and among other explanations, one included the impact of distribution of income at the national level on aggregate life expectancy. Rodgers (1979) analysed data from 56 countries to investigate the relationship between country-level mean income, income distribution, and three different outcomes of mortality: life expectancy at birth, life expectancy at fifth birthday, and infant mortality. The study reported highly significant negative correlations between income inequality and rates of life expectancy at birth, life expectancy at fifth birthday, and infant mortality. A widely-cited study tested the associations between income inequality and life expectancy in the data from the Luxembourg study and reported a significant positive correlation coefficient of 0.86 between life expectancy at birth and the percentage of post-tax and benefit income received by the least well off 70% of families, after accounting for national mean income (Wilkinson, 1992). The observation of a high and significant correlation coefficient between income distribution and life expectancy at the national level suggested that rather than being a by-product of an association between income and health at the individual level, income inequality had an independent association with average life expectancy of a population (Wilkinson, 1992). Since then over 300 studies have examined income inequality as a determinant of health outcomes at both national and sub-national levels (Pickett and Wilkinson, 2015b).

Summary of findings

Several reviews provide collective evidence on the association between income inequality and health outcomes (Judge et al., 1998b; Wagstaff and Doorslaer, 2000; Macinko et al., 2003; Subramanian et al., 2003; Lynch et al., 2004; Kondo et al., 2009; Wilkinson and Pickett, 2006). The reviews show that studies of income inequality and health have examined a wide range of risk factors of diseases and general health outcomes of morbidity, mortality and symptoms. Often these reviews applied specific criteria of analytical design (analytical unit and statistical approaches) for the inclusion of studies when assessing the evidence on income inequality–health relationship and. For example, one review only assessed the evidence from individual-level studies and excluded any ecological study that assessed the association between income inequality and population health (Wagstaff and Doorslaer, 2000). Table 1 presents the overall characteristics of the reviews along with their conclusions.

Table 1. Summary of findings from reviews on the association between income inequality and health

Authors	Year published	Type of review	Studies (n)	Unique health outcomes assessed in reviewed studies	Overall conclusion
Judge et al.	1998	Literature review	12	Infant mortality, life expectancy, neonatal mortality, post neo-natal mortality, age at death, male mortality, height, cause specific death rates, potential life years lost,	Very little support for the view that income inequality is associated with variations in average levels of national health in rich industrial countries
Wagstaff and Doorslaer	2000	Literature review – Individual level studies	6	Life expectancy, self-rated health and 5-year mortality risk	Absolute-income hypothesis most likely to explain observed strong association between population health and income inequality levels
Macinko et al.	2003	Integrative literature review	45	All-cause mortality, self-rated health, cardiovascular risk factors, mortality, infant mortality rate, abdominal obesity, depressive symptoms, low birth weight, coronary disease, cancer, homicide, suicide, chronic medical condition and mental health	33 of 45 studies indicate significant association between income inequality and worse health. Multiple inconsistencies highlighted in the body of evidence: a) differences in model of health determinants b) inconsistent income inequality measures and data c) different geographic settings d) different time periods e) differences in health outcomes

Subramanian et al.	2003	Literature review–Multilevel studies	17	Self-rated health, mortality, cardiovascular risk factors, depressive symptoms and self-reports of 17 common conditions	a) Studies supporting a link between income inequality and worse health exclusively carried out in US. Null studies carried out in more egalitarian countries than US b) Studies with positive findings generally have larger sample size c) More studies on positive findings from US conceptualised income inequality at state levels rather than smaller levels of geographic aggregation
Lynch et al.	2004	Systematic review	98	Life expectancy, infant mortality rate, fertility, height, mortality, sex differential in life-expectancy, homicides, self-rated health, smoking, violent crime rate, property crime rate, all-cause and cause-specific mortality, sexually transmitted disease rates, stroke, physical disability, fertility rate, proportion of adolescent mothers, sex-specific abdominal gain, depression, depressive symptoms, sex-specific mortality, overdose fatality	Little support that income inequality is a major, generalisable determinant of population health differences within or between rich countries. Strongest evidence of direct negative health effects of income inequality is among states in the USA

				versus accidental fatality, alcohol dependence, common mental disorders, health utilities index and low birth weight	
Wilkinson and Pickett	2006	Literature review	155	Population health (No specific outcomes from included studies specified in the paper)	70% of the selected studies suggest that health is less good in societies where income differences are bigger. Substantial differences observed in proportion of supportive findings according to whether inequality was measured in large or small areas. Unsupportive findings by minority of studies due to: a) Studies measured inequality in areas too small to reflect the scale of social differences in a society b) Studies controlled for factors that, rather than being genuine confounders, are likely either to mediate between class and health or be other reflections of scale of social stratifications c) International relationship between income inequality and health lost

					during the decade from mid-1980s when income differences were widening
Kondo et al.	2009	Meta-analysis (Multilevel studies on income inequality, mortality and self-rated health)	28	Mortality and self-reported health	Modest adverse effect of income inequality on health. A possible threshold of income inequality beyond which adverse impacts on health emerge

Overall, the evidence from literature reviews on the association between income inequality and health outcomes is inconsistent. Only one of the seven reviews has provided strong support for the negative association between income inequality and health outcomes (Wilkinson and Pickett, 2006). Three provided moderate support (Kondo et al., 2009; Macinko et al., 2003; Subramanian et al., 2003), and three found no substantive evidence for the association between income inequality and health (Judge et al., 1998b; Lynch et al., 2004; Wagstaff and Doorslaer, 2000). One review of 98 studies indicated that the positive association between income inequality and worse health outcomes is not universal, and limited to a few outcomes (Lynch et al., 2004). While, two reviews concluded that very little support exists proving that income inequality is a determinant of population and individual variations in health (Judge et al., 1998b; Wagstaff and Doorslaer, 2000) (Table 1).

Reviews on income inequality and health have provided valuable and critical insights on conceptual and methodological aspects of investigations on the association between income inequality and health. These insights relate to:

a) differences in theoretical pathways that explain the mechanisms through which income inequality negatively impacts on health outcomes (Macinko et al., 2003; Lynch et al., 2004; Wilkinson and Pickett, 2006),
b) analytical unit for outcomes (Wagstaff and Doorslaer, 2000),
c) level at which income inequality is measured and conceptualised (Subramanian et al., 2003; Wilkinson and Pickett, 2006),
d) variations according to measures of income inequality (Macinko et al., 2003), the threshold effect of income inequality (Kondo et al., 2009).
e) variations in the associations according to health outcomes (Macinko et al., 2003; Lynch et al., 2004),

f) contextual variations and non-universal nature of the association (Subramanian et al., 2003; Lynch et al., 2004),

As sections (2.3 and 2.4) of this Literature Review describes in some of these aspects (a–d) in detail, critical insights on variability in the associations according to health outcomes, and the contextual variations, and non-universal nature of the association, are summarised below.

Variations in the associations according to health outcomes: One of the conclusions made by Lynch et al., (2004) in a systematic review of 98 studies was that most international studies of income inequality and health use general indicators such as life expectancy and all-cause mortality, and there is little evidence of association between income inequality and these outcomes. Within-country studies have examined more specific outcomes such as infant mortality, low birth weight, different causes of death including heart disease and stroke, sexually transmitted disease, depressive symptoms, abdominal weight gain, risk factors of ischaemic heart disease (IHD), and, fatality from drug overdose. Among these outcomes, the review reported that consistent associations are found only in studies from the USA and only with the outcomes of IHD and homicide. Similarly, the review conducted by Macinko et al., (2003) noted that for each health outcome (life expectancy, infant mortality, all cause adult mortality, and self-rated health), there is evidence both for and against an effect of income inequality. Furthermore, Lynch et al., (2004) argued that the association between income inequality and each health outcome may not be associated through the same mechanisms and each outcome may require a different lag time to occur. Therefore, substantial variation may exist in the association between income inequality and health depending on the health outcome examined.

Contextual variations and the non-universal nature of the association: Depending on the historical social, economic and political climate there is considerable contextual variation in the associations between income inequality and health outcomes (Lynch et al., 2004). The strongest evidence for direct health effects of income inequality is among the states in the USA (Lynch et al., 2004). The evidence on the negative association between income inequality and health outcomes was mostly dominant in the USA and studies from United Kingdom, Canada, Sweden, Denmark, New Zealand, Australia and other rich nations reported no associations (Lynch et al., 2004). Differences in the contextual characteristics in the USA and other countries in income definitions and the nature of labour market, universal health care, taxation and social policy, characteristics of neighbourhoods, were offered as possible explanations for the observed differences in the association between income inequality and health outcomes.

2.3. Theoretical explanations for association between income inequality and population health

Theoretical explanations proposed to explain how income inequality negatively impact on health outcomes have received significant attention (Smith, 1996; Lynch and Kaplan, 1997; Muntaner and Lynch, 1999; Muntaner et al., 1999; Wilkinson, 1999; Coburn, 2000a; Lynch, 2000a; Lynch, 2000b; Lynch et al., 2000; Marmot and Wilkinson, 2000; Navarro and Shi, 2001; Navarro, 2002; Macinko et al., 2003; Bartley, 2004; Lynch et al., 2004; Navarro, 2004; Subramanian and Kawachi, 2004; Wilkinson and Pickett, 2006). Two underlying reasons appear as the basis for this attention. First, differences in positions on the theoretical pathways emerge from the differences in the stance on the sociological concepts and dimensions of social inequality that income inequality captures (Muntaner and Lynch, 1999; Muntaner et al., 1999; Wilkinson, 1999). Consequently, this difference leads to different interpretations of the relationship between income inequality and health. Second, the theoretical explanations provide a framework for development of interventions for politicians and policymakers that are likely to reduce the impact of income inequality on health outcomes (Smith, 1996; Muntaner and Lynch, 1999; Wilkinson, 1999; Krieger, 2001; Krieger, 2014).

Theoretical explanations proposed to explain the negative impacts of income inequality on population health are grounded in sociological and epidemiological theory. These explanations are different to the ones used to explain the presence of the association between income inequality and health at the ecological level as an aggregate representation of the association between income and health at the individual level (Judge and Wilkinson, 1995; Judge et al., 1998a; Macinko et al., 2003). Therefore, the latter are data driven and based on analytical limitations.

2.3.1. Socio-epidemiologic theories

Socio-epidemiologic theories are grounded on social relations and systematic distribution and misallocation of social resources relevant to health (Krieger, 2001; Bartley, 2004; Krieger, 2011; 2014). Socio-epidemiologic theories proposed to explain income inequality–health relationships are derivations of theoretical approaches proposed in the *Black Report* to explain how social inequality impacts on health outcomes. The following four theoretical categories were proposed to explain the relationship between social inequality and health (Townsend et al., 1982):

i) Artefact explanations

ii) Theories of natural or social selection

iii) Materialist or structuralist explanations

iv) Behavioural/Cultural explanations

The first two theoretical categories (artefactual explanation and theories of natural or social selection) do not support any causal relationship leading from social class to health, while the latter two emerged as a foundation for theoretical explanations to explain the variations in health outcomes according to social classes. Materialist/structuralist and cultural/behavioural explanations also formed the basis of distinction for theories to explain the negative impact of social inequality on population health outcomes.

Materialist or structuralist explanations: Materialist explanation places importance on the role of economic and socio-structural factors in the distribution of health and well-being. This line of explanation for variations in health status is consistent with the radical Marxian critique on the direct impact of economic conditions on the production of variations in rates of mortality attributed to exploitation and poverty. The theoretical framework stresses the role of material deprivation in the social production of disease. Materialist explanation is contested because variations in health status are still observed in societies that have achieved high levels of economic development. The material deprivation and labour exploitation in such societies is minimal due to trade-union organisations and wage council machinery. A counter-argument to this raised limitation is that in countries that have achieved high levels of economic development, relative rather than absolute deprivation in terms of health resources and material circumstances are more relevant. Consequently, relative deprivation leads to variations in health status according to social positions (Townsend et al., 1982).

Behavioural/Cultural explanations: A behavioural/cultural approach is based upon the independent and autonomous causal role of health behaviours in morbidity and mortality. One version of this theoretical approach values individuals as a unit of analysis. Consequently, this approach stresses life-style and irresponsible behaviour of individuals among certain social groups as the reasons for poorer health. The underlying reasons for such behaviour include lack of education, knowledge and attitudes towards healthy behaviour. Another more theoretically developed version relates to the ‘culture of poverty’ thesis. This approach considers the process of biological and social adaptation at lower levels of social position leading to a structure of norms, ideas and behaviours. This culture develops integrity and stability over time due to its role in helping individuals cope with their environments and impacts on their socialisation practices, and therefore on their health behaviours (Townsend et al., 1982).

The Black Report concluded that choosing between these complex and competing theoretical approaches may be difficult, while the authors believe that the best answer lies in a materialist approach (Townsend et al., 1982). The theoretical approaches discussed in the *Black Report* have been both used to explain health inequalities (differences in health among social groups within a society) as well as differences in average health of societies according to their income distribution (studies of social ecology) (Bartley, 2004). However, some specific theories/theoretical approaches are developed that aim only to explain the relationship between income inequality and average health status at the levels of different geo-political units (Bartley, 2004). Literature on these theoretical explanations are reviewed below:

i) **Materialist explanation:** the materialist explanations stresses the role of environmental factors on health, which tend to vary according the degree of income inequality of a society. Macroeconomic factors such as unemployment and levels of economic development lead to hazardous work and living environments that lead to poorer health on average (MacIntyre, 1997).

ii) **Behavioural:** the behavioural explanations state that societies that are more unequal produce more unhealthy behaviours compared to equal societies. This is either due to individual inadequacies and/or due to the presence of social gradients in health behaviours (MacIntyre, 1997).

iii) **Psychosocial:** at an individual level, the psychosocial explanation claims that inequality impacts on health in two different ways. First, people’s perception of their position in the social hierarchy affects health. Second, lack of control and lower levels of social hierarchy leads to persistent stress that can physiologically lead to poor health or health damaging behaviours that consequently lead to poorer health. Compared to an equal society, in a more unequal society, there is a greater degree of social evaluative threats (comparisons between people). When added with the lack of control and coping strategies, it leads to higher levels of persistent stress. Therefore, a greater decrement in power and control across the social hierarchy in more unequal societies leads to poorer health on average (Wilkinson, 1997; Marmot and Wilkinson, 2000; Bartley, 2004).

iv) **Social Capital:** social capital explanations branch out from the psychosocial explanation as this theory posits that a more unequal distribution in income undermines trust and damages social relationships at a population level (Kawachi et al., 1997; Kawachi and Kennedy, 1999; Macinko et al., 2003). The lack of trust and social support are the key reasons for poorer population health in unequal societies.

v) **Neo-material:** in contrast to the psychosocial and the social capital theories, the neo-material theory posits that more unequal societies tend to have a cluster of lack of material resources, and a systematic underinvestment in social infrastructure, such as healthy public policies that leads to poorer health at a population level (Lynch et al., 2000; Lynch et al., 2004).

Among the different theoretical explanations, a significant debate in social epidemiology persists about the relevance of psychosocial and social capital pathways in comparison to the neo-material pathway to explain the negative impact of income inequality on population health (Muntaner and Lynch, 1999; Muntaner et al., 1999; Wilkinson, 1999; Lynch, 2000a; Lynch, 2000b; Lynch et al., 2000; Marmot and Wilkinson, 2000). An underlying sociological distinction between the two positions is that while the psychosocial and social capital pathways originate from a Durkhemian perspective on collective consciousness and social integration, the neo-material pathway stems from Marxist or rational choice orientation (Macinko et al., 2003). Due to the difference in the origin of the theories, a conceptual challenge also relates to the interpretation of what aspects of social inequality does income inequality capture that is related to poor health or higher mortality rates at the population level (Muntaner and Lynch, 1999; Wilkinson, 1999). Those supporting the neo-material pathway identify income inequality as a product of structural socio-political determinants such as the dominant political paradigm, welfare state, social class relations including exploitation due to unequal distribution of production resources (Muntaner and Lynch, 1999; Muntaner et al., 1999). On the other hand, supporters of psychosocial and social capital pathways identify income inequality as an operational measure of social stratification and hierarchy. They argue that the detrimental impacts of income inequality are related to a higher degree of social stratification. A high degree of social stratification in unequal societies results in loss of trust, social support, and social cohesion. Through jealousy it leads to negative psychological impacts on individuals across the social hierarchy.

2.3.2. Alternative explanations

Preston proposed multiple explanations for the curvilinear relationship between income and life expectancy at a national level (Preston, 1975). Preston's data was inadequate for examining the relationship between income distribution and life expectancy. Nevertheless, he concluded that the curvilinear relationship between national income and health suggests that the distribution of income affects aggregate life expectancy. The justification was that if at the individual level, the dose-response relationship between income and health was linear and similar across nations, then countries with the same average incomes will have the same life expectancy. Therefore, in that case the life expectancy of the population will be a linear function of average income – which was not consistent with his finding. However, if life expectancy is an increasing function of individual income but subjected to diminishing returns, then after a certain level average national income life expectancy is dependent on the variance in distribution of incomes. This explanation of the relationship between distribution of income and average life expectancy as a likely result of curvilinear relationship between income and health, was based in a time when no compelling evidence existed to support that greater income equality would raise life expectancy beyond the level achieved by the rise in average income (Preston, 1975; Lynch et al., 2004).

Wagstaff and Doorslaer (2000) presented five different hypotheses that aimed to explain the different circumstances in which an association can be observed between income inequality and health at a population level. A key conclusion made by the authors was that a relationship consistent with any of the five hypotheses at an individual level may lead to the presence of an association between income inequality and population health at the ecological level (Table 2). Therefore, associations observed at the population level between income inequality and health may not be the only presentation of an independent effect of income inequality on health.

Table 2. Hypothesised relationships between income and health at the individual level and same outcome at the population level *(Wagstaff and Doorslaer, 2000)(permission to reuse obtained from the publisher)*

Hypothesis		Individual level	Community level	Population level
Absolute income hypothesis (AIH)		(1) $h_i = f_I(y_i)$; $(f'_I > 0, f''_I < 0)$	(2) $h_c = f_C(y_c, I_c)$	(3) $h_P = f_P(y_P, I_P)$
Relative income hypothesis (RIH)	[a]	(4) $h_i = f_I(y_i - y_P)$	(5) $h_c = f_C(y_c, y_P, I_c)$	(3) $h_P = f_P(y_P, I_P)$
	[b]	(6) $h_i = f_I(y_i - y_c)$	(2) $h_c = f_C(y_c, I_c)$	(3) $h_P = f_P(y_P, I_P)$
Deprivation hypothesis (DH)		(7) $h_i = f_I(g_i, z)$	(8) $h_c = f_C(y_{c,poor}, I_{c,poor}, z, H_c)$	(9) $h_P = f_P(y_{P,poor}, I_{P,poor}, z, H_P)$
Relative position hypothesis (RPH)	[a]	(10) $h_i = f_I(y_i, R_i)$	(11) $h_c = f_C(y_c, I_c, R_c)$	(3) $h_P = f_P(y_P, I_P)$
	[b]	(12) $h_i = f_I(y_i, R_{i \in N_c})$	(11) $h_c = f_C(y_c, I_c, R_c)$	(3) $h_P = f_P(y_P, I_P)$
	[c]	(13) $h_i = f_I(y_i, R_c)$	(11) $h_c = f_C(y_c, I_c, R_c)$	(3) $h_P = f_P(y_P, I_P)$
Income inequality hypothesis (IIH)	[a]	(14) $h_i = f_I(y_i, I_c)$	(2) $h_c = f_C(y_c, I_c)$	(3) $h_P = f_P(y_P, I_P)$
	[b]	(15) $h_i = f_I(y_i, I_P)$	(16) $h_c = f_C(y_c, I_P)$	(3) $h_P = f_P(y_P, I_P)$

The hypotheses are described below:

a) Absolute Income Hypothesis (AIH): There is an influence of an individual's absolute level of income on their health. The relationship between health and income is concave and each additional dollar of income raises an individual's health by smaller amounts. If all that matters to health is absolute income at an individual level, and the health-income relationship is nonlinear, average health in the society will improve as the average income increases and inequality of income decreases.

b) Relative Income Hypothesis (RIH): An individual’s relative rather than absolute income impacts on his/her health. At the individual level, health depends on the deviation in the income of the individual from the population mean income.

c) Deprivation Hypothesis (DH): Deprivation is a situation when an individual’s income or living standard falls lower than a critical level – the poverty line. The deprivation hypothesis means that rather than the individual’s absolute income, the extent of deprivation measured by the income gap impacts on health at the individual level.

d) Relative Position Hypothesis (RPH): In addition to an individual’s income, his/her position in the income distribution influences his/her health.

e) Income Inequality Hypothesis (IIH): An individual’s health is affected by the societal income inequality. The degree of inequality in one’s society affects his/her health in addition to the absolute-income level.

The AIH has also raised the possibility of the association between income inequality and population health as being a ‘statistical artefact’ as a result of using aggregate rather than individual data – an example of ecological fallacy (Gravelle, 1998; Gravelle et al., 2002). Even with the lack of an impact of income inequality on an individual health per se, just the non-linear relation between income and health at the individual level may lead to an artefactual observation of an association between income inequality and health at the population level from aggregate studies. Therefore, an aggregation problem exists when testing IIH in aggregate data when there is a non-linear relationship between income and health (Gravelle et al., 2002).

2.4. Theoretical and methodological aspects critical to testing association between income inequality and health

A number of theoretical and methodological aspects related to testing the association between income inequality and health are discussed in the literature that require due attention and have key implications on the interpretations on the findings (Blakely et al., 2000; Wagstaff and Doorslaer, 2000; Gravelle et al., 2002; Deaton, 2003; Lynch et al., 2004; Subramanian and Kawachi, 2004; Wilkinson and Pickett, 2006; De Maio, 2007; Goldthorpe, 2010; Kondo et al., 2012). The literature on income inequality and health has been challenged on the grounds of lack of careful handling of the theoretical and methodological aspects (Judge, 1995; Gravelle, 1998; Muntaner and Lynch, 1999; Wagstaff and Doorslaer, 2000; Deaton, 2003; Lynch et al., 2004; Jen et al., 2009; Goldthorpe, 2010). These theoretical and methodological aspects along with their implications on testing associations between income inequality and health are summarised below:

Income inequality as a marker of social inequality

Social inequality is a multi-dimensional concept, and economic inequality is one dimension in which it can occur (Lynch and Smith, 2002). Limitations of income inequality in capturing economic inequality, has also been raised (Sen, 1992; Sen, 1997). Grounded in Rawl’s theory of justice through the concentration on primary goods, Sen (1997) highlighted that the valuation of income as a means to other ends, as well as income being only one among other means. Other means include rights, liberties and opportunities, wealth, and the social bases of self-respect. Additionally, a range of systematic variations including personal heterogeneities, environmental diversities, variations in social climate, differences in relational perspectives, and income distribution within the family, can impact on an individual’s ability to use income to achieve goals for well-being (Sen, 1997). The use of income inequality as a measure of social inequality, when testing its association with population health, has also been critiqued on the basis that it fails to completely integrate with the concept of social stratification (Goldthorpe, 2010).

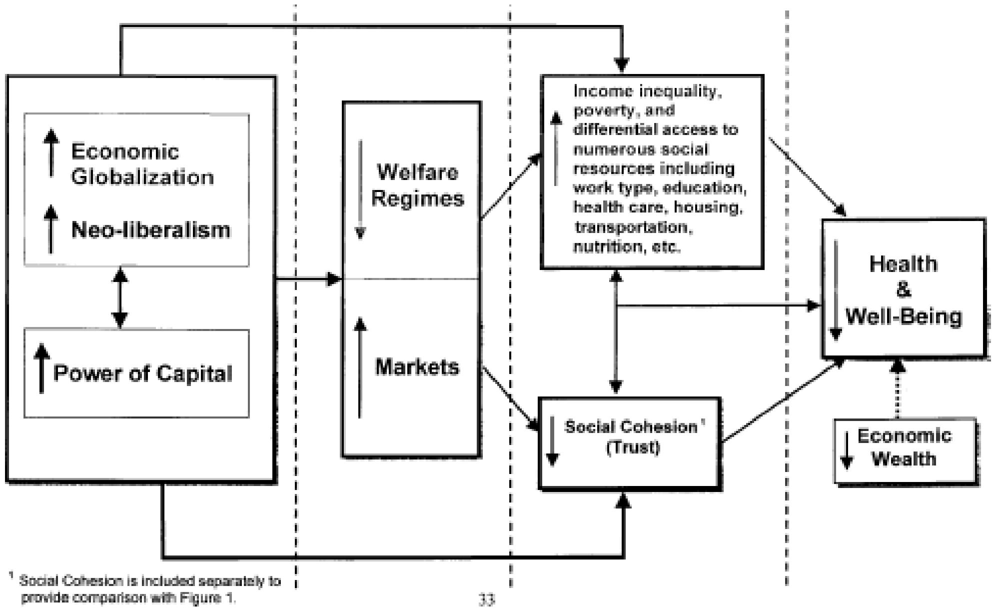
Two contrasting schools of thought have emerged that collectively point towards income inequality as a marker of social inequality from a materialist and Durkhemian perspective. Muntaner and Lynch (1999) consider income inequality as a product of underlying social class relations that are based upon Marxian conflict theory, ownership of production resources, and the consequent exploitation between social classes. On the other hand, in the absence of a qualitative criterion that can demarcate classes, Wilkinson (1999) identifies income as a good and operational basis to provide a picture of social hierarchical ordering. A limitation to using income inequality as a presentation of social stratification is that it fails to clarify the qualitative differences between social 'class' and 'status' and treats social stratification uni-dimensionally (Goldthorpe, 2010). Alternatives to using income inequality as a measure for social inequality proposed in the literature, include class exploitation, and measures based on utility comparisons and quality of life, functioning and capabilities, educational differences, inequalities in distribution of power and wealth, and scores of Social Dominance Orientation Scales (Muntaner and Lynch, 1999; Sen, 1997; Wilkinson and Pickett, 2006). The debate on the use of income inequality as a marker of social inequality, in the research on the association between social inequality and health in the literature, is less detailed (De Maio, 2012). The possibility of an exposure misclassification while testing the association between income inequality and health exists in the light of disagreements about the attributes of social inequality that income inequality captures.

Neoliberalism as an umbrella framework

A theoretical debate has also emerged arguing that the scholarship on income inequality and health has paid less attention to the social context of income inequality (Muntaner et al., 1999), one article which includes neo-liberalism (market-oriented political doctrine) (Coburn, 2000a; Coburn, 2000b; 2004; Coburn, 2015). It is argued that neo-liberalism leads to both high income inequality and lowered social cohesion, and has an additional undermining effect on the welfare state. Collectively, through the effects on income inequality, social cohesion and the welfare state, neo-liberalism leads to poor population health (Coburn, 2000a). This approach towards understanding the income inequality-health relationship reflects the political economy approach that links health effects of income inequality with social and class changes including spread of neo-liberalism, decline of the welfare state, and differences in nations regarding a welfare regime (Coburn, 2004). Because of this thinking, income inequality acts as a proxy for a variety of social conditions, operating through individual and collective, material and psychosocial pathways, rather than income inequality being a single main cause of health (Coburn, 2004). This alternative theoretical model, consistent with the neo-liberalism as a determinant of health was proposed by Coburn as shown in Figure 1.

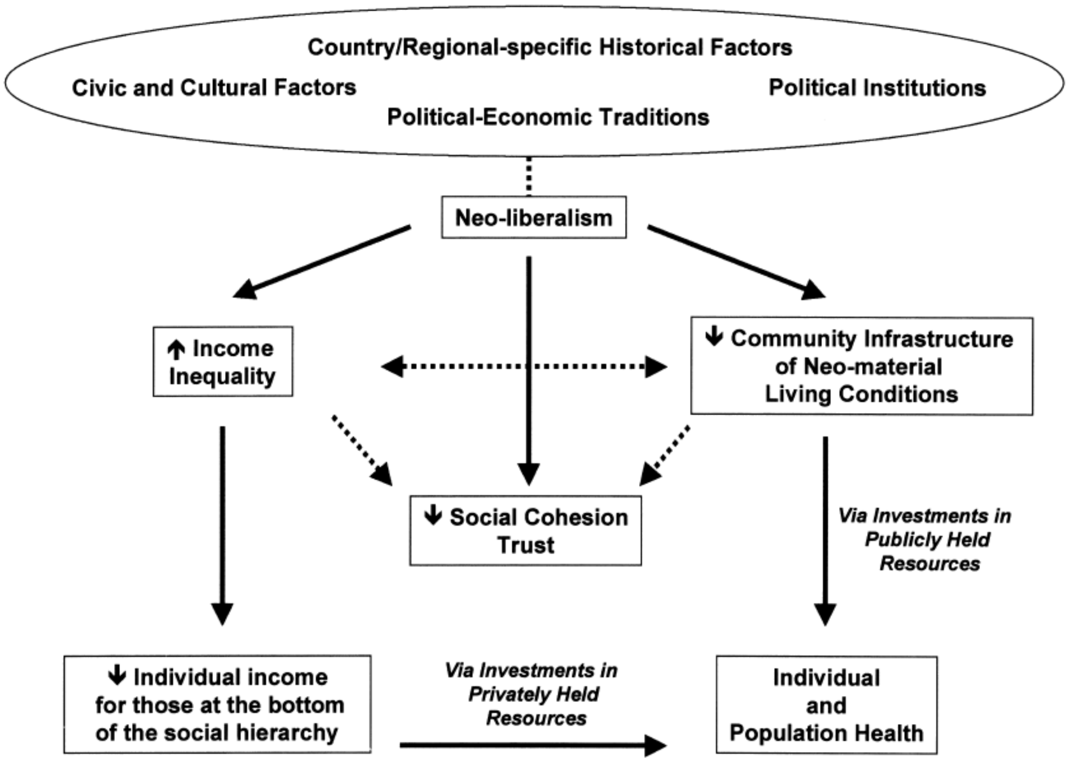
Figure 1. The class/welfare regime model

(Coburn, 2004) (permission to reuse obtained from the publisher)



In agreement with Coburn's neo-liberalism framework, Lynch (2000b) (proponents of neo-material theory) supported that income inequality is one of the important manifestations of historical, political, cultural and economic factors. Apart from determining the pattern of income distribution, these factors shape the context of community infrastructure through policies affecting education, public health services, transportation, occupational health regulations, supply of healthy food, zoning laws, pollution, housing etc. Subsequently, this led to the integration of the neo-material explanation in a neo-liberal framework to explain the negative impact of income inequality on health as shown in Figure 2. However, the role of neo-liberalism as a factor greater than income inequality has also been contested on the grounds that welfare services are unable to explain major differences in rates of health and social problems (Wilkinson, 2000; Wilkinson and Pickett, 2015).

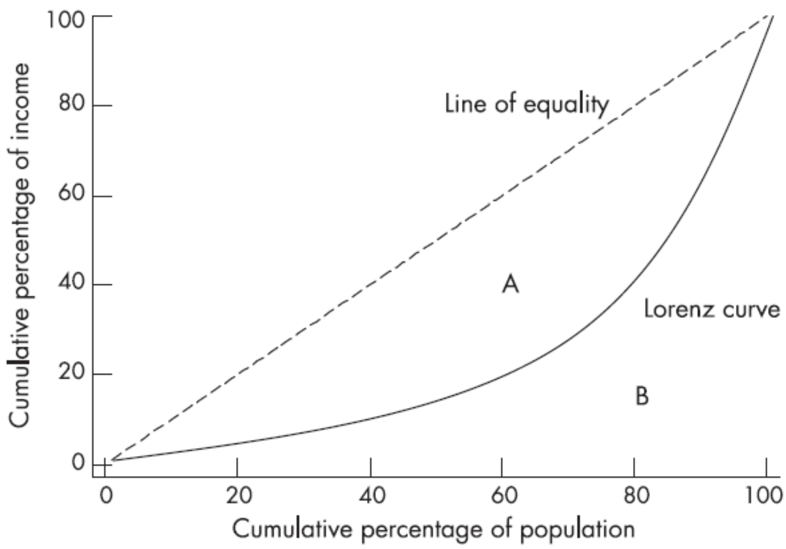
Figure 2. Neo-material interpretation of income inequality and health
(Lynch, 2000b) (permission to reuse obtained from the publisher)



Measures of income inequality

The Gini coefficient is a measure of income inequality that is derived from the Lorenz curve based on distribution of income and population count (Figure 3) (De Maio, 2007). The curve shows the percentage of total income earned by the cumulative percentage of population. It follows a 45-degree line of equality when the total percentage of income is equal to the cumulative percentage of population. With increasing inequality, the deviation of the Lorenz curve from the line of equality increases. A Gini coefficient is equivalent to the size of the area between the Lorenz curve and the line of equality divided by the total area under the line of equality. It has a value between 0 and 1 and a coefficient of 0 reflects perfect equality while a value of 1 is perfect inequality (Liao, 2006; De Maio, 2007).

Figure 3. Lorenz curve framework
(De Maio, 2007) (permission to reuse obtained from the publisher)



As a summary statistic of area-level income distribution the Gini co-efficient is a popular measure in the research on income inequality and health (De Maio, 2007). However, it has limitations in differentiating between different kinds of income inequalities as it is less sensitive to stratified differences in income than to the individual differences in income (Liao, 2006; De Maio, 2007). This reflects the limitation of the Gini coefficient as a measure of income inequality to capture underlying social class inequality (Liao, 2006). As an alternative, Atkinson's Index and Generalised Entropy Index including Theil's entropy measure have a sensitivity parameter that varies in weight given to the inequalities in different parts of the income distribution (De Maio, 2007). Due to the limitations of relying on the Gini coefficient as a measure of income inequality, the validity of the literature on income inequality and health has been questioned (Judge, 1995; Daly et al., 1998; De Maio, 2007). To resolve this issue, associations between income inequality and health have been tested with different measures of income inequality in the same population (Kawachi and Kennedy, 1997; Daly et al., 1998; Weich et al., 2002; De Maio, 2008). The study by Kawachi and Kennedy (1997) reported no differences in the state-level association between income inequality and health in the USA according the measure of income inequality (Gini, Decile ratio, Bottom 50%, Bottom, 60%, Bottom 70%, Robin hood Index, Atkinson and Theil index). The remaining three studies from Argentina, the UK and the USA reported differences in association when subjected to different income inequality measures (Daly et al., 1998; Weich et al., 2002; De Maio, 2008).

Geographic level of aggregation

Income inequality is a societal property that can be attributed only to population groups, not to individuals. Populations can be grouped at different levels of geographic aggregation ranging from small areas such as municipalities and census tracts to states and nations. Therefore, associations between income inequality and health outcomes can be tested at different levels of geographic aggregation (Soobader and LaClere, 1999). A literature review on income inequality and population health noted that studies testing associations between income inequality and health at a larger geographic level found a positive association between income inequality and mortality or morbidity when compared to the studies applied at smaller levels of geographic aggregation (Wilkinson and Pickett, 2006). This pattern was explained by concluding that a larger geographic area serves as a better measure of the scale of social stratification and its hierarchy contrary to smaller areas (Wilkinson and Pickett, 2006; Pickett and Wilkinson, 2015b). The level of geographic aggregation of income inequality also needs to be consistent with the mediating pathways relevant to the health outcomes (Celeste and Nadanovsky, 2010). Consistent with these explanation, four studies evaluated differences in the association between income inequality and health at different levels of geographic aggregation in the USA and Sweden (Soobader and LaClere, 1999; Franzini et al., 2001; Chen and Crawford, 2012; Rostila et al., 2012). Differences in the associations between income inequality and health outcomes were confirmed according to the level of geographic aggregation in all three studies.

Role of residential segregation: structural pathway

Income inequality can lead to an economic residential segregation as the richer individuals from a society can opt to relocate to affluent areas or increase the bid/price for local housing (Kawachi, 2002). Consequent spiralling of costs in housing can lead to the displacement of families with lower levels of income due to the lack of affordability. Consequently, families with lower levels of income will have no choice but to live in residential areas that can be distant from their workplace leading to exposure to high levels of stress. Residential segregation, in particular, impacts on poorer families as they have to live in neighbourhoods with a low tax base and resources for public education, public transport, and other public facilities. Therefore, through residential segregation income inequality can lead to poorer health at an average. In the USA, residential segregation has been shown to partially mediate the association between income inequality and mortality for infants and older adults (65 years and above) (Lobmayer and Wilkinson, 2002). The explanation for the relationship between income inequality and health through residential segregation is known as the structural pathway (Subramanian and Kawachi, 2004).

Role of race, educational attainment and poverty

There is conflicting evidence on the role of race, educational attainment, and poverty in the association between income inequality and health (Muller, 2002; Deaton, 2003; Deaton and Lubotsky, 2003; Subramanian and Kawachi, 2003; Subramanian and Kawachi, 2004; Wilkinson and Pickett, 2006; Pickett and Wilkinson, 2015a; Rambotti, 2015). Deaton and Lubotsky (2003) showed that effects of racial composition confounded the correlation between income inequality and mortality rates at the state and city level within the USA. This evidence of racial composition as the underlying reason for the association between income inequality and mortality in the USA underpinned a strong critique of the overall associations between income inequality and health outcomes (Deaton, 2002; 2003). To resolve this issue, Subramanian and Kawachi (2003) tested the associations between state-level income inequality and self-rated health at the individual level using multilevel modelling to control for the individual effects of race and contextual effects of racial composition. Despite the adjustment of both individual race and racial composition at the state level, an association between state-level income inequality and poor self-rated health was observed (Subramanian and Kawachi, 2003).

There is also a lack of clarity on the role of educational attainment in the association between income inequality and health (Muller, 2002; Subramanian and Kawachi, 2004; Wilkinson and Pickett, 2006). A study reported that the percentage of people without a high school diploma explained the association between income inequality and mortality rates at the state level in the USA (Muller, 2002). However, findings from a multilevel study on income inequality and self-rated health was not consistent with this report, and found only attenuation of odds ratios on inclusion of educational attainment, while the association remained significant (Subramanian and Kawachi, 2004). Wilkinson and Pickett (2006) argued that the adjustment for educational attainment when testing the association between income inequality and health outcomes might be inappropriate, as it is likely to be on the causal pathway.

Rambotti (2015) tested whether the effect of income inequality on health was stronger in high-poverty areas than low-poverty areas and found a significant interaction was observed between income inequality and poverty, and income inequality-affected life expectancy only in high-poverty countries but not in low-poverty countries. Income inequality affected health and social problems in all countries, but more strongly in countries with high poverty (Rambotti, 2015). However, Pickett and Wilkinson (2015a) defended that large volume of literature that shows that health effects of income inequality are across the income scale and not dependent on poverty.

Clarifying slope and level effects of income inequality

Many studies have examined whether societies with higher levels of income inequality have lower levels of average life expectancy compared to societies with lower levels of income inequality (Pickett and Wilkinson, 2015b; Truesdale and Jencks, 2016). However, very few studies have examined whether income inequalities in health outcomes are larger in societies with higher levels of income inequality expectancy compared to societies with lower levels of income inequality (Truesdale and Jencks, 2016). To differentiate between the two types of studies, the effect of income inequality on the average health outcome at the societal level is termed as the *level* effect while the effect of income inequality on the association between individual/household income and health is termed as the *slope* effect (Truesdale and Jencks, 2016). Truesdale and Jencks (2016) argued that the link between the level and slope effects of income inequality on average health and the magnitude of health inequalities has been neglected in the literature. They state that the two types of effects should be seen as complementary. The possible effects of increasing income inequality on health, at the individual and societal level, through both the level and slope effects, was shown using a framework diagram (Figure 4). Existing theoretical explanations (discussed above in the Literature Review) were used to explain how income inequality may impact on average health at the societal level as well as the individual/household income relationship (Truesdale and Jencks, 2016).

Figure 4. Slope and level effects of income inequality on health (Truesdale and Jencks, 2016)

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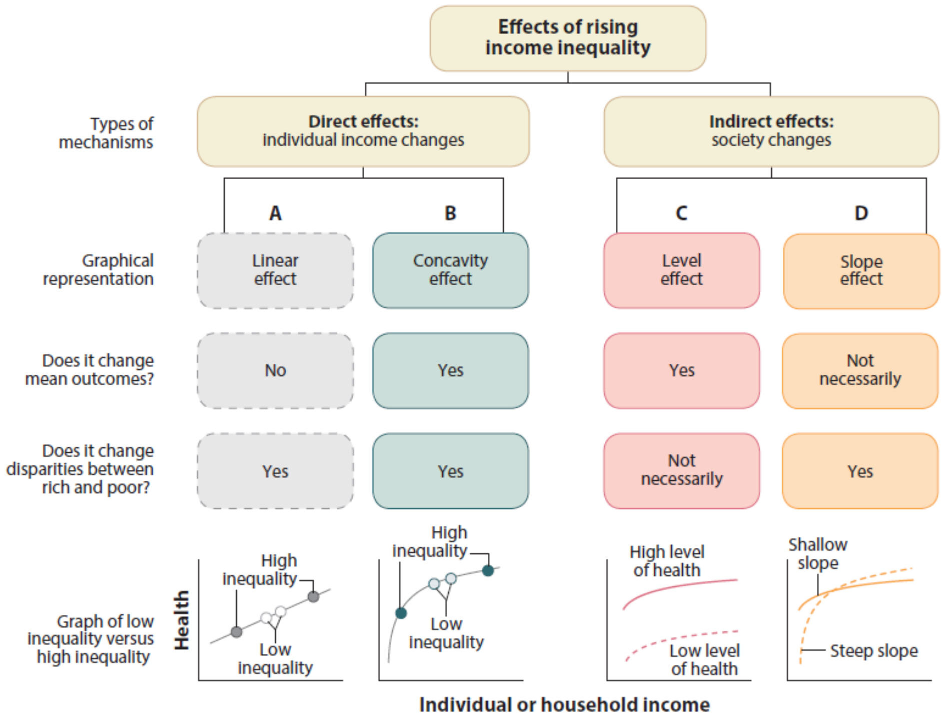

Level of analytical unit and choice of statistical modelling

The possibility of an artefactual presentation of the non-linear relationship between individual income and individual health at the population level as an association between income inequality and health has had significant implications on the level at which health outcomes are analysed and the choice of statistical modelling (Wagstaff and Doorslaer, 2000; Gravelle et al., 2002; Subramanian and Kawachi, 2004). Suggestions have been made that any true effects of income inequality on health can only be tested at an individual level, as the population-level presentation of an association can be due to reasons other than the impact of income inequality on health (Wagstaff and Doorslaer, 2000; Gravelle et al., 2002). In order to resolve this issue and the limitations in ecological analysis of income inequality and health, the use of multilevel statistical analysis is recommended over single level regression models. This relates to its advantage in being able to test the contextual effect of societal income inequality on health at the individual level, after accounting for the individual income-health relationship (Subramanian and Kawachi, 2004).

Inequality threshold, period effects and lag effects

A meta-analysis of multilevel studies on income inequality and the health outcomes of premature mortality and poor self-rated health has pointed out that the income inequality-health association are stronger in societies where the average income inequality is higher (threshold effect). Period effects of income inequality on health typically after and around 1990 were also reported. The meta-analysis also showed that studies that incorporate a time lag between income inequality and health also provide stronger evidence on the association between income inequality and health compared to the studies that do not (Kondo et al., 2012). Variations in the associations according to different lag times between income inequality and the outcomes of self-rated health, (Blakely et al., 2000) and dental caries (Celeste et al., 2011) have been reported.

2.5. Income inequality and oral health

Oral diseases are highly prevalent, associated with high economic costs and negative impacts on labour productivity, and have detrimental impacts on individual’s quality of life as they cause pain and discomfort, affect chewing ability, impact on aesthetics and consequently social interaction and productivity (Sheiham, 2005; Marcenes et al., 2013; Listl et al., 2015).

Oral diseases impact 3.5 billion individuals or 50% of the global population. The worldwide prevalence of oral diseases in 2015 ranged from 1.9% to 35.8% in the following decreasing order: dental caries (tooth decay) in permanent teeth (38%), deciduous caries (tooth decay in primary teeth) (9.8%), periodontal disease (gum disease) (7.6%), edentulism (complete loss of teeth) and severe tooth loss (3.9%), and other oral disorders (1.9%) (IHME, 2016).

Several studies have examined the association between income inequality and oral health outcomes in different contexts and with multiple oral health outcomes (Pattussi et al., 2001; Peres et al., 2003; Bernabe et al., 2009; Celeste et al., 2009; Bernabe and Hobdell, 2010; Celeste and Nadanovsky, 2010; Sabbah et al., 2010; Aida et al., 2011; Bernabe and Marcenes, 2011; Celeste et al., 2011; Vettore et al., 2013; Bhandari et al., 2014; Chalub et al., 2014; Goulart and Vettore, 2015; Vettore and Aqeeli, 2015). Studies on income inequality and oral health outcomes exist at both country level (Bernabe et al., 2009; Bernabe and Hobdell, 2010; Sabbah et al., 2010; Bhandari et al., 2014; 2015) and at sub-national levels from Japan (Aida et al., 2011), the USA (Bernabe and Marcenes, 2011; Moeller et al., 2017) and Brazil (Pattussi et al., 2001; Peres et al., 2003; Celeste et al., 2009; Celeste and Nadanovsky, 2010; Celeste et al., 2011; Vettore et al., 2013; Chalub et al., 2014; Goulart and Vettore, 2015; Vettore and Aqeeli, 2015). Findings for various oral health outcomes are summarised below:

Outcomes of dental caries

The DMFT (mean count of decayed, missing and filled teeth) Index is a widely used composite Index to estimate the population levels of dental caries for epidemiological purposes. At a country level, a study analysed data on oral health of 35-44 year olds from 18 rich countries and reported that while income inequality measured by the Gini coefficient and 20:20 ratio was inversely related to the number of filled teeth and overall DMFT score, it was not associated with the number of decayed or missing teeth (Bernabe et al., 2009). A second study analysed the association between country-level income inequality and the DMFT Index among 5-6 year-old children. The authors found that among rich countries income inequality was significantly correlated with DMFT Index (Bernabe and Hobdell, 2010). At a sub-national level, three studies from Brazil have examined the association between income inequality and dental caries (Pattussi et al., 2001; Peres et al., 2003; Celeste et al., 2009). Two reported positive associations between income inequality and outcomes of dental caries, with the study by Peres et al. being the exception.

Periodontal disease

A country-level study analysed data from 17 rich countries and showed income inequality to be positively associated with periodontal disease (Sabbah et al., 2010). At a sub-national level, two multilevel studies from Brazil have examined the association between income inequality and health (Celeste et al., 2011; Vettore et al., 2013). While one study found a positive association between income inequality and severe periodontal disease (Vettore et al., 2013), the other study reported a lack of association (Celeste et al., 2011).

Tooth loss

The associations between income inequality and tooth loss have been tested only at the sub-national level in Brazil, the USA and Japan (Celeste et al., 2009; Celeste and Nadanovsky, 2010; Aida et al., 2011; Bernabe and Marcenes, 2011; Celeste et al., 2011; Goulart and Vettore, 2015; Chalub et al., 2016). Different definitions of tooth loss were applied across the studies. A study of Japanese adults reported a positive association between income inequality and having less than 20 teeth (Aida et al., 2011). An investigation of the association between state-level income inequality and tooth loss among individuals in the USA reported a positive association. Tooth loss was treated as an ordinal variable with three different cut-offs: missing 1 or more teeth vs. missing no teeth, missing 6 or more teeth vs. missing no more than 5 teeth, and missing all teeth vs. missing some but not all teeth (Bernabe and Marcenes, 2011). Five studies from Brazil have analysed the association between income inequality and tooth loss

(Celeste et al., 2009; Celeste and Nadanovsky, 2010; Celeste et al., 2011; Goulart and Vettore, 2015; Chalub et al., 2016). Of the five studies, positive associations between income inequality and at least one outcome of tooth loss is reported in three studies (Celeste et al., 2009; Celeste and Nadanovsky, 2010; Goulart and Vettore, 2015). These outcomes included a count of missing teeth and missing at least one tooth among 15-19 year olds (Celeste et al., 2009; Celeste and Nadanovsky, 2010) and severe tooth loss (having fewer than nine teeth) and lack of functional dentition (having fewer than 21 natural teeth) (Goulart and Vettore, 2015). It should be noted that Goulart and Vettore (2015) tested the associations between the relative increase in income inequality and the outcomes of severe tooth loss and lack of functional dentition. Therefore, this study tested the change in income inequality over time, as the exposure that cannot be compared with studies that evaluated income inequality at only one time-point.

Subjective oral health outcomes

Two studies have tested associations between income inequality and subjective oral health outcomes (Vettore and Aqeeli, 2015; Moeller et al., 2017). One tested the association between income inequality and oral health-related quality of life (OHRQoL) among 35-44 year old Brazilian adults at a sub-national level (Vettore and Aqeeli, 2015). The study did not find an association between income inequality and overall OHRQoL scores, whereas positive associations were reported for the outcomes of negative oral health impacts on emotional status, work, and social contact (Vettore and Aqeeli, 2015). The second study, conducted among adults in the USA reported inverse associations between income inequality and self-rated oral health and life satisfaction related to oral health (Moeller et al., 2017).

Dental care utilisation

Three studies have investigated the associations between income inequality and dental care utilisation at the country-level (Bernabe et al., 2009; Bhandari et al., 2014; 2015). All reported an inverse association between income inequality and dental care utilisation.

Other oral disorders

One study tested the association between income inequality and malocclusion at a sub-national level among 15-19 year olds and reported no association (Celeste and Nadanovsky, 2010). Another study tested correlations between income inequality and oral cancer incidence and mortality between 120 countries. They reported a positive association between income inequality and oral cancer incidence and mortality across all countries, but did not find an association when the analysis was restricted to rich countries (Jaewedkar and Bernabe, 2012).

2.6. Conclusions drawn from the chapter

A large volume of literature has shown that societies that are more unequal have poorer average health compared to less unequal areas. Multilevel studies have shown that individuals in societies with more income inequality are more likely to have worse health outcomes than those in societies with less income inequality. However, this evidence has been criticised both on theoretical and methodological fronts. Socio-epidemiologic theoretical pathways/frameworks are critical to explaining how income inequality can negatively impact on health outcomes. Disagreements persist on the relevance of different theoretical pathways that are proposed to explain how income inequality may impact on health outcomes. Evidence from general health has shown that depending on the historical social, economic and political climate there is considerable contextual variation in the associations between income inequality and health outcomes. Additionally, the evidence on associations between income inequality and health varies substantially at the sub-national levels.

This Literature Review highlights a lack of consensus on multiple theoretical and methodological aspects related to the research on income inequality and health. These theoretical and methodological aspects need to be acknowledged and possibly addressed from the study design stage to the stages of analysis and make inferences cautiously to understand the impact of income inequality on health outcomes.

The review showed that evidence exists on the associations between income inequality and oral health outcomes both at the national and sub-national level. However, studies on the associations between income inequality and oral health at the sub-national level are limited to only three countries (USA, Brazil and Japan). This is an important gap in the evidence in the oral health literature, as evidence generated on the ill effects of income inequality on population oral health in one context may have limited relevance for another context.

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‘He who loves practice without theory is like the sailor who boards ship without a rudder and compass and never knows where he may cast’

- *(Leonardo da Vinci 1452-1519)*

3. The role of theories in explaining the association between social inequalities and population oral health: a scoping review protocol

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Contribution to the Paper	Developed the protocol, registered the title, drafted the manuscript and acted as the corresponding author		
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.		
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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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Contribution to the Paper	Supervised development of work, provided critical feedback on draft, manuscript evaluation and editing
Signature	Date 6/6/2017

This chapter is by publication and informs the methodology to address the first research question:

'Which socio-epidemiologic theories can be used to explain the linkages between social inequalities and population oral health?"

3.2 Rationale for the publication

Evaluation of the application of socio-epidemiologic theories to studies of income inequality and oral health is complex. A limited number of studies have examined the extent to which theories have been applied to a specific research question in social epidemiology (Campbell et al., 2014; Krieger, 2014). A lack of such theoretical assessments in oral health is well highlighted (Baker and Gibson, 2014). Campbell et al. (2014) applied a systematic review approach to review theories that are proposed to explain a causal relationship between income and health. Limitations of the systematic review methodology in the assessment of the theoretical basis and its integration in the analytical strategy of primary studies, are well highlighted in the published methodological paper (Campbell et al., 2014).

The strict inclusion and exclusion criteria for studies in a systematic review methodology can significantly limit the inclusion of potentially useful studies that can be drawn from a relatively limited literature on income inequality and oral health. Systematic reviews were developed to either quantitatively or qualitatively summarise the evidence on effectiveness of treatments or strengths of associations between an exposure and outcome, after accounting for the methodological rigour of included studies. This purpose is inconsistent with the objective of mapping different types of socio-epidemiologic theories applied in the literature on income inequality and oral health, and to evaluate the extent they are embedded in the analytical design. Therefore, a methodological gap exists in addressing the first research question designed in this thesis. To address the limitations of existing methodological alternatives to comprehensively address the first research question, a review protocol was drafted and published in the *JBI Database of Systematic Reviews & Implementation Reports*.

Scoping review as an alternate and more suitable review method

A scoping review is more inclusive in approach towards identification and selection of studies than a systematic review. Compared to a systematic review, a scoping review provides more flexibility to map different types of socio-epidemiologic theories and to analyse the extent of their incorporation in the analytical design of individual studies. The purpose of conducting a scoping review is to map the extent of literature when there is a lack of clarity regarding the evidence base. This purpose was consistent with the background on the lack of theoretical assessments in studies of social inequalities and oral health (Levac et al., 2010). The iterative process of refining the search strategy in a scoping review to identify relevant literature allows the search to be more inclusive of studies on social inequality and oral health. Additionally, a scoping review does not strictly require a quality assessment of included studies as it does not aim to summarise the evidence according to methodological rigour of selected studies. The systematic review approach is more relevant to a research question that aims to summarise the evidence on the strength and direction of association between income inequality and oral health, but not to examine their theoretical basis. However, a scoping review applies similar steps to that of a systematic review including systematic selection, collection and summarising of existing knowledge in a broad thematic area, but with a more flexible design.

PAPER 1

The role of theories in explaining the association between social inequalities and population oral health: a scoping review protocol

http://journals.lww.com/jbisrir/Fulltext/2015/13040/The_role_of_theories_in_explaining_the_association.4.aspx

The role of theories in explaining the association between social inequalities and population oral health: a scoping review protocol

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Review question/objective

There is a lack of explicit theoretical basis and clarification for the association between social inequalities and population oral health outcomes in the dental literature. This scoping review aims to gauge and explore the existing evidence on theoretical explanations for pathways and mechanisms through which social inequalities affects population oral health. The objectives of this scoping review are:

1. To organize and present the existing evidence on the association between social inequalities and population oral health according to social theories.
2. To identify and categorize conceptual and measurement alternatives used in the existing evidence to measure social class or socio-economic inequalities according to either stratification or relational approach.
3. To highlight the existing gap in evidence for future research implications in this field.

Specifically, this review seeks to answer the following question:

- What is the nature and extent of social theories being used as a basis to explain the associations between social inequalities and population oral health in the existing literature?

Background

In the past few decades a vast amount of literature on the effects of social inequalities on a range of population health outcomes has emerged. This includes outcomes such as mortality, life expectancy, self-rated health, hypertension and suicide, among others.[1-11] Studies assessing the effects of area level inequalities on population level health outcomes are termed as studies of 'social ecology'.[1] Since the 1980s, Richard Wilkinson, in a series of publications, highlighted how income inequality (a marker of social inequality) is a key determinant of population health and is relevant to economic and public health policy.[9,11-13] Several studies in the 1990s examined the relationship between inequality and population health outcomes and reported consistent findings regarding detrimental effects of income inequalities.[5,14-17] Despite these findings, a systematic review of 98 aggregate studies examining income inequality and population health concluded that there is little support that income inequality is a major, generalizable determinant of population health differences within or between countries but that it may have a direct influence on some population health outcomes, like homicides, in some contexts.[8] In the past two decades many studies have preferred a multi-level modelling over an ecological study design for social ecology studies due to its advantage of clarifying the independent effects of individual and aggregated level inequalities on population health outcomes.[18] A recent meta-analysis of multi-level studies reported that income inequality was only associated with modest excess risk of premature mortality and poor self-rated health.[7] While the evidence on the effect of social inequalities on population health outcomes remains conflicting, a recent study confirms positive associations between income inequality and mortality in a panel survey of 21 developed countries over 30 years.[19]

Studies of social inequalities and population oral health outcomes

Oral health is an integral part of general health. Oral diseases affect 3.9 billion people and untreated dental caries (tooth decay) is the most prevalent disease globally.[20] Oral diseases significantly affect quality of life[20] and the associated health care has significant costs. There are also links between oral health and chronic non communicable diseases,[21-26] including an association between tooth loss and pre-mature mortality.[27,28] Considering the pervasiveness of oral diseases it is important to study and assess the effects of social inequalities on population oral health outcomes.

Researchers have investigated relationships between inequalities and population oral health outcomes both ecologically[29-31] and using a multi-level technique.[32-35]. Bernabe and Sheiham[29] in their ecological study of the 50 richest nations (based on the Gross National Income [GNI]) reported that income inequality was significantly and inversely related to the number of filled teeth and decayed, missing, filled permanent teeth (DMFT) scores and restorative treatment but not to the number of missing and decayed teeth.

A study conducted in the United States reported state Gini coefficients (a widely used measure of inequality),[36] to be associated with tooth loss.[32] Celeste andFritzell[37] assessed the association between different levels of Gini, lagged and current, with dental caries and periodontal outcomes in Brazil. Their study reported that while lagged Gini was neither related to caries or periodontal diseases, current Gini was associated only with dental caries but not periodontal diseases. Several other studies of social ecology also reported negative effects of income inequality on population oral health outcomes.[30,34,35,38-40]

It should be recognized that studies mostly focused on income inequality as a measure of social inequalities, and thus other aspects of social inequality such as social class, gender, race etc. were largely ignored. One exception is the Brazilian multi-level study by Peres and Peres[41] assessing the association between the contextual Human Development Index (HDI) and dental pain. This study found higher prevalence of dental pain in ethnically black girls with lower educational attainment. The study also reported that students from areas of low HDI had higher prevalence of dental pain compared to those from areas of higher HDI, regardless of individual characteristics.

Theoretical pathways explaining relationship between inequalities and population health outcomes

Apart from the strength of the association between social inequalities and population oral health outcomes, one of the key debates persistent in the field of social epidemiology has been around the theoretical pathways by which the association can be explained. Studies which attempt to compile these theoretical pathways have done it in many different ways. While Mel Bartley in her book "Health Inequality" described the theories that explain health inequalities and extrapolated these explanations to explain the social ecology studies[1], Wagstaff and Doorslaer attempted to clarify various hypotheses which had been advanced to explain the negative effects of income inequalities on population health.[42] Several other studies attempted to explain the existing pathways[43] as well as propose new theoretical pathways.[44] Overall, the leading social theories, which are proposed in the literature to explain this relationship, are:[1]

1. Material explanations: In areas where there is more inequality, a larger population lives under material disadvantage and exposure to potential physical hazards hence, there is greater social production of disease.[1]
2. Cultural and behavioral explanations: Amongst individuals in a lower social position, the existing perception of social disadvantage reinforces a 'habitus' for compromised self-care which leads to persistent ill behavior. People who are not wealthy may feel less valued and hence are not likely to improve their health through healthy behaviors.[1]
3. Psychosocial explanations: In more unequal societies, people at lower social positions perceive themselves at a low status which affects their psychological wellbeing, affecting the endocrine mechanisms and leading to production of disease. It is also proposed that such relative perceptions further affects the quality of social relationships and reduces social capital, which additionally affects these mechanisms.[1]
4. Neo-material explanations: Under the neo-material explanations the focus remains on the lack of material factors as a result of the inadequate public policies and public services for people, which leads to disease production.[8]
5. Life course explanations: Accumulation of different material conditions through the life course of an individual has also been proposed to be a reason for social production of disease.[1] The life course explanation focuses on the key stages of life when the consequences of inequalities can lead to development of diseases in the future.
6. Political economy explanations: Some social epidemiologists argue that, in addition to the mechanisms linking existing social inequalities and population health outcomes, the socio-political processes, which lead to the production of social inequalities in the first place, are also of great importance in social production of disease. These socio-political processes primarily focus on power, politics, economics and rights as the key societal determinants of health. These socio-political theories propose that, to varying degrees, a society's political and economic institutions as well as priorities determine societal levels of disease.[45] The leading theoretical explanations are:
    - Neo-materialist explanations[45,46] which are an extension of the either theories proposed by Marx regarding how power differences between social classes according to ownership of means of productions may lead to disease production[47] or Weber's theories of how life chances linked to occupation and educational qualifications are distributed and affect the social production of disease.[1]

- Neo-liberal explanations which suggest that neo-liberalism leads to greater income inequalities, depletion of social cohesion and welfare systems, thus leading to the production of disease.[3]

Apart from the above discussed social theories, Wagstaff and Doorslaer[42] also attempted to clarify various hypotheses which had been aiming to explain the negative effects of income inequalities on population health. According to their study the various hypotheses that explain this relationship were:

1. Absolute income hypothesis:[48,49]: individual absolute income explains the observed health effects of aggregate income inequality [8]
2. Relative income hypothesis (RIH):[50] it is income relative to a social group average that is important.[8]
3. Deprivation hypothesis: a variant of the RIH and predicts that it is income relative to poverty that is important.[8]
4. Relative position hypothesis:[51] it is an individual's position in the income distribution that matters.[8]
5. Income inequality hypothesis:[51] the amount of income inequality in a community matters for health in addition to absolute income.[8]

Ultimately, they concluded that studies measuring inequality at an area level were largely insufficient for discriminating between competing hypotheses and only individual level studies have the potential to discriminate between most hypotheses.[42] The focus of the current review is on the social theories which are proposed to explain the income inequality hypothesis amongst all mentioned above. Central to all discussed hypotheses and theories is the issue of quantification of social position and social inequality.[1] Different measurements of social position and social inequalities reflect different processes and great caution is required while interpreting theoretical pathways relating social inequality to population health outcomes without giving due importance to the type of measurement.

While the importance of social theories and hypothesis has been discussed in the general health literature, studies on oral diseases have given less importance to theoretical explanations and mechanisms of production. This is despite oral diseases being commonly referred as social diseases due to both their causation as well as their social consequences.[52] A recent review by Baker and Gibson pointed out that there is sparse discussion on either the basis of the theory or its application in social oral epidemiology.[53] They further report that a search for "theory" in 682 articles indexed under "dental public health" or "oral epidemiology" in Web of Science database from 190 -2012 showed only three articles including the word "theory".

Methods

A systematic review is a type of literature review which adheres tightly to a set methodology that aims to limit bias, by seeking to identify, appraise and synthesize relevant studies to answer a particular research question.[54] Considering the uncertainty regarding the overall evidence on the theoretical pathways in the literature on social inequalities and population oral health, a conventional systematic review is not an appropriate method to assess the collective evidence on this research topic. A scoping review is a review vehicle which accommodates this limitation as one of its primary objective is to determine the extent, range and nature of any research activity.[55] Due to its relevance and suitability over a systematic review as a method[55,56] to address the highlighted research gap, a scoping review is proposed to address this significant gap in literature. Initial searches of the Pubmed, EMBASE and Cochrane databases confirm that no systematic or scoping reviews with similar objectives have been published.

The stages of a scoping review are similar to that of a systematic review (systematic selection, collection and summarization of existing knowledge in a broad thematic area), one of the main variations is that rather than emphasis on the detailed appraisal of the identified evidence sources, the focus is to collate the existing evidence in a thematic or analytical framework using a narrative synthesis.[55,56] Studies which have proposed a methodological framework for conducting a scoping review have recommended the following stages.[55,57]

STAGE I: Identifying the research question

STAGE II: Identifying relevant studies

STAGE III: Study selection

STAGE IV: Charting the data

STAGE V: Collating, summarizing and reporting the results

Keywords

social class, socioeconomic factors, poverty, occupation, labor, unemployment, tooth loss, dental caries, periodontal disease, toothache, inequality, disparity, differences, contextual, area, ecological

Inclusion criteria

Types of participants

This review will consider all studies regardless of specific age group, gender or geographical context.

Context

i. Studies assessing an association between the following measurements of social inequalities at an aggregate level: measurements of social inequality, income inequality, Gini Index, income share, Robinhood index, slope index of inequality, relative index of inequality and relative concentration index
ii. Social inequalities: occupational measurements, employer-employee relationship, ethnicity, gender, caste, power relations and the following clinical and self-reported outcomes:

- Self-reported outcomes: self-rated oral health, number of teeth, tooth loss, oral health related quality of life (OHRQoL) and dental pain
- Clinical outcomes: dental caries (DMFT), periodontal disease

Concept

To use social theories as explanations for pathways and mechanisms through which social inequalities affects population oral health.

Types of studies

The review will consider all types of studies which measure social inequality at an aggregated level (area level, country level or multi country level) and will exclude studies which measure either inequality at individual level or which account for social position at an individual or aggregated level.

Search strategy

The search strategy aims to find both published and unpublished studies. A three step search strategy will be utilized in this review. An initial limited search of MEDLINE will be undertaken followed by analysis of the text words contained in the title and abstract, and of the index terms used to describe the article. A second search using all identified keywords and index terms will then be undertaken across all included databases. Thirdly, the reference list of all identified reports and articles will be searched for additional studies. Only studies published in English will be considered for inclusion in this review. Studies published post 1900 will be considered for inclusion in this review. As the search for the scoping review may be quite iterative, the reviewers will revisit the search strategy when they become more familiar with the evidence base, as additional keywords sources and potentially useful search terms may be discovered.[58]

The databases to be searched include:

PubMed, Medline (Ovid), EMBASE, Web of Science, ERIC (Education Resources Information Center), Sociological Abstracts, Social Services Abstracts

The search for unpublished studies will include:

Reference lists, book chapters and contact with experts; Thesis (ProQuest) and Conference abstracts.

Data collection

A data charting form will be developed by collective discussion among all the reviewers and the variables will be reported in the following categories:

a. Use of theoretical explanations
b. Choice of variables to measure exposure (social inequality)
c. Evidence, explanation and justification for the choice of variables

The data charting form will be consistently updated in consultation with the reviewers and experts on the basis of emerging information from the studies. Existing resources on data charting from selected studies in systematic reviews of theories will also be referred in development of the form.[59] Two investigators will independently perform data charting of the first five studies and will pilot the developed data charting form. They will meet to cross check the extracted formation and strategies will be formulated to address the discrepancies. Following the existing methods adopted for data charting of scoping reviews,[60] the author will chart all the extracted information and a second reviewer will cross check the information independently. Any disagreements will be resolved either through discussion or by a third reviewer.

Data mapping

A "narrative review" or a "descriptive analysis" of the extracted contextual or process oriented information can be conducted in place of data synthesis for the purposes of a scoping review.[55] A 'qualitative content analysis' is also an alternative for this step. The proposed a-priori approach to data mapping will be to attempt to categorize the included studies both by the type of social theory used and the extent to which social theory is drawn upon by the authors. The criterion to analyse this aspect in the selected studies will be to assess them under the following categories drawn and modified from previous systematic reviews conducted with objectives to evaluate theory and its use:[59, 61]

1. Explicitly theory based: Study explicitly stated a theory and provided a direct test of one or more of the hypotheses deduced from a named theory in order to design the study.

2. Some conceptual basis: Study in which theory was judged to have been used in the study, but where the study did not provide a test of any of the hypotheses deduced from the theory in order to design the study. Studies included in this category were those where the authors stated that they had employed a theory within the study or where the study described a framework or approach that appeared to be theoretically based.
3. Theoretical construct used: Studies included in this category are those in which one or more constructs were examined within the study, but the use of constructs was not embedded within the framework of a theory. Where a construct was referred to within the context of a theory, but it was the only component of the theory that was measured and considered, this was considered to be use of the theory within the 'some conceptual basis' category.
4. Post hoc explanation: Study uses theory retrospectively to explain the results of the study or to stimulate further discussion.
5. Indirect use**:** Study does not name or disclose any theoretical basis but the discussion of results are directed towards one of the social theory.
6. No theory: When the study has no theoretical basis.

A sub-analysis will focus on the choice of measurement variables for social inequality. The selected studies will be categorized on the basis of the aggregate level of measurements and how they are quantified.

The reviewers also propose to conduct further mapping of the evidence in order to map out the available literature on the topic. This will be carried out in two ways. Firstly, systematic mapping will be used to aid identification of which research questions are answerable, and in what ways. [62] The reviewers will examine the statistical and methodological techniques through which included studies have assessed the association between social inequality and population oral health outcomes. Descriptive mapping will then be used to provide a snapshot of the wider field in which the literature in the review is located.[62] The existing resources on the key wording tool will be modified according to the objectives of the review and will be used to describe the field of available literature. [62]

Conflicts of interest

The reviewers have no potential conflicts of interest.

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3.3 Conclusions drawn from the chapter

The scoping review protocol provided a methodological vehicle to address the first research question for this thesis. The review protocol identified qualitative content analysis as a reproducible and unbiased strategy to categorise studies according to their theoretical basis (explicit theory-based, some conceptual basis, theoretical construct used, post-hoc explanation, indirect use of theory and no theory). Identification of this approach was a significant contribution of this scoping review protocol to provide a platform for effectively answering the first research question. Additionally, this publication helped to document the methodological approach applied in the next step of the thesis, that is conducting the scoping review.

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4. Theoretical basis and explanation for the relationship between area-level social inequalities and population oral health outcomes – A scoping review

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Contribution to the Paper	Prepared the search strategy, conducted the search, performed title and abstract screening, performed data charting, developed the methodology for categorizing theory, prepared the first draft, acted as the corresponding author		
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	6/7/2017

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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This chapter is by publication and reports the findings from the scoping review conducted to inform the theoretical basis for the association between area-level social inequality and population oral health.

4.2 Rationale for the publication

A critical gap in understanding socio-epidemiologic theoretical pathways/frameworks that explain the association between income inequality and oral health was highlighted in the Literature Review. Theory, traced to its Greek roots 'theoria' refers to seeing inwards, and to use vision systematically, following articulated principles, discerning meaningful patterns amongst ideas, and making observations in order to develop causal explanations (Krieger, 2014). The lack of a coherent theory or theoretical framework to explain how income inequality negatively impacts on oral health outcomes can severely limit the development of appropriate strategies to reduce the negative impact of income inequality on the health of individuals and populations. Additionally, with the existing doubts on any independent effect of societal income inequality on oral health over and above the effect of individual income, it makes an important case for thoroughly examining the theoretical basis for the relationship between income inequality and oral health.

Using the methodological approach identified in the scoping review protocol to examine the theoretical basis of the studies on income inequality and oral health, the scoping review was conducted with following objectives:

i. To assess the availability of evidence on the association between area-level social inequality and population oral health according to social theories.
ii. To assess the extent to which the literature on this association is theoretically based.

iii. To identify and categorize conceptual and measurement alternatives used in evidence to measure social class or socioeconomic inequalities according to the stratification and relational approaches.

iv. To identify and highlight any gaps in the literature.

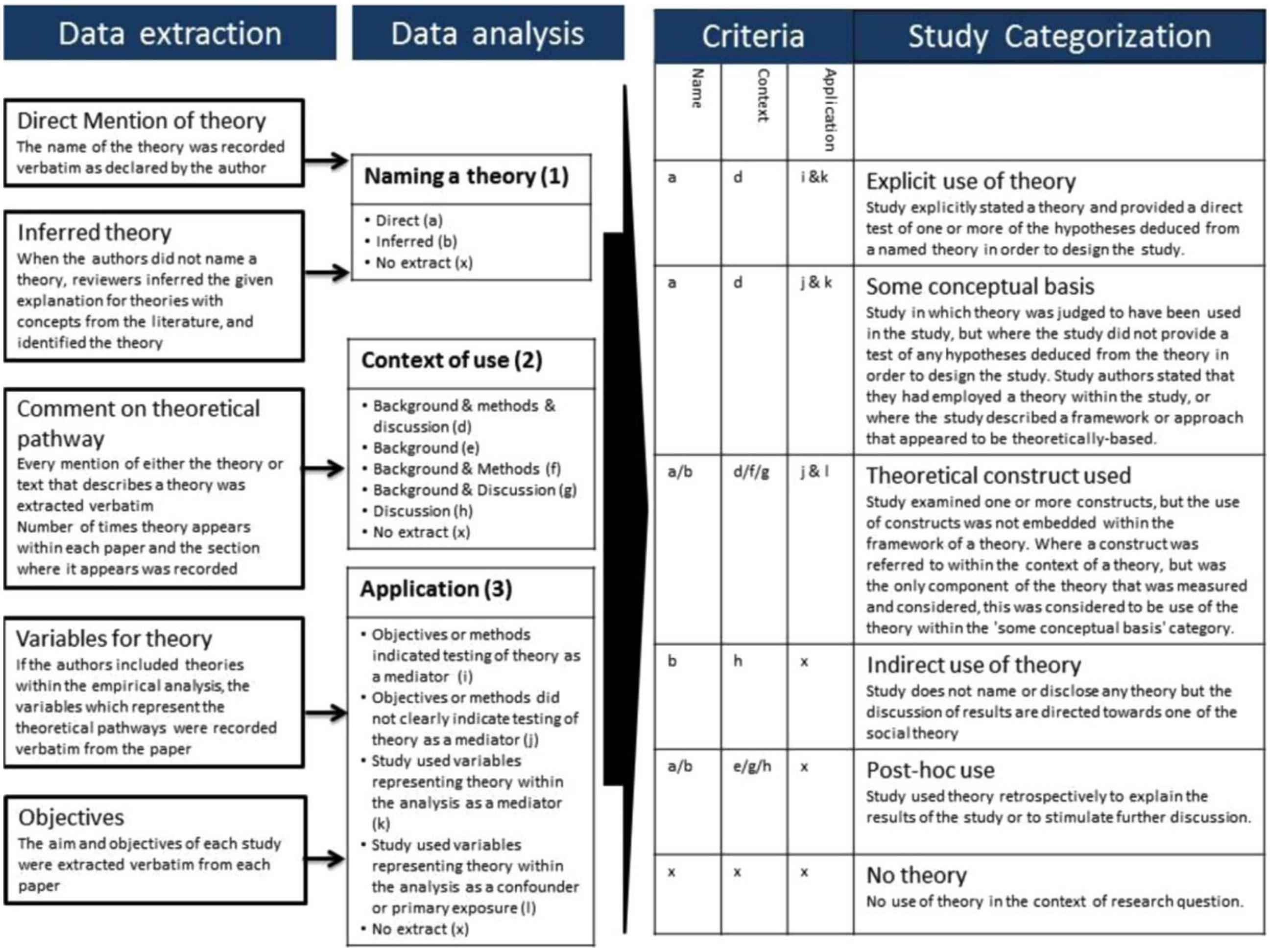
The scope of this research activity was purposely increased to studies of area-level ‘social inequality’ rather than limiting it to area-level ‘income inequality’. This decision was based on two reasons. First, assessment of theoretical explanations for the association between social inequality and oral health helped in stressing the role of socio-epidemiologic theories consistent with the causal role of social inequality in health, rather than the alternative explanations that position the association between income inequality and health as a ‘statistical artefact’. Second, increasing the scope to social inequality as an exposure also helped in classifying the literature according to their conceptual and measurement alternatives used to measure social class relations and social inequalities. There are key challenges in measuring social class relations and social inequality (Liberatos et al., 1988; Lombardi et al., 1988; Muntaner et al., 2010; Barata et al., 2013). The position on underlying sociological dimensions of social inequality that income inequality aims to measure is of significant importance in understanding how income inequality negatively impacts on health (Muntaner and Lynch, 1999; Wilkinson, 1999). Differences in measuring social inequality as a matter of stratification, or because of relations between social positions and their implications on the understanding of the impact of social inequality on health, have been established in the literature (Goldthorpe, 2010; Muntaner et al., 2010). Due to the value in investigating the underlying sociological position of testing income inequality and oral health, and the different alternatives other than income inequality used in the literature to investigate the relationship between social inequality and health, this review adopted a more comprehensive approach towards understanding the socio-epidemiologic theories underpinning associations between social inequality and oral health.

4.3 Methodology

A search strategy was developed for PubMed with the help of a research librarian at the University of Adelaide. Once developed, the search strategy was then tailored to different electronic databases including Medline (Ovid), Web of Science, Embase, Sociological abstracts (Proquest), ERIC (Proquest), and Social Services abstracts (Proquest) (Appendix 1.1). In order to identify grey literature, eight experts, with each having a minimum of two publications on the association between income inequality and oral health identified through the search were contacted through individual letters sent via email (Appendix 3). Selected studies identified through electronic searches were imported into Endnote X6 software to identify and remove duplicates. The title and abstract screening were independently conducted by two authors. Disagreements on selection of studies were resolved through discussion. A third reviewer intervened to resolve disagreements that could not be resolved through discussion. Full-text of the selected studies were retrieved and further screened for eligibility. References of selected studies were also screened to identify any further relevant study.

Pre-piloted data charting forms were used to chart the information on study characteristics, use of theory, measures of social inequality, and the key findings on explanatory potential of different theoretical pathways. This data charting was conducted by one author and independently cross-checked by a co-author. An integrated deductive content analysis within the scoping review methodology was applied to identify, categorise and analyse the extent to which socio-epidemiological theories are applied in the literature on social inequality and oral health. All the selected articles were imported in NVivo v10 software, and the text within the selected papers relevant to the mention of theory, context of use of theory, and overall application in the analytical framework were extracted and analysed. Based on the analysis of extracted information on these aspects, each study was categorized into one of the following categories: explicit use of theory, some conceptual basis, theoretical construct used, indirect use of theory, post-hoc use and no theory (Figure 1). In order to ensure a reliable process and reduce individual bias, two reviewers participated in both the data extraction process in NVivo and analysis and study categorization exercise (Appendix 2). A sub-analysis also focused on the measurement variables for social inequality applied in the selected studies. Results were described using a narrative synthesis approach.

Figure 1. Deductive content analysis to categorise studies according to extent of use of theory



PAPER 2

Theoretical basis and explanation for the relationship between area-level social inequalities and population oral health outcomes – A scoping review

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Review Article

Theoretical basis and explanation for the relationship between area-level social inequalities and population oral health outcomes – A scoping review

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ABSTRACT

This study was conducted to review the evidence on the association between area-level social inequalities and population oral health according to type and extent of social theories. A scoping review was conducted of studies, which assessed the association between area-level social inequality measures, and population oral health outcomes including self-rated oral health, number of teeth, dental caries, periodontal disease, tooth loss, oral health-related quality of life (OHRQoL) and dental pain. A search strategy was applied to identify evidence on PubMed, MEDLINE (Ovid), EMBASE, Web of Science, ERIC, Sociological Abstracts, Social Services Abstracts, references of selected studies, and further grey literature. A qualitative content analysis of the selected studies was conducted to identify theories and categorize studies according to their theoretical basis. A total of 2892 studies were identified with 16 included in the review. Seven types of social theories were used on 48 occasions within the selected studies including: psychosocial ($n=13$), behavioural ($n=10$), neo-material ($n=10$), social capital ($n=6$), social cohesion ($n=4$), material ($n=3$) and social support ($n=2$). Of the selected studies, four explicitly tested social theories as pathways from inequalities to population oral health outcomes, three used a theoretical construct, seven used theories for post-hoc explanation and two did not have any use of theory. In conclusion, psychosocial theories were used most frequently. Although theories were often mentioned, majority of these studies did not test a social theory.

Contents

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1. Introduction

> 'He who loves practice without theory is like the sailor who boards ship without a rudder and compass and never knows where he may cast' – *(Leonardo da Vinci* 1452–1519*)*.

Theory is essential to understanding patterns in ideas and observations, and to develop causal explanations (Krieger, 2011, 2014). It has a paramount role in the field of social epidemiology (Bartley, 2004; Krieger, 2014) as the discipline is not only limited to study effects of socio-structural factors on health (Honjo, 2004; Kawachi & Berkman, 2000) but also to understand the causal explanations and to intervene in order to effect change. Oral diseases affect 3.9 billion people and untreated dental caries (tooth decay) is the most prevalent condition globally (Marcenes et al., 2013). Oral diseases significantly affect quality of life (Marcenes et al., 2013) and are associated with significant health care costs (Listl, Galloway, Mossey & Marcenes, 2015). Baker and Gibson (2014) have argued that routine testing of theoretical pathways is not generally evident in the field of social oral epidemiology. This scoping review assesses the extent to which theory is used in any capacity in studies of social inequality and oral health.

1.1. *Theory, social ecology and health*

A curvilinear association between average national income and overall health has been observed since the late 1970s (Rodgers, 1979). These observations gave rise to the 'income inequality hypothesis' (IIH), which states that beyond a certain threshold of average income within a society, the distribution of income has a greater effect on average population health than average income (Wagstaff & Doorslaer, 2000). This hypothesis has given rise to studies of 'social ecology' to test the association between inequality and overall health. At least 300 studies of social ecology with various health outcomes have been published (Pickett & Wilkinson, 2015a), and, the importance of income inequality as a 'social pollutant' (Subramanian & Kawachi, 2006) has been widely debated over the past three decades (Pickett & Wilkinson, 2015b). While earlier reviews expressed scepticism with regards to the evidence on this relationship (Lynch et al., 2004; Wagstaff & Doorslaer, 2000), more recent reviews have supported this association. These later reviews concluded that detrimental effects of area-level social inequality, primarily income inequality, are universally evident (Kondo et al., 2009; Wilkinson & Pickett, 2006), causally related and affect the majority of the population (Pickett & Wilkinson, 2015a). They are not simply the result of higher rates of poverty in more unequal societies (Pickett & Wilkinson, 2015b).

Several theories/theoretical models have been proposed to explain how area inequalities may influence societal levels of health and disease (Bartley, 2004; Coburn, 2000; Kawachi & Kennedy, 1999; Lynch et al., 2004; Lynch, Smith, Kaplan & House, 2000; Marmot & Wilkinson, 2000; Navarro, 2002; Wilkinson & Pickett, 2006). Six distinct theories are identified that can be tested in studies of the association between social inequality and oral health (Bartley, 2004). The first two represents ecological counterparts to explanations for the association between individual socioeconomic position and health within the Black Report (Townsend, Davidson & Black, 1982), while the remainder were developed specifically to explain differences between populations:

i) Materialist: materialist explanations emphasize the role of the external environment on health; these vary with the level of inequality. Exposure to risks to health, and to protective factors varies with social position. Macroeconomic variables such as levels of production and unemployment affect health. Attention is paid to the roles of stress associated with material factors and with the hazardous nature of work. At an ecological level, more unequal societies have more people exposed to these risks (Townsend et al., 1982; Macintyre, 1997).
ii) Behavioural: behavioural explanations state that unequal societies generate higher levels of unhealthy behaviours. There are two versions of this explanation (Macintyre, 1997). One (hard) version of behavioural explanations identifies individual inadequacy as the main source of this behaviour. A second (soft) version is that behaviours have social gradients and contribute to observed gradients in health status.
iii) Psychosocial: psychosocial was developed to explain individual-level inequalities. At an individual level, psychosocial explanations claim that social position affects health in one of two ways. First, people's perception of their social position affects health. Second, there is an inverse association between levels of control, and resulting chronic stress and social position that affects health. Whether through perception or control/stress, the subsequent effect on health is either through direct physiological changes or through health damaging behaviours (Bartley, 2004). Within unequal societies, due to constant social evaluative threats, it is likely that people who are less well-off tend to compare themselves to those who are relatively better. Such comparisons lead to a constant perception of belonging to a low status group, along with lack of control and coping strategies consequently leads to chronic stress. This stress through either health compromising behaviours or through directly affecting physiological health, may lead to higher levels of disease (Wilkinson, 1997). The more unequal a society, the greater the decrement in power and control and the more damaging the perception and lack of psychosocial assets, thus the greater the impact on health. Because the social gradient is steeper within unequal societies, these effects may be more evident higher up the social gradient compared to more equal societies (Marmot & Wilkinson, 2000).
iv) Social capital: social capital explanations are often described as a subset of psychosocial explanations. These explanations state that unequal distribution of income undermines trust and damages social relationships. This can manifest in low levels of social support or civic participation, or in high levels of antisocial behaviour, particularly crime. This has been accepted as a potential pathway since Kawachi, Kennedy, Lochner, and Prothrow-Stith (1997) demonstrated that the association between inequality and mortality in the United States was mediated by social capital (Kawachi & Kennedy, 1999; Subramanian & Kawachi, 2004).
v) Neo-material: neo-material explanations arise from criticism that the psychosocial and social capital explanations ignore upstream factors that affect health and may be associated with greater inequality. Specifically, they ignore the role of uneven distribution of power and class relations, and labour market dynamics in sustaining and driving inequalities (Muntaner, Lynch & Oates, 1999; Navarro, 2002; Coburn, 2000). This results from a systematic underinvestment in human, physical, health, and social infrastructure that support health (Lynch et al., 2000, 2004).
vi) Structural: the structural explanation states that it is likely that the income inequality results in greater residential segregation leading to spatial concentrations of race and poverty, which in turn influences individual health. This may consequently lead to worse population health (Subramanian & Kawachi, 2004).

Many of these pathways are linked (Lynch & Kaplan, 1997) and some are treated as a subset of others in the literature. These pathways are unlikely to be mutually exclusive with more than one operating at any time or place, but the role of each may vary according to context and health outcome. But, depending on the different sociological origins of each theory, the policy implications of each theory will be accordingly different. Muntaner and Lynch (1999) argue that 'IIH' and psychosocial interpretation treat income as a resource for purchasing social goods rather than as a product of production relations. At an area level this argument relates to whether inequality is conceptualized on a stratificational (gradational) scale or as a relational product (Muntaner & Lynch, 1999), as also shown at an individual level (Muntaner et al., 2010). Ignoring the relational property of inequality ignores underlying class relations, power dynamics and consequent exploitation that may affect health separately to income. So, a more psychosocial and social capital emphasis may deviate the attention of policymakers from addressing more relevant structural factors related to social inequalities which impact population health (Muntaner & Lynch, 1999). On the contrary, the psychosocial theorists argue that ignoring the psychosocial mechanisms may ignore the negative impacts of relative deprivation and social comparisons on the physiological and psychological health and social fabric (Marmot and Wilkinson, 2000).

The need to test theoretical pathways between social inequalities and overall health is well established (Bartley, 2004; Campbell et al., 2014; Krieger, 2011, 2014). But, the evidence regarding the use of theory in explaining area level social inequalities and population oral health has not been reviewed. Evidence on the role of pathways between area-level social inequalities and population oral health outcomes clarifies the basis for specific policies in order to reduce the health effects of social inequalities. In order to address the significant gap regarding the use of theory in studies of social ecology in oral health, this scoping review was performed with four objectives: (i) to assess the availability of evidence on the association between area-level social inequality and population oral health according to type of social theories, (ii) to assess the extent to which the literature on this association is theoretically based, (iii) to identify and categorize conceptual and measurement alternatives used in the evidence to measure social class or socioeconomic inequalities according to either stratification or relational approach, and (iv) to identify and highlight any gaps in the literature.

2. Methods

A scoping review determines the extent, range and nature of any research activity, making it a more suitable approach than a systematic review for this research question (Arksey & O'Malley, 2005; Levac, Colquhoun, & O'Brien, 2010). Given the complexity of the review design, a detailed protocol for this scoping review was published which also elaborates this justification (Singh, Harford, Watt, & Peres, 2015). A methodological framework for this review is based on the existing literature and has five steps (Arksey & O'Malley, 2005):

(1) *Identifying the research question*: the research question framed was, 'What is the nature and extent of social theories/theoretical models being used as a basis to explain the associations between area-level social inequalities and population oral health in the existing literature?'
(2) *Identifying relevant studies*: a search strategy was formulated to identify both published studies and grey literature. A three-step search strategy was developed for this review. An initial limited search of MEDLINE was undertaken followed by analysis of the text contained in the title and abstract, and of the index terms used to describe the articles. Following this the next step involved using all identified keywords and index terms to search across all selected databases: PubMed, MEDLINE (Ovid), EMBASE, Web of Science, ERIC (Education Resources Information Center), Sociological Abstracts, Social Services Abstracts. A detailed search strategy including the relevant keywords and MeSH terms was constructed specifically for each selected database. Each data source was individually checked for availability and usage of controlled vocabulary for indexation through the use of hierarchically defined and periodically updated thesauruses (Appendix 1). The search was first conducted on 14th January, 2015 and further updated to identify recent studies on 7th March, 2016. The reference list of all identified reports and articles was searched to identify any additional studies. Finally, the search for unpublished studies included reference lists, book chapters, Thesis (Proquest) and conference abstracts. Furthermore, eight experts were identified and contacted for relevant grey literature based on the criterion that within the literature search they should have published at least twice on this research topic.
(3) *Study selection*: pre-defined inclusion and exclusion criteria were developed to identify relevant studies (Arksey & O'Malley, 2005). Studies were excluded if they were published in a language other than English, or did not include a measure of inequality, or focussed on individual-level inequalities in health outcomes, or had outcomes of interest other than dental caries, periodontal disease, self-rated oral health, number of teeth, tooth loss, oral health-related quality of life (OHRQoL) and dental pain. The detailed inclusion and exclusion criteria are reported elsewhere (Singh et al., 2015).
(4) *Charting the data*: a data charting guide and recording proforma were developed by the reviewers and piloted independently by two investigators (AS and HSS) on five studies who cross-checked extracted information and revised the guide and proforma to address discrepancies. The information charted included study details (author, publication type, study design, locations, population focus, sample size, statistical modelling, geographical unit of aggregation and population oral health outcomes), details on theory (mention of theory, number of use and type of theories) and measure of social inequality (type of inequality and area based quantitative measure of inequality). Based on emerging information from studies this form was constantly updated in consultation with the reviewers. Two (AS and HSS) reviewers independently charted all the extracted information and crosschecked the information to reduce individual bias (Riva, Gauvin, & Barnett, 2007). Any disagreements were resolved firstly by discussion then by intervention of a third reviewer (JH).
(5) *Collating, summarizing and reporting the results*: Extracted data was summarised using narrative synthesis (Arksey & O'Malley, 2005). The proposed *a-priori* approach to data mapping was to categorize included studies both by the type of social theory used and the extent to which social theory as drawn upon by the authors. Selected papers were entered into NVivo v10 software, which was used to identify theories and categorise studies according to extent of their theoretical use. A deductive content analysis using pre-defined categories was performed by analysing extracts on theories from the primary studies (Fig. 1). This process involved analysing elements such as naming the theory, context in which theories are introduced, and, application of theory based on their emphasis within objectives and use as variables within the analysis strategy. Information reflecting these aspects was extracted from the papers under following categories, 'comment on theoretical pathways', 'direct mention of theory', 'inferred theory', 'variables for theory', and 'objectives' (Fig. 1). Based on the analysis of extracted information under these

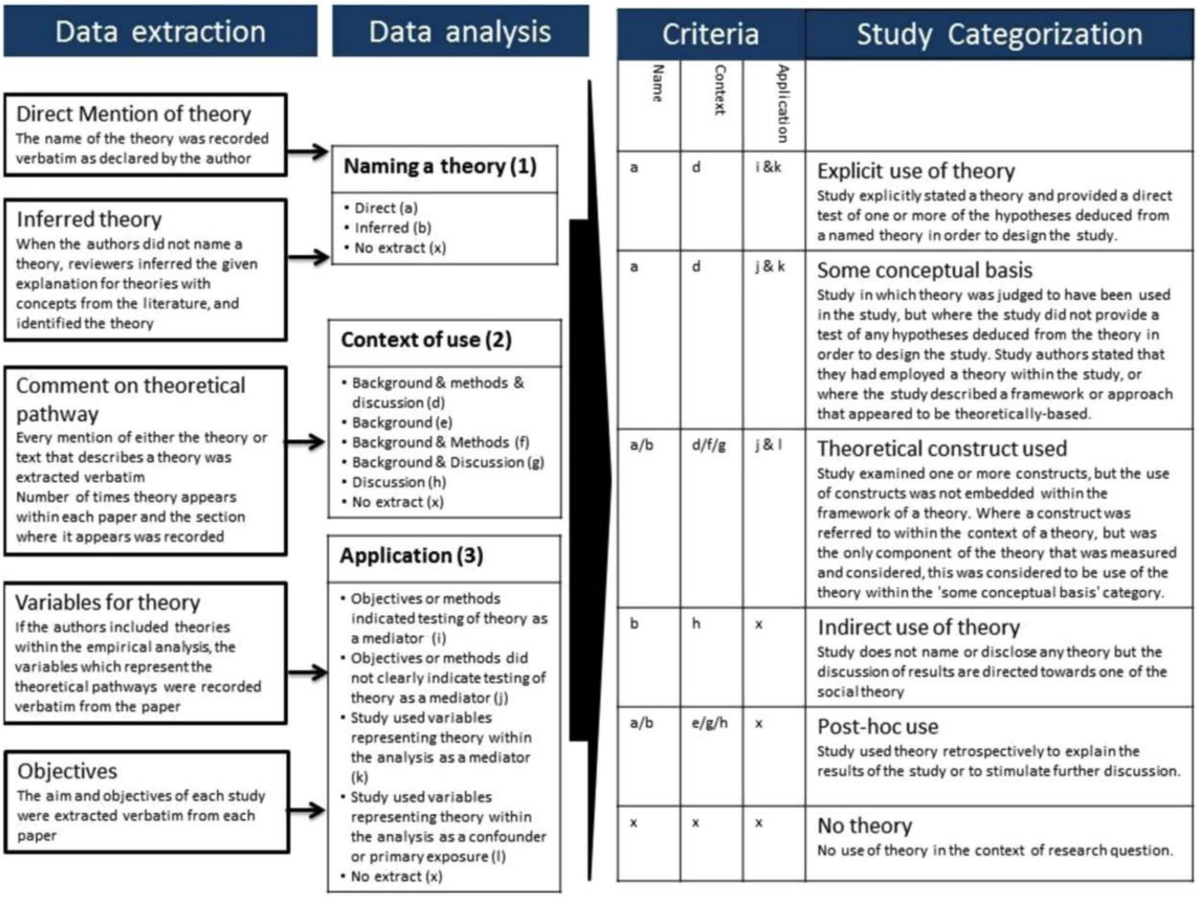

Fig. 1. Deductive content analysis to categorize studies according to their extent of use of theory.

categories, each study was then categorized exclusively into one of the following pre-defined categories for use of theory: 'explicit use of theory', 'some conceptual basis', 'theoretical construct used', 'post-hoc use', 'indirect use of theory' and 'no theory' (Singh et al., 2015). For instance, the study by Aida et al. (2011) had 6 unique mentions of theories, within the introduction, methods and discussion section. The study's objectives clearly mentioned that it aimed to test whether social capital explained the associations between income inequality and dental status. The study explicitly named the 'social capital' theory and used the variables representing theory within the analytical strategy (Appendix 1). Based on this information, the study was categorized under the 'explicit use of theory'. The unit of analysis for this activity was a study rather than a theory, therefore any study with multiple theories was classified according to the highest level use of theory as indicated by this ordering of categories. Additionally, a narrative synthesis was added to highlight the between study differences identified within categories.

The criteria for each of these categories were derived from a systematic review for a similar research question, but applied in a different field (Davies, Walker, & Grimshaw, 2010). Furthermore, the extracted information under 'direct mention of theory' and 'inferred theory' assisted in identifying all types of social theories and the frequency of their use within the studies selected. In order to be inclusive of depletion of social capital pathway as an independent theoretical pathway (Kawachi & Kennedy, 1999), apart from those theories summarized by Bartley (2004); material, neo-material, behavioural/cultural and psychosocial; all extracts (implicit and inferred) that made reference to any dimension of social capital were also identified.

To ensure a reliable process and to reduce individual bias, two reviewers participated in both the data extraction exercise and data categorization exercises. The initial data extraction exercise was performed by AS with HSS crosschecking the decisions regarding number and relevance of extracts. A pilot exercise on two selected studies compared the consistency in data extraction. Both AS and JH conducted the study categorization exercise independently with disagreements resolved through discussion.

A sub-analysis focussed on the choice of measurement variables for area-level social inequality. Studies were categorized according to the measure of inequality used and how it was quantified. A quality assessment of the selected studies was not conducted, as a scoping review does not aim to synthesize evidence according to methodological quality (Arksey & O'Malley, 2005).

3. Results

Overall, 2892 studies were identified by a systematic search on all selected databases, and 1188 duplicates were removed. Some

1600 records were excluded where it was clear from title and abstract they were out of scope based on the inclusion/exclusion criteria leaving 105 relevant titles. Upon full text review another 89 studies were excluded leaving 16 relevant studies for data charting. A flowchart of this process is shown in Fig. 2.

3.1. Summary characteristics of the identified studies

The majority of studies examined the impact on health of inequalities within countries (IDs B,D,F,H,J,K,L,M,N,O&P in Table 1). Five studies examined multiple high income countries (IDs A,C,E,

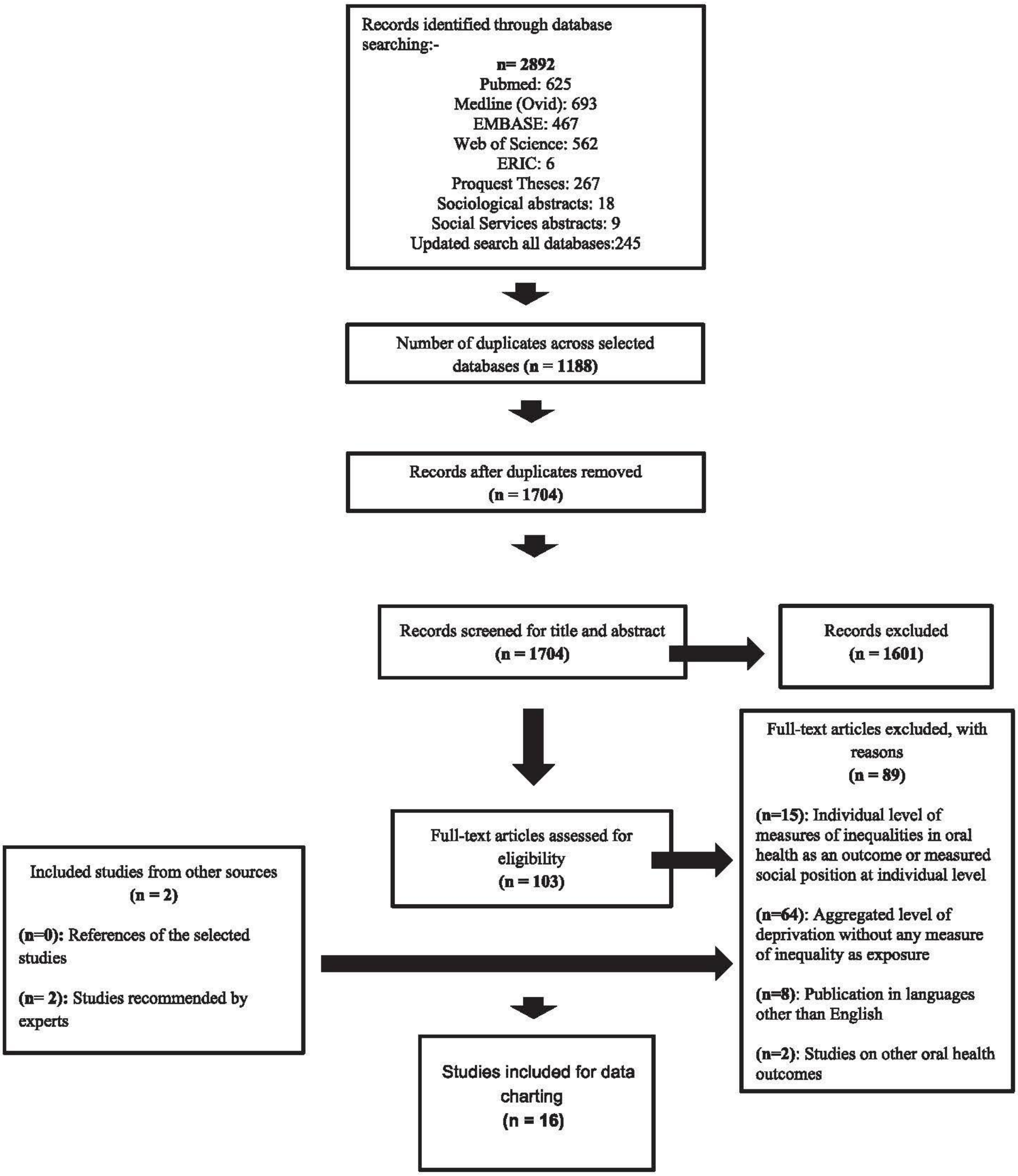

Fig. 2. Flow chart for the process of literature search to study selection.

Table 1
Descriptive summary of the selected studies.

Code	Study	Study design/ analysis	Location	Population focus	Aggregate level	Oral health outcomes	Main Results (inequality – oral health)	Main Results (Theories)
A	Nadanovsky and Sheiham (1995)	Ecological/ correlations	18 industrialized countries	12-year-old children	Country	12-year-old DMFT Compound Annual Rate (%)	The higher the concentration of income in the top 20% income households in 1970–75, the lower the rate of DMFT reduction.	NA
B	Pattussi, Marcenes, Croucher, and Sheiham (2001)	Cross sectional/ correlations	Brazil	6–12-year-old school children	Intra-urban areas of Brasilia (Federal District)	Dental caries levels: the percent of children free of caries, mean DMF-T scores	GINI coefficient was negatively statistically significantly associated with both measures of dental caries experience, percent of caries free ($P=0.003$) and mean DMF-T scores ($P=0.01$).	NA
C	Hobdell et al. (2003)	Ecological/ correlations	99 countries (Dental caries) 44 countries (CPITN)	12 year olds (caries) and 35–44 year old adults (CPITN)	Country	Dental caries (DMFT) and destructive periodontal disease (CPITN)	Gini Index was positively and significantly correlated with dental caries and CPITN scores	NA
D	Peres et al. (2003)	Ecological/ correlations	São Paulo, Brazil	5–6 year old children	Cities and Town	Dental caries: mean DMFT	DMFT not associated with income inequality	NA
E	Bernabe, Sheiham, and Sabbah (2009)	Ecological, cross-sectional study/ correlations	High income countries	35–44 year old adults from rich countries	Country	Dental caries experience: untreated caries, missing teeth, filled teeth and DMFT; dental care index: restorative index, treatment index	Income inequality was significantly and inversely related to the number of filled teeth, DMFT score and provision of restorative treatment, but not to the number of decayed or missing teeth.	NA
F	Celeste, Nadanovsky, Ponce de Leon and Fritzell (2009)	Cross sectional/ multi-level	Brazil	15–19 and 35–44 year olds	Municipal level	Tooth loss: all natural teeth (yes/ no); untreated dental caries: number of teeth with untreated dental caries	Income inequality showed an effect after controlling for known confounders and mediators based on a priori postulated pathways with missing teeth and number of teeth with untreated decay. (VPC for at least one missing tooth=9.36%; Number of teeth with untreated caries=5.28%; Edentulism=9.08%; Number of teeth with untreated caries=4.37%)	Models representings social capital and health services did not change the Gini effect considerably
G	Bernabe and Hobdell (2010)	Cross sectional/ correlations	48 countries	5- to 6-year old children	Country	Dental Caries (DMFT Index)	The dmft index was significantly correlated with the Gini index in rich countries but not all countries	NA
H	Celeste and Nadanovsky (2010)	Cross sectional/ multi-level	Brazil	15–19 year olds	Municipal level	Number of missing teeth and number of decayed teeth	Municipal level public policies were the main explanation for the income inequality effects on oral health	Most of the Gini effect was explained by the number of years of water fluoridation and Scale of Municipal Public Policies (SMPP)
I	Sabbah, Sheiham and Bernabe (2010)	Ecological/ correlations	17 rich countries	Adults aged 35–44 years	Country	Periodontal disease: percentage of adults with periodontal pockets >4 mm 'Community Periodontal Index (CPI) 3 or 4' and with periodontal pockets > 6 mm (CPI 4)	Higher levels of income inequality in rich countries were associated with higher levels of periodontal disease in adults, even after adjusting for measures of absolute national income	NA
J	Aida et al. (2011)	Cross sectional/ multi-level	Aichi, Japan	Older adults (65 and above)	District	Number of remaining natural teeth (having 20 or more teeth vs having 19 or less teeth)	Income inequality in communities was significantly associated with poor dental status. Income inequality was a major contributor to the variation in dental status between communities (Dental	Individual- and community-level non-volunteering and mistrust did not substantially reduce the odds for poorer dental status

							status, Variance=0.011, SE=0.012)	
K	Bernabe and Marcenes (2011)	Cross sectional/ multi-level	USA	18 years and above	State	Self-reported tooth loss: (none, 1–5, 6 or more but not all, and all teeth)	State Gini coefficient was associated with higher odds of reporting greater tooth loss. (Between state Variance=0.025; SE=0.005)	The state Gini coefficient remained significantly associated with tooth loss after adjustment for state dentist-to population ratio and percent receiving fluoridated water (neo-material) and individuals' marital status (social capital).
L	Celeste, Fritzell and Nadanovsky (2011)	Cross sectional/ multi-level	Brazil	35–44 year-olds adults	Municipal level	Untreated dental caries, edentulism, at least one site with CAL > 8 mm, bleeding or dental calculus	Lagged Gini showed no association with any outcome; current Gini was associated with untreated dental caries but not with edentulism and periodontal disease. (VPC for untreated dental caries=3.6%)	NA
M	Vettore, Marques and Peres (2013)	Cross sectional/ multi-level	Brazil	Adults aged 35–44	State Capitals and Federal Districts	Periodontal disease: "Moderate to severe" periodontal disease; "Severe" periodontal disease	Income inequality was independently associated with "severe" periodontal disease (OR=3.0, 95%CI 1.5;5.9); Variance=0.101, SE=0.044	NA
N	Vettore and Aqeeli (2015)	Cross sectional/ multi-level	Brazil	Adults aged 35–44	City	Oral Health Related Quality of Life (ORHQoL) measured by Oral Impacts on Daily Performance (OIDP)	Income inequality associated with emotional status, work and social contact. (Gini 1991; Variance=0.070, SE=0.021; Gini 2000; Variance= 0.072, SE=0.021)	NA
O	Goulart and Vettore (2016)	Cross sectional/ Multi-level	Brazil	Adults aged 35 to 44	City	Tooth loss (Measured by M component of DMFT): Severe tooth loss (<9 teeth) and lack of functional dentition (< 21 teeth)	Moderate and high increase in income inequality associated with both outcomes (Severe Tooth Loss – Variance=0.104, SE=0.055; Functional dentition, Variance=0.189; SE=0.061)	
P	Chalub, Martins, Ferreira and Vargas (2016)	Cross sectional/ multi-level	Brazil	Adults aged 35–44	Municipal level	Functional dentition (4 Definitions:- WHO functional dentition, Well distributed teeth, Functional dentition classified by aesthetics and occlusion, Functional dentition classified by esthetics, occlusion and periodontal status)	Income inequality was not associated with any definition of functional dentition	

G&I). Nine studies pertained to Brazil (IDs B,D,H,L,M,N,O&P), with three of these (IDs F,G&L) reporting overlapping outcomes for two identical population groups from the same survey. The selected studies included ages five years and upwards. All 16 studies were cross-sectional with seven assessing the association by correlations while nine conducted a multi-level analysis. Random parameters were reported in six out of nine multi-level studies. The geographic unit of analysis ranged from municipal level to country level. Among the selected studies, nine were designed specifically to test associations between inequality and oral health while seven were exploratory studies which tested inequality as one of the contextual factors. Oral health outcomes tested included dental caries (n=9), tooth loss (n=8), periodontal disease/outcomes (n=4) and oral health related quality of life (n=1) (Table 1).

3.2. *Theories – type and extent in the selected studies*

Overall, there were 48 uses of seven types of social theories in the selected studies including psychosocial (13-IDs C,E,F,G,H,I,J,K,L, M&N), behavioural (10-IDs A,C,D,E,G,K,L,M,N&P), neo-material (10-IDs D,F,G,H,I,K,L,N,O&P), social capital (6-IDs B,E,F,I,J&N), social cohesion (4-IDs B,E,K&O), material (3-ID D,F&N) and social support (2-IDs K&M) (Table 2). This includes all theories that were either directly mentioned by authors in the text or in which the text appeared to describe one of these theories. Six of theories were directly mentioned; psychosocial (11-IDs C,E,F,G,H,I,K,L,M&N,P), behavioural (7-IDs C,E,G,L,M,N&P), social capital (5-IDs E,F,I,J&N), social cohesion (4-IDs B,E,K,&O), material (3-IDs F,N,P) and neo-material (2-IDs F&H) (Table 2).

Four studies (IDs F,H,J&K) explicitly tested the theories as mediators or pathways between social inequalities and population oral health outcomes (Table 2, Appendix 2). Three studies (IDs B, M&P) discussed at least one construct that was consistent with a theory in the introduction and discussion, but did not test it. Seven studies (IDs C,E,G,I,L,N&O) used theories for post-hoc explanations to either discuss their findings or to stimulate further discussion. Three studies had no theoretical basis at all (ID A&D) (Table 2).

3.3. *Within category differences between studies*

Despite testing theories as mediators, differences according to the explicitness and comprehensibility regarding the theories were observed among the four explicitly theory based studies (IDs F,H,J&K). While (IDs F,H&J) explicitly stated that they intended to test the potential of one or alternate theoretical models, in explaining the associations between income inequality and health outcomes, (ID K) only incorporated theories within the modelling strategy and stated that it accounted for diverse set of individual and state level factors. In terms of comprehensibility, while (IDs F, H,K) included multiple theoretical models, (ID J) only tested the potential of social capital to explain the relationship. The studies categorized under 'post-hoc' group differed in the way that while studies (IDs E&O) only introduced theories in the introduction to justify testing for inequality – oral health association, studies (IDs I&L) used theories in both introduction and discussion to justify the objective and potential explanations for their findings. Finally, studies (IDs C,G&N) only discussed theories in the discussion as potential explanations for their findings. Such between study differences were not observed under those identified with 'no theory' and 'theoretical construct used'.

3.4. *Measurement of social inequality in the selected studies*

All the selected studies used income inequality as the measure of area-level social inequality. 15 out of the 16 selected studies used the Gini Index as a measure of income inequality, while one study (ID E) used both the Gini index and the 20:20% (ratio of total annual household income received by the richest 20% of the population to that received by the poorest 20%). Only one study (ID A) used the percentage of national income earned by the top 20% as the measure of area-level social income inequality (Table 3).

4. Discussion

All but one of the selected studies mentioned at least one theoretical pathway between social inequality and population oral health; however, theories were seldom explicitly stated and tested. Psychosocial theory was most frequently used. Income inequality was the only measure of inequality reported and always measured on a stratificational scale.

Although social theories are often mentioned in studies of social ecology in social (oral) epidemiology and have drawn interest over time, the lack of explicit theoretical basis among selected studies substantiates the findings from the study by Baker and Gibson (2014). Using a qualitative methodology the current study observed that theories were mostly used for a post-hoc explanation of results rather than being explicitly stated or incorporated in analytical models. Furthermore, differences were also observed in the context in which theories were used in a post-hoc manner. When theories were tested for mediation, the studies differed according to their comprehensibility and explicitness. The differences in descriptive and explanatory objectives of the selected studies may be a potential explanation for such differences. Most of the selected studies were designed to test the empirical association between inequality and oral health, rather than to explain them. On the other hand, some studies were exploratory and included inequality as one of the exposures. A very small proportion of studies aimed to test any theoretical pathways. As a scoping review, the current study did not draw conclusions on the associations between inequality and population oral health. However, summary of findings (Table 1) suggests an association between income inequality and multiple oral health outcomes. Considering that theories form a strong basis for choosing appropriate strategies to reduce ill effects of inequalities on population oral health, findings from the current review highlights the lack of theory and underscores the necessity for explicit theoretical basis in future studies.

The different theoretical pathways have key implications for the pathogenesis of different oral health outcomes. For example, fluoride intake affects the risk of experiencing caries, but is not considered to be causative for periodontal disease. Even within one oral disease, caries, intermediate and proximal factors that affect the risk of having disease in the first place (e.g. sugar, fluoride) are not the same as the risk of losing a tooth due to caries (add access to timely dental care to sugar and fluoride). This highlights the need for outcome-specific theoretical models to explain the associations and for robust data collection based on outcome specific theoretical models. This would make research recognize the heterogeneity of etiologies and these may be important for which pathways matter for different conditions. Furthermore, inequality is a true ecological variable (Diez-Roux, Link, & Northridge, 2000), and the intervening mechanisms or resources may differentially impact individual and population health status (Rose, 1992). Therefore, the theoretical models demand more clarifications when differentiating between ecological relationship between inequality and population health, and contextual effects of inequality on individual health. Use of direct acyclic graphs (DAGs) (Fleischer & Diez-Roux, 2008) to identify *a-priori* confounders and mediators can also help in this process.

The predominance of psychosocial theory including depletion of psychosocial assets such as social capital and social support theory in oral health literature is mirrored in its use in research in general

Table 2
Analysis of the theoretical basis of selected studies assessing the association between area level social inequality and population health outcomes.

Study	Type of theory/theories: Direct (*) and Inferred (#)	Explicitly theory-based	Some conceptual basis	Theoretical construct used	Post-hoc	No Theory
A	No extract					✚
B	Social cohesion* and social capital#			✚		
C	Behavioural* and psychosocial*				✚	
D	Behavioural#, material# and neo-material#					✚
E	Social capital*, social cohesion*, psychosocial# and behavioural*				✚	
F	Social capital*, material*, psychosocial*, neo-material*	✚				
G	Behavioural*, psychosocial* and neo-material#				✚	
H	Psychosocial*, neo-material*	✚				
I	Psychosocial*, social capital* and neo-material#				✚	
J	Social capital* and psychosocial#	✚				
K	Social cohesion*, psychosocial* and behavioural*, neo-material# and social support#	✚				
L	Psychosocial*, behavioural* and neo-material#				✚	
M	Psychosocial*, behavioural* and social support#			✚		
N	Material*, social capital*, behavioural*, psychosocial* and neo-material#				✚	
O	Social cohesion*, neo-material# and psychosocial#				✚	
P	Behavioural* and psychosocial*			✚		

health literature (Islam, Gerdtham, Gullberg, Lindstrom & Merlo, 2008; Murayama, Fujiwara & Kawachi, 2012; Oksanen et al., 2008; Robert, 2001). The use of social capital, social cohesion, social network and social support along with the levels at which they are conceptualized needs more clarification. First, social capital is a broader concept which includes both social cohesion and social network (Mackenbach et al., 2016). Second, these inter-personal constructs and resources may mean different things at the individual and contextual level. Finally, their potential explanatory power may differ for different outcomes. This is substantiated by the evidence showing community-level structural social capital to attenuate the odds of inequality for poorer self-rated health but having no substantial impact on the odds for worse dental status (Aida et al., 2011). The limited explicit attention to the neo-material pathway within the selected studies could be due to the lack of clarity on its conceptualisation and measurement. The definition of neo-material theory contains two important elements: 'structural factors differentiating equal and unequal societies' and 'systematic underinvestment in public policies and health care' (Lynch et al., 2000). In terms of public health policies and health care, some of the key determinants of oral diseases in the population may include infrastructures such as access to dental health care, water fluoridation, food supply and population-level tobacco control measures (Watt, 2012). Under the neo-material interpretations of the inequality – health relationship, it is argued that the historical, cultural, political and economic processes, which lead to inequality, may also shape the nature and availability of health supportive infrastructure (Lynch et al., 2004). In eight out of the ten selected studies where neo-material explanations were inferred, policy determinants such as water fluoridation; social spending and public investment, and, dentist to population ratio were mentioned; but the pathway was not identified as neo-material. It should be noted that all selected studies conducted a secondary analysis which limits conceptualization of the theoretical pathways as the investigators are restricted to use the available variables and examine only a few constructs.

All the selected studies conceptualized social inequality as income inequality. Social inequality contains structured and recurrent patterns of unequal distributions of goods, wealth, opportunities, rewards, and punishments. It is argued in the literature that income inequality may not capture all dimensions in which social inequality can occur such as those canvassed widely in the health inequalities literature including gender, ethnicity, indigenous status, education and economic position/wealth (Costa-Font & Hernández-Quevedo, 2012; Krieger, 1999; Bartley, 2004). Economic inequality is one dimension in which social inequality may occur. In addition, using income inequality does not capture all aspects of economic inequality (Sen, 1992, 1997, 1999). The value of income is entirely as a means to realizing individual achievements and freedoms. Income is not the only means by which this is achieved. The other means

Table 3
Conceptual and measurement alternatives used to measure social inequality in the selected studies.

Study[a]	Type of social inequality	Area based quantitative measure of inequality	Categorization of inequality variable
A	National distribution of income	Percentage of national income	Percentage of national income earned by the top 20%
B	Income inequality	Gini Index	Continuous measure of Gini
C	Income Inequality	Gini Index	Continuous measure of Gini
D	Income Inequality	Gini Index	Continuous measure of Gini
E	Income inequality	(1) Gini Index (2) 20:20: Ratio of the total annual household income received by the richest 20% of the population to that received by the poorest 20%	Continuous measure of Gini
F	Income inequality	Gini Index	A change of 10 points in the Gini scale
G	Income inequality	Gini Index	Continuous measure of Gini
H	Income inequality	Gini Index	A change of 0.46 points in Gini: difference between the Gini value of the lowest and the highest Brazilian municipalities
I	Income inequality	Gini coefficient and the ratio between annual income of richest and poorest 20% of the population (20:20 ratio)	Continuous measure of Gini
J	Income inequality	Gini Index	0.1 point difference in Gini coefficient
K	Income inequality	Gini Index	Per 0.05 unit increase (or 5%) in the Gini coefficient
L	Income inequality	Gini Index	A change of 10 points in the Gini scale
M	Income inequality	Gini Index	Tertiles of distribution into low, moderate and high
N	Income inequality	Gini Index	Tertiles of distribution into low, moderate and high
O	Income Inequality	Gini Index	Tertiles of distribution into low, moderate and high and then change in Gini over time by categorizing into (Stable, reduction, moderate increase and high increase)
P	Income Inequality	Gini Index	Tertiles of distribution

[a] All studies assessed social status rather than social class, and examined inequalities on a stratificational or gradational scale.

include rights, liberties and opportunities and wealth, and the social bases of self-respect (Sen, 1997). Whether or not a particular level of income provides economic equality depends on a range of factors, including personal characteristics, environmental conditions, variations in social climate, differences in local commodity requirement and the distribution of income within a family. Further, while many studies of individual social position explore the impact of belonging to one group or another within these dimensions, ecological studies have examined social inequalities and population health primarily using the dimension of income inequality (Navarro, 2009). The use of income inequality to measure social inequality only captures one dimension of social inequality. As such it risks ignoring the underlying class relations, power dynamics and exploitation (Muntaner & Lynch, 1999), which are responsible for generating these income inequalities. Muntaner and Lynch (1999) further stated that a measure of class exploitation can be measured at any aggregate level and is more informative due to its explicit social mechanism.

The current review had several strengths and some limitations. This study scoped the area-level inequality oral health literature using a novel and robust methodology. The use of deductive content analysis using qualitative software for critical evaluation of the theoretical basis of empirical studies has not been published elsewhere. The search strategy of the current scoping review included a wide range of electronic databases as well as grey literature. A limitation includes that potentially relevant studies (n=8) (Appendix 1) could not be included in the review as they were not published in English. Furthermore, the scoping review assessed the use of theory in a specific research question which is the association between area level social inequalities and population oral health, and some of the evaluated social theories (behavioural, material and psychosocial) are also used to explain health inequalities within societies (Bartley, 2004). The individual level oral health inequalities literature was not assessed in our review for the use of theory and future studies may use the current methodology to address this question. Finally, the evaluated social epidemiological theories included those which were generalizable across societies which may lead to the lack of inclusion of context specific explanations.

4.1. Research implications and conclusions

The need for more robust empirical testing of pathways in the association between area-level social inequality and population oral health has emerged as one of the main research implications from this review. With the importance placed on the conceptualization and measurement of social inequality, an understanding of how other societal measures of inequality such as labour market inequality (Muntaner, Chung, Benach & Ng, 2012) and rate of exploitation (Muntaner et al., 2002) affect population oral health would complement the research on the income inequality hypothesis. Systematic reviews and meta-analysis should be conducted to summarize evidence on the inequality – oral health relationship. However, it is conceivable that meta-analysis may not be appropriate as different pathways operate to different extents in different contexts. Finally, outcome specific theoretical models would provide insight to potential interventions to reduce the public health burden of oral diseases associated with inequality. With growing income and social inequalities globally, this research is an important line of investigation to reduce the overall public health burden of oral diseases.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ssmph.2016.06.001.

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4.4 Conclusions drawn from the chapter

This scoping review provided a comprehensive overview of the global evidence on the association between area-level income inequality and population oral health. Findings from the review confirmed that there is a lack of explicit theoretical basis for the association between area-level income inequality and population oral health. It applied a novel and robust methodology of integrating deductive content analysis into a scoping review to draw conclusions on the application of theory in the analytical framework of the included studies. Apart from the specific conclusions drawn on the research gap on the theoretical basis of the association between income inequality and oral health, this scoping review identified key issues related to the literature on income inequality and oral health relevant to the other research question of this thesis: *Is area-level income inequality inversely associated with population oral health in Australian context?* These issues include:

i) The review identified that variations exist in the association between income inequality and oral health according to the oral health outcomes analysed.

ii) Conducting the scoping revealed a related key challenge related due to the lack of distinction between population oral health and individual oral health as the unit of analysis for the outcome. The original income inequality hypothesis was based on investigating population variations in average health status according to societal income inequality (Wilkinson, 1992). Applying this hypothesis, an inclusion criteria for selecting the studies for scoping review was to select the studies that have tested associations between area-level social inequality and average oral health status of societies. Multilevel studies that examine individual rather than population risk according to income inequality do not qualify for inclusion on this rule as they examine the association between income inequality and oral health at the individual level. Additionally, findings from multilevel studies and previous ecological studies on income inequality and population health are incomparable as they both answer different research questions. However, the Literature Review of this thesis indicates that application of multilevel modelling in the studies of income inequality and health is necessary to control for compositional effects of individual income on health. Therefore, while changing the analytical unit to individuals in a multilevel model addresses an important methodological limitation of ecological studies, it does not answer whether income inequality is associated with the average oral health status across populations. Identification of the differences in ecological and multilevel studies on income inequality and oral health was a key outcome from the scoping review for this thesis.

iii) The review found that there is no distinction between theoretical explanations proposed to explain the associations between income inequality and oral health at a population level, and those at the individual level. Population and individual versions of theoretical pathways are treated differently in one review in the general health literature (Macinko et al., 2003). But multilevel studies do not clarify differences in application of pathways at individual and population level despite the difference in unit of analysis.

iv) All studies used income inequality to measure social inequality but there is a substantial lack of clarity on the dimensions of social inequality that income inequality captures in these societies.

v) Studies on income inequality and oral health were mostly of two types. First, studies that explored income inequality as one of the societal determinants among other societal determinants for the same oral health outcome. Second, studies that specifically tested associations between area-level income inequality and one or multiple oral health outcomes. Among the latter, each study reported a positive association between income inequality and worse oral health for atleast one outcome. However, at the sub-national level, both type of studies are limited to only the USA, Brazil and Japan suggesting that within these contexts income inequality is negatively associated with some oral health outcomes.

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4.5 Appendices for Paper 2

Submitted with the paper (http://ars.els-cdn.com/content/image/1-s2.0-S2352827316300301-mmc1.doc)

Appendix 1.1: Search strategy adopted for different electronic databases

Appendix 1.2: List of studies excluded for language

Appendix 2: Qualitative analysis to categorise studies according to the extent of theoretical application

Not submitted with the paper

Appendix 3: Tailored letters sent to following experts for grey literature

Appendix 1

1.1 Search Strategy

PUBMED:

Outcome	Exposure	Phenomenon	Context
Oral Health[TIAB] OR Tooth Loss*[TIAB] OR Decayed Missing and Filled Teeth[TIAB] OR DMF*[TIAB] OR Edent*[TIAB] OR Dental Status*[TIAB] OR Periodontitis [MH] OR Periodont* [TIAB] OR Caries [TIAB] OR Toothach* [TIAB] OR Dental pain [TIAB]	Psychosocial Deprivation* [TIAB] OR Interpersonal Relations [MH] OR Family characteristics [MH] OR Hierarchy, Social [MH] OR Social Hierarch* [TIAB] OR Minority Group* [TIAB] OR Social Class [MH] OR Social class* [TIAB] OR Social Mobilit* [TIAB] OR Caste* [TIAB] OR Social Condition* [TIAB] OR Sociology [MH] OR Poverty [TIAB] OR Socioeconomic Factors [MH] OR Socioeconomic*[TIAB] OR Salary [TIAB] OR Salaries [TIAB] OR Income* [TIAB] OR Wage* [TIAB] OR	Inequalit*[TIAB] OR Disparit* [TIAB] OR Inequit* [TIAB] OR Difference* [TIAB] OR Discriminat* [TIAB] OR Depriv* [TIAB]	Context* [TIAB] OR Neighbour* [TIAB] OR Neighbor* [TIAB] OR Communit* [TIAB] OR Ecolog* [TIAB] OR Residence Characteristics [MH] OR Multilevel analysis [MH] OR Population density [MH]

	Remuneration* [TIAB] OR Occupation* [TIAB] OR Unemploy* [TIAB] OR Labour* [TIAB] OR Labor* [TIAB] OR Educational Status[TIAB] OR Educational Achievement*[TIAB] OR Ethnic Groups [MH] OR Ethnic* [TIAB] OR Race* [TIAB] OR Raci* [TIAB] OR Sexism [MH] OR Sexis* [TIAB] OR Gender Identity [MH] OR Gender* [TIAB] OR Social Capital* [TIAB] OR Neomaterial* [TIAB] OR Social Cohesi* [TIAB] OR Materalis* [TIAB] OR Neomaterial* [TIAB]		

MEDLINE

Outcome	Exposure	Phenomenon	Context
Oral Health.ti. OR Tooth Loss*.ti. OR Decayed Missing and Filled Teeth.ti. OR DMF*.ti. OR Edent*.ti. OR Dental Status*.ti. OR exp Periodontitis/OR Periodont* .ti. OR Caries .ti. OR Toothach* .ti. OR Dental pain .ti. OR Oral Health.ab. OR Tooth Loss*.ab. OR Decayed Missing and Filled Teeth.ab. OR DMF*.ab. OR Edent*.ab. OR Dental Status*.ab. OR Periodont* .ab. OR Caries .ab. OR Toothach* .ab. OR Dental pain .ab.	Psychosocial Deprivation* .ti. OR exp Family characteristics/OR exp Hierarchy, Social/OR Social Hierarch* .ti. OR Minority Group* .ti. OR exp Social Class/OR Social class* .ti. OR Social Mobilit* .ti. OR Caste* .ti. OR Social Condition* .ti. OR exp Sociology/OR Poverty .ti. OR exp Socioeconomic Factors/OR Socioeconomic*.ti. OR Salary .ti. OR Salaries .ti. OR Income* .ti. OR Wage* .ti. OR Remuneration* .ti. OR Occupation* .ti. OR Unemploy* .ti. OR Labour* .ti. OR Labor* .ti. OR Educational Status.ti. OR Educational Achievement*.ti. OR exp Ethnic Groups/OR Ethnic* .ti. OR	Inequalit*.ab. OR Disparit* .ab. OR Inequit* .ab. OR Difference* .ab. OR Discriminat* .ab. OR Depriv* .ab. OR Inequalit*.ti. OR Disparit* .ti. OR Inequit* .ti. OR Difference* .ti. OR Discriminat* .ti. OR Depriv* .ti.	Context* .ti. OR Neighbour* .ti. OR Neighbor* .ti. OR Communit* .ti. OR Ecolog* .ti. OR exp Residence Characteristics/OR Multilevel* .ti. OR exp Population groups/ OR Context* .ab. OR Neighbour* .ab. OR Neighbor* .ab. OR Communit* .ab. OR Ecolog* .ab. OR Multilevel* .ab.

	Race* .ti. OR Raci* .ti. OR exp Sexism/OR Sexis* .ti. OR exp Gender Identity/OR Gender* .ti. OR Social Capital* .ti. OR Neomaterial* .ti. OR Social Cohesi* .ti. OR Materalis* .ti. OR Neomaterial* .ti. OR Psychosocial Deprivation* .ab. OR Social Hierarch* .ab. OR Minority Group* .ab. OR Social class* .ab. OR Social Mobilit* .ab. OR Caste* .ab. OR Social Condition* .ab. OR Poverty .ab. OR Socioeconomic*.ab. OR Salary .ab. OR Salaries .ab. OR Income* .ab. OR Wage* .ab. OR Remuneration* .ab. OR Occupation* .ab. OR Unemploy* .ab. OR Labour* .ab. OR		

	Labor* .ab. OR Educational Status.ab. OR Educational Achievement*.ab. OR Ethnic* .ab. OR Race* .ab. OR Raci* .ab. OR Sexis* .ab. OR Gender* .ab. OR Social Capital* .ab. OR Neomaterial* .ab. OR Social Cohesi* .ab. OR Materalis* .ab. OR Neomaterial* .ab.		

Web of Science

Outcome	Exposure	Phenomenon	Context
TS = (“Oral Health” OR “Tooth Loss*” OR “Decayed Missing and Filled Teeth” OR DMF* OR Edent* OR “Dental Status*” OR Periodontitis OR Periodont* OR Caries OR Toothach* OR “Dental pain”)	TS = (“Psychosocial Deprivation*” OR “Family characteristics” OR “Social Hierarch*” OR “Minority Group*” OR “Social class*” OR “Social Mobilit*” OR Caste* OR “Social Condition*” OR Sociology OR Poverty OR Socioeconomic* OR Salary OR Salaries OR Income* OR Wage* OR Remuneration* OR Occupation* OR Unemploy* OR Labour* OR Labor* OR “Educational Status” OR “Educational Achievement*” OR Ethnic* OR Race* OR Raci* OR Sexis* OR Gender*	TS = (Inequalit* OR Disparit* OR Inequit* OR Difference* OR Discriminat* OR Depriv*)	TS = (Context* OR Area* OR Neighbour* OR Neighbor* OR Communit* OR Ecolog* OR “Residence Characteristics” OR Multilevel* OR “Population groups*”)

	“Social Capital*” OR Neomaterial* OR “Social Cohesi*” OR Materalis* OR Neomaterial*)		

EMBASE

'Oral Health':ti OR (Tooth near/2 Loss*):ti OR ('Decayed Missing' next/2 'Filled Teeth'):ti OR DMF*:ti OR Edent*:ti OR 'Dental Status':ti OR Periodontitis/syn OR Periodont*:ti OR Caries OR Toothach*:ti OR 'Dental pain':ti OR 'Oral Health':ab OR (Tooth near/2 Loss*):ab OR ('Decayed Missing' next/2 'Filled Teeth'):ab OR DMF*:ab OR Edent*:ab OR 'Dental Status':ab OR Periodontitis/syn OR Periodont*:ab OR Caries OR Toothach*:ab OR 'Dental pain':ab

AND

(Psychosocial next/2 Deprivation*):ti OR 'family size'/syn OR 'Social dominance'/syn OR (Social next/1 Hierarch*):ti OR (Minority next/1 Group*):ti OR 'Social Class'/syn OR (Social next/1 class*):ti OR (Social next/1 Mobilit*):ti OR Caste*:ti OR (Social next/1 Condition*):ti OR 'Ethnology'/syn OR sociology/de OR Poverty:ti OR Socioeconomics/syn OR Salary:ti OR Salaries:ti OR Income*:ti OR Wage*:ti OR Remuneration*:ti OR Occupation*:ti OR Unemploy*:ti OR Labour*:ti OR Labor*:ti OR (Educational next/1 Status):ti OR (Educational next/1 Achievement*):ti OR Ethnic*:ti OR Race*:ti OR Raci*:ti OR 'social discrimination'/exp OR (social near/2 discrimination):ti OR Sexis*:ti OR 'Gender Identity'/de OR Gender*:ti OR (Social next/1 Capital*):ti OR Neomaterial*:ti OR (Social next/1 Cohesion):ti OR Materalis*:ti OR (Psychosocial next/2 Deprivation*):ab OR 'family size'/syn OR 'Social dominance'/syn OR (Social next/1 Hierarch*):ab OR (Minority next/1 Group*):ab OR 'Social Class'/syn OR (Social next/1 class*):ab OR (Social next/1 Mobilit*):ab OR Caste*:ab OR (Social next/1 Condition*):ab OR 'Ethnology'/syn OR sociology/de OR Poverty:ab OR Socioeconomics/syn OR Salary:ab OR Salaries:ab OR Income*:ab OR Wage*:ab OR Remuneration*:ab OR Occupation*:ab OR Unemploy*:ab OR Labour*:ab OR Labor*:ab OR (Educational next/1 Status):ab OR (Educational next/1 Achievement*):ab OR Ethnic*:ab OR Race*:ab OR Raci*:ab OR 'social discrimination'/exp OR (social near/2 discrimination):ab OR Sexis*:ab OR 'Gender Identity'/de OR Gender*:ab OR (Social next/1 Capital*):ab OR Neomaterial*:ab OR (Social next/1 Cohesion):ab OR Materalis*:ab

AND

Inequalit*:ti OR Disparit*:ti OR Inequit*:ti OR Difference*:ti OR Discriminat*:ti OR Depriv*:ti OR Inequalit*:ab OR Disparit*:ab OR Inequit*:ab OR Difference*:ab OR Discriminat*:ab OR Depriv*:ab

AND

Context*:ti OR Neighbour*:ti OR Neighbor*:ti OR Communit*:ti OR Ecolog*:ti OR Multilevel*:ti OR (Population next/1 group*):ti OR Context*:ab OR Neighbour*:ab OR Neighbor*:ab OR Communit*:ab OR Ecolog*:ab OR Multilevel*:ab OR (Population next/1 group*):ab

Proquest (Anywhere except full text), Sociological Abstracts (Abstracts), ERIC (Abstracts), Social Services Abstracts

‘‘Oral Health’‘ OR Tooth near/2 Loss* OR ‘‘Decayed Missing’‘ pre/2 ‘‘Filled Teeth’‘ OR DMF* OR Edent* OR ‘‘Dental Status’‘ OR Periodontitis OR Periodont* OR Caries OR Toothach* OR ‘‘Dental pain’‘

AND

Psychosocial pre/2 Deprivation* OR ‘‘family size’‘ OR ‘‘Social dominance’‘ OR Social pre/1 Hierarch* OR Minority pre/1 Group* OR ‘‘Social Class’‘ OR Social pre/1 class* OR Social pre/1 Mobilit* OR Caste* OR Social pre/1 Condition* OR ‘‘Ethnology’‘ OR sociology OR Poverty OR Socioeconomics OR Salary OR Salaries OR Income* OR Wage* OR Remuneration* OR Occupation* OR Unemploy* OR Labour* OR Labor* OR Educational pre/1 Status OR Educational pre/1 Achievement* OR Ethnic* OR Race* OR Raci* OR ‘‘social discrimination’‘ OR social near/2 discrimination OR Sexis* OR ‘‘Gender Identity’‘ OR Gender* OR Social pre/1 Capital* OR Neomaterial* OR Social pre/1 Cohesion OR Materalis*

AND

Inequalit* OR Disparit* OR Inequit* OR Difference* OR Discriminat* OR Depriv*

AND

Context* OR Area* OR Neighbour* OR Neighbor* OR Communit* OR District* OR Localit* OR State* OR Countr* OR County OR Counties OR Geograph* OR Municipal* OR Locat* OR Ecolog* OR Multilevel* OR Population near/2 group*

1.2 List of studies excluded for language

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6. Tassinari, W.D.S., de Leon, A.P., Werneck, G.L., Faerstein, E., Lopes, C.S., Chor, D., et al. (2007). Socioeconomic context and perceived oral health in an adult population in Rio de Janeiro, Brazil: a multilevel analysis. Cadernos De Saude Publica, 23, 127-136.
7. Celeste, R.K., & Nadanovsky, P. (2010). [Issues regarding the effects on health of income inequality: contextual mechanisms]. Cien Saude Colet, 15, 2507-2519.

8. Peres, M.A., Iser, B.P., Peres, K.G., Malta, D.C., & Antunes, J.L. (2012). [Contextual and individual inequalities in dental pain prevalence among Brazilian adults and elders]. Cad Saude Publica, 28 Suppl, s114-123.

Appendix - 2

Qualitative Analysis: Assignment of Categories

(Extracted by AS, Cross-checked by HSS and allocation of studies to categories by AS and JH)

Extent of theory

- **Explicitly theory based**: - Study explicitly stated a theory and provided a direct test of one or more of the hypotheses deduced from a named theory in order to design the study.
- **Some conceptual basis**: - Study in which theory was judged to have been used in the study, but where the study did not provide a test of any of the hypotheses deduced from the theory in order to design the study. Studies included in this category were those where the authors stated that they had employed a theory within the study, or where the study described a framework or approach that appeared to be theoretically-based.
- **Theoretical construct used**: Studies included in this category are those where one or more constructs were examined within the study, but the use of constructs was not embedded within the framework of a theory. Where a construct was referred to within the context of a theory, but was the only component of the theory that was measured and considered, this was considered to be use of the theory within the 'some conceptual basis' category.
- **Post hoc explanation**: Study used theory retrospectively to explain the results of the study or to stimulate further discussion.
- **Indirect use**: Study does not name or disclose any theoretical basis but the discussion of results are directed towards one of the social theory.
- **No theory**: When the study has no theoretical basis.

Study	**Categories**					
	Comments on theoretical pathway	Direct mention of theory	Inferred theory	Variables for theory	Objective	Category
Aida 2011	• 6 extracts (1: Introduction; 1: Methods; 4: Discussion) • Theories are introduced in detail in the background to explain pathways through which inequality can affect dental status. • Variables are chosen to represent one of the theoretical pathways	Social capital	Psycho-social theory	• Trust (cognitive social capital) and volunteer participation (structural social capital) • A community-level social capital variable was created by aggregating individual-level data (Kawachi et al., 2008). Rates of subjects reporting	This study was therefore planned with the objective of examining whether individual- and community-level social capital attenuated the associations between income inequality and two disparate health outcomes, self-rated health and dental status (number of remaining natural teeth).	Explicitly theory based

	and statistical modelling is done to test for mediation. • Theoretical pathways are re-introduced for discussing the findings of the study			mistrust and non-volunteering in each 79 local district were used as cognitive and structural community-level social capital variables.		
Bernabe 2009	• 2 extracts (1: Introduction; 1: Discussion) • Theoretical pathways are introduced in the background to explain the mechanism through which inequality can affect health • An extract in the discussion states as a limitation that future studies should explore mechanisms underlying the associations between inequality and caries.	Social capital, Social cohesion, Psychosocial and Behavioural	No extract	No extract	In accordance with the income inequality theory, the hypothesis of this study was that adult caries experience and dental care are related to relative income rather than absolute income in rich countries. Therefore, the objective of this ecological, cross-sectional study was to assess the relationships of income and income inequality with caries experience and dental care levels in 35- to 44-year-old adults among rich countries.	Post hoc explanation
Bernabe 2010	• 2 extracts (Discussion) • Theoretical pathways introduced in the discussion section only to explain the findings of the study.	Behavioural, Psychosocial	Neo-material (dentist: population ratio)	No extract	What appears to be the key factor is the size of the gap between the wealthiest 20 percent of a population and the poorest 20 percent of the same population—	Post hoc explanation

					what is now called "income inequality." Wilkinson and Pickett (ref) expanded on an earlier work of theirs on the same subject. (ref) They also showed that it is not only health that suffers as a result of income inequality, but other socially related issues—such as educational performance, The purpose of this study was to determine if similar relationships exist for income, income inequality and dental caries in young children at the population level.	
Bernabe 2011	• 6 extracts (2: Introduction; 2: Methods; 1: Discussion) • Theoretical pathways are stressed upon in the background and then explained in detail. • Justification of variables according to theoretical pathways is provided in the	Psychosocial, Health behaviour, Social cohesion	Neo-material (social spending and public investment; % of state receiving fluoridated water & dentist:population); Social support (damaging interpersonal relationships)	• Percent of state population receiving fluoridated water and state dentist-to-population ratio (per 100,000 population) as well as individuals' marital status (a crude measure of the support provided by one's spouse/partner as opposed to living	Therefore, this multilevel study examined the relationship between the state-level Gini coefficient and individual tooth loss, after accounting for a diverse set of individual and state-level factors.	Explicitly theory based

	methods along with modelling strategy to test for mediation by these variables. • Findings of the study are discussed in light of the theoretical pathways in the discussion section			alone) and last dental visit were regarded as mediators		
Celeste 2011	• 6 extracts (3: Introduction; 3: Discussion) • An extract in background explains that without understanding specific mechanisms by which income inequality works, the debate on the association between inequality and health cannot be resolved. Outcome specific theoretical pathways are then introduced in the background. • Findings of the study are discussed in terms of theoretical pathways in the discussion section.	Psychosocial, Behavioural	Neo-material (under investment in public policy including delivery of services)	No extract	The aim of this study is to evaluate the association of income inequality at lagged time of 2 and 11 years with two short-latency outcomes (untreated dental caries and gingivitis) and with two long-latency outcomes (edentulism and periodontal attachment loss > 8mm).	Post hoc explanation
Celeste 2009	• 11 extracts (3: Introduction; 3:	Social capital, material, psychosocial, neo-material	No extract	• municipal total homicide rate per 100,000 inhabitants	So, the aims of this study were to evaluate the association between	Explicitly theory based

	Methods; 5: Discussion) • Each theoretical pathway is introduced in the background and then discussed in lieu to the outcome of the study. • The methods section both include a detailed justification of variables according to the literature on theory and the modelling strategy tests for relative explanatory power of the theoretical pathways • Extracts from discussion section demonstrate that the findings of the study are discussed according to the competing mechanisms.			(mean rate from 2000 to 2002) as a proxy for social capital • To represent health services/public health policies, we selected four variables: time since last dental check (self-reported from SBBrasil 2002–2003); municipal rate of dental procedures per 100,000 inhabitant in the public dental services (mean rate from 2000 to 2002); municipal rate of dentists registered in the Federal Dentistry Council (public and private Dentists in 2002) per 100,000 inhabitant; and years of water fluoridation in the municipality (from SBBrasil in 2002–2003).	income inequality and oral health in Brazil, to assess the role of alternative models that could explain this association and to assess whether income levels modify the income inequality effect.	
Celeste 2010	• 8 extracts (3: Introduction; 2 Methods; 3: Discussion)	Psychosocial, neomaterial	No extract	• SMPP (education, child's welfare, sanitation and infra-structure, and public dental services)	Our objectives were to evaluate whether: (a) income inequality and public policies are related to oral health;	Explicitly theory based

	• Each theoretical pathway is introduced in the background and is also included in the hypothesis • Choice of variables is justified on the basis of theoretical pathways but the modelling strategy is not well detailed. It demonstrates that a calculation was performed to measure how much of the effect of inequality was explained by public policies. • The findings of the study are discussed according to how public policy explains the association between income inequality and oral health in the discussion section			• As a proxy for social capital: crude homicide rate per 100,000 inhabitants per year at municipal level	(b) income inequality is associated with public policies, and (c) the poor benefit more than the rich from public policies.	
Nadanovsky 1995	• 1 extract (Discussion) • Theoretical pathway proposed to explain relationship between broad socio-economic factors and dental caries but not specific to income inequality	No extract	Behavioural (fruit and vegetable consumption, tooth brushing)	No extract	Because of the paucity of analytic studies, the aim of this study was to assess the contribution of dental services to the changes in DMFT levels of 12 year old children before the mid	No theory

					1980s in 18 industrialized countries. As a secondary aim, the association of changes in 12-year-old DMFT levels with broad socioeconomic indicators (including the fluoridated toothpaste market) was explored.	
Pattussi 2001	• 3 extracts (1 Introduction; 2 Discussion) • Social capital pathway introduced in the introduction section • Findings of the study discussed in support of social cohesion and social capital theory • Study independently assessed associations between contextual factors (deprivation, inequality and social cohesion) and caries rather than testing social cohesion as a pathway between inequality and caries.	Social cohesion	Social capital (features of social organisation that enables participants to act together more effectively to pursue shared objectives and mutual benefits)	• Social cohesion:- Per thousand number of participants in meetings of the participative budget • Per thousand numbers of homicides and attempted homicides	The objective of this study was to investigate the association between deprivation, income inequality, social cohesion and dental caries in children from 6 to 12 years of age. It was hypothesised that the prevalence and severity of dental caries was positively related to high levels of deprivation, income inequality and low levels of social cohesion.	Theoretical construct used
Sabbah 2010	• 6 extracts (2 Introduction; 4 Discussion) • Theories are introduced in the	Psychosocial, Social capital	Neo-material (Disinvestment on public services)	No extract	The objective of this study is to examine the relationship between income inequality and periodontal disease in	Post hoc explanation

	background and explained in detail. • Theories are discussed in the discussion section as possible explanations for the association between inequality and outcome as well as in support of psychosocial mechanism				rich countries for individuals aged 35-44 years old.	
Vettore 2013	• 2 extracts (1 Introduction; 1 Discussion) • Psychosocial and behavioural theories introduced in the background as an explanation for the possible influence of inequalities on periodontal diseases • Theoretical pathways are discussed in the discussion section as explanations for the findings of the study	Behavioural and psychosocial	Social support (Degradation of interpersonal relationships)	• level of integration of oral health care teams into Family Health Programme (Estratégia de Saúde da Família) (OHT/FHP) • % of smokers	This study aimed to describe the prevalence of periodontal disease in Brazilian adult population and to investigate the association of contextual social inequalities and individual sociodemographic characteristics with periodontal disease.	Theoretical construct used
Vettore 2015	• 1 extract (1 Discussion) • The theoretical pathways are introduced to explain how poor OHRQoL	Material, social capital, behavioural and psychosocial	Neo-material (Better public policies associated with equal societies)	No extract	To conduct a robust study to test the hypothesis that adults living in cities with poor social indicators, i.e. high income inequality and	Post hoc explanation

	can accrue from income inequality				low social development, had poorer OHRQoL than those living in cities with better-off contextual social measures. The objective was to test the relationship of contextual and individual socio-economic indicators with OHRQoL considering demographics and oral health conditions in adults between 35 and 44 years of age.	
Goulart 2015	• 1 extract (Introduction) • The theoretical pathways are introduced in the background to explain how individuals in unequal societies may have bad oral health	Social Cohesion	Neo-material (disinvestment in human capital – healthcare and education), Psychosocial (psychological pathway through invidious social comparison)	No extract	The objective of this study was to assess whether middle aged adults living in cities that experienced a relative increase on income inequality during recent decades were more likely to have severe tooth loss and lack a functional dentition. In addition, we also conjectured that the influence of low family income on tooth loss in middle-aged adults was partly attenuated by relative increase in income inequality in the area where people lived.	Post hoc explanation

Peres 2003	• 1 Extract (Discussion) • Theoretical pathway introduced to explain how socio-economic development indicator at town level may lead to dental caries, but did not specifically include income inequality. The study did not find an association between inequality and oral health outcomes		Behavioural (intake of high levels of carbohydrates, including sweets) Material (limited use of fluoridated toothpaste and inadequate dental treatment	No extract	The purpose of this study was to investigate the association that town level indices of socioeconomic development had with outcomes for the oral health status of children who were 5 or 6 years old and living in the state of São Paulo.	No theory
Chalub 2015	• 3 extracts (1 Introduction, 1 Methods and 1 Discussion) • Theoretical pathway proposed in Introduction and Discussion to identify risk factors for functional dentition but not to test mediation • Theoretical model used in the Methods to explain how structural determinants (inequality and HDI) may impact functional dentition through intermediary determinants	Behavioural, Material, Psychosocial	Neo-material (Provision of Health Services, Fluoridated water supply	Fluoridated water supply, oral health coverage, schooling, self-rated treatment need, dental pain, dental appointment in the previous 12 months and dental services.	The aim of the present study was to estimate the prevalence of functional dentition in Brazilian adults aged 35 to 44 years using four different definitions and identify associated individual and contextual factors.	Theoretical construct used

	(behaviour and material factors)					
Hobdell 2002	• 4 extracts (1 Introduction, 1 Methods and 2 Discussion) • Theories proposed in the introduction to explain inequalities in oral health • Study independently assessed correlations between behavioural risk factors, inequality and the oral health outcomes. • Theories introduced in the discussion section to explain how inequalities affect health	Behavioural, Psychosocial		Mean sugar intake and Number of cigarettes smoked everyday	To investigate associations between the patterns of certain oral conditions (dental caries, chronic destructive periodontal disease and oral cancer) in different countries and certain national socioeconomic characteristics of the populations (SES indicators).	Post hoc

Appendix 3: Tailored letters sent to following experts identified based on criteria that they had published at least two papers on the association between income inequality and oral health outcomes to identify grey literature:

1) Professor Aubrey Sheiham
2) Doctor Eduardo Bernabe
3) Professor Johan Fritzell
4) Professor Roger K Celeste
5) Doctor Wael Sabbah
6) Professor Wagner Marcenes
7) Professor Martin Hobdell
8) Professor Paulo Nadanovsky

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23rd January 2015

Professor *********
*****
*****
*****
*****

Dear Professor ****,

Greetings of the day,

I am a PhD student at the Australian Research Centre for Population Oral Health (ARCPOH), School of Dentistry, The University of Adelaide. As a component of my PhD project, I am conducting a scoping review of studies which have assessed the association between social inequalities at an ecological level and population oral health outcomes. The scoping review aims to map the theoretical explanations proposed to explain this association.

Considering that you have published in this research area and with your expertise in this subject, I am writing to request you to help me identify unpublished studies which may not present in the search conducted in scientific databases. In scientific interest it would be of great help if you could share any unpublished or published document (grey literature) which you consider should be included in this review. The authors of the scoping review will acknowledge any material provided in the proposed publication in a scientific journal.

Thanking you,

Yours sincerely,

Ankur Singh
(On behalf of Dr. Jane Harford, Dr. Helena Silveira Schuch, Prof. Richard G Watt and Prof. Marco A Peres)

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5. Investigating societal determinants of oral health: opportunities and challenges in multilevel studies

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Submitted to *Community Dentistry and Oral Epidemiology*

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Principal Author

Name of Principal Author (Candidate)	Ankur Kumar Singh		
Contribution to the Paper	Identified research gap, proposed the idea, prepared the first draft, acted as the corresponding author		
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	6/7/2017

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	Jane Harford
Contribution to the Paper	Supervised development of work, provided critical feedback on draft, manuscript evaluation and editing
Signature	Date 7/7/2017

Name of Co-Author	Marco A Peres
Contribution to the Paper	Supervised development of work, provided critical feedback on draft, manuscript evaluation and editing
Signature	Date 6/6/2017

This chapter is by publication and it evaluates the value in studying population variations in oral health outcomes and their societal determinants compared to studies of individual variations in oral health and its determinants. This paper aims to recognise the distinction between studying risks (income inequality) of variations in oral health between populations (ecological approaches) and within populations (multilevel approaches that do not quantify population variations in oral health). Based on the theoretical observations on the distinction between studying risks of between and within population variations in oral health, and the current challenges for population oral health, this paper advocates increased studies in oral epidemiology on population variations in oral health and its societal determinants. This paper also reviews the key methodological aspects related to testing associations between societal determinants and oral health outcomes.

5.2 Rationale for the publication

The scoping review highlighted a lack of consensus on the level at which outcomes should be analysed in studies of income inequality and oral health. Multiple studies have challenged the literature on income inequality and population health, based on the inability of ecological studies to effectively separate associations between income inequality and health at the population level from the compositional effect of individual income on health (Judge, 1995; Gravelle, 1998; Judge et al., 1998; Wolfson et al., 1999; Wagstaff and Doorslaer, 2000; Gravelle et al., 2002). On the other hand, use of ecological approaches and studying population variations in health and its societal risk factor are strongly advocated by some in epidemiology (Rose, 1985; Schwartz, 1994; Susser, 1994a; b; McMichael, 1995; 1999; Morgenstern, 1995; Pearce, 1999; 2000). Introduction of multilevel modelling to the studies of income inequality and health outcomes have resolved the methodological challenge of separating the compositional effect of individual income on individual health outcomes, from the contextual effect of societal income inequality on individual health outcome (Subramanian and Kawachi, 2004). However, a practice of limited reporting the population variations in individual health outcomes estimated through decomposing variance at a population level in general among multilevel studies has been suggested (Merlo, 2003; Subramanian, 2004; Larsen and Merlo, 2005; Merlo et al., 2005a; b; Merlo et al., 2006; Merlo et al., 2009). The theoretical and methodological discussion on the choice of the analytical unit and its methodological and policy consequences is mostly limited to general health literature and is relatively lacking in the oral health literature. Therefore, the theoretical value underpinning investigation of the association between income inequality and health at a population level has a wider relevance to studies on population oral health and its societal determinants.

Studies on societal determinants of oral health outcomes, as is the case of association between income inequality and oral health, are complex due to the hypotheses generated at multiple levels of social organization (Diez Roux, 2004a; Diez Roux, 2004b). The Literature Review of this thesis listed and discussed the implications of methodological issues including geographic level of aggregation, role of individual level variables, level of analytical unit and corresponding choice of statistical modelling, sample size for multilevel modelling, and lag effects, on the association between income inequality and health. Additionally, cross-level effects of societal determinants, fallacies (ecological, atomistic, sociologistic and psychologistic), classifications and construct of ecological variables, meaningful definitions of population, multiple membership, and modifiable areal unit problem are highlighted in general health literature and are critical to studies of societal determinants of health outcomes. Evidence exists that oral and general health outcomes often behave differently with the same social determinant (Aida et al., 2011; Vahid et al., 2013). However, there is lack of discussion on the methodological considerations related to investigations on societal determinants of oral health in the oral health literature. This paper further addresses this gap by collating the methodological considerations from general health literature and discusses this gap in the context of oral health. Wherever possible, examples based on the literature from the income inequality hypothesis and oral health are used to explain the relevance of the methodological considerations. Theoretical and methodological concepts identified in this paper regarding multilevel models will be of key relevance to the empirical testing of association between area-level income inequality and oral health outcomes in Australian context.

PAPER 3

Investigating societal determinants of oral health: opportunities and challenges in multilevel studies

Title: Investigating societal determinants of oral health – opportunities and challenges in multilevel studies

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Abstract:

The high prevalence of oral diseases and the persistent nature of socioeconomic inequalities in oral health outcomes across societies presents a significant challenge for public health globally. A debate exists in epidemiology on the merits of investigating population variations in health and its determinants over studying individual health and its individual risk factors. The choice of analytical unit for health outcomes at the population level has policy implications and consequences for the causal understanding of population-level variations in health/disease. There is a lack of discussion in oral epidemiology on the relevance of studying population variations in oral health. Evidence on the role of societal factors in shaping variations in oral health at both the individual level, and the population level, is also mounting. Multilevel studies are increasingly applied in social epidemiology to address hypotheses generated at different levels of social organization, but the opportunities offered by multilevel approaches are less applied for studying determinants of oral health at the societal level. Multilevel studies are complex as they aim to examine hypotheses generated at multiple levels of social organization and require attention to a range of theoretical and methodological aspects from the stage of design to analysis and interpretation. This discussion paper aims to highlight the value in studying population variations in oral health. It discusses the opportunities provided by multilevel approaches to study societal determinants of oral health. Finally, it reviews the key methodological aspects related to operationalizing multilevel studies of societal determinants of oral health.

Introduction

Oral diseases affect half of the global population (Kassebaum et al. 2017). Untreated dental caries remains as the most prevalent non-communicable disease world-wide (Kassebaum et al. 2017), despite some success in reducing childhood dental caries in high-income countries during the latter part of the twentieth century (Do 2012). Persistent socioeconomic inequalities in oral health outcomes within and between societies are also highlighted (Watt et al. 2015). Collectively, the two issues reflect limited or inadequate policy responses at both global and local levels. High levels of disease and inequalities in oral health persist because current prevention methods that are based mainly on the biomedical approach and focus on changing individual behaviour. These approaches tend to result in only short terms improvements for certain patients but do not address the underlying causes of diseases (Watt 2007; Watt et al. 2015). Evidence-based actions at the population level are necessary to reduce the enormous burden of oral diseases and counter the persistent socioeconomic inequalities in oral health outcomes.

Majority of oral epidemiologic studies investigate only individual variations in oral health and its individual determinants notwithstanding the current challenges in population oral health (Kassebaum et al. 2017; Watt et al. 2015). The underlying biomedical and individual-based approach is a key limitation of such epidemiological investigation as it does not address the underlying causes of diseases. This approach neglects population variations in oral health and its societal risks. Studies of population variations in health are fundamental if the goal is to ascertain the determinants of population health (Pearce 1999). Studies of population variations in health are also critical to understanding systematic differences due to which oral health inequalities mirror the social inequalities present within societies. These investigations are directed to study population-level variations in oral health and its determinants, also called ecologic effects (Morgenstern 2008). Conversely, studies that examine individual-variations in oral health within populations and its determinants tend to examine biologic/behavioural effects (Morgenstern 2008; Pearce 1999; Susser 1998). A timely discussion of the theoretical rationale for investigating population variations in oral health is essential in the light of current challenges.

Multilevel studies are progressively applied in the discipline of social epidemiology and in oral health (Diez Roux 2008). The foundation of a multilevel approach lies in the inexorable dependency of individual's health on the surrounding social and physical environment. Social contexts and their characteristics are integral determinants of variations in health outcomes both within populations and between populations. Societal patterns of oral diseases represent the biological consequences of living and working conditions differentially afforded to social groups as a product of economic and political priorities of societies (Diez Roux 2016; Krieger 2008; Marcenes et al. 2013; Watt et al. 2015). These priorities vary across different levels of administrative and political boundaries ranging from global and national, to small areas like neighbourhoods, local areas, municipalities, performing a fundamental role in the distribution and access to oral health promoting/risks factors. Multilevel studies pay equal attention to both intimate and ultimate causes of health without discounting that individual health and its individual risk factors do not function in isolation (Krieger 2008). Hence, the opportunities and challenges offered in multilevel approaches for a better understanding of the role of societal determinants of oral health need to be highlighted.

Testing hypotheses at multiple levels of social organization using multilevel studies, although very useful, are complex (Diez Roux 2004). These complexities arise due to the mutual interactions and interdependencies between individual-level and societal-level factors related to health. Methodological experts in epidemiology, particularly social epidemiologists, have highlighted some challenges (relevant groups/levels, lag times, fallacies, confounding among others) in the light of general health outcomes (Blakely and Woodward 2000; Diez-Roux 2000; Diez Roux 2004; Subramanian 2004). However, general health outcomes and oral health outcomes are reported to differ in their relationship with social determinants when examined simultaneously (Aida et al. 2011; Vahid et al. 2013). Social inequalities in oral health outcomes were found to be more pronounced than general health outcomes in Canada (Vahid et al. 2013). A stronger association between income inequality and dentition status (presence of teeth) than between income inequality and self-rated health was reported in Japan (Aida et al. 2011). Therefore, multilevel studies on societal determinants of oral health outcomes demand important methodological considerations.

In the light of the public health challenges presented in oral health at the population level, this paper aims to:

i) present theoretical and pragmatic reasons to consider re-balancing the weight of studies on individual-level variations in oral health towards studies on population-level variations in oral health,

ii) discuss the contribution of multilevel studies to generate valuable evidence on societal determinants of oral health and understanding population variations in oral health, and,

iii) review methodological aspects relevant to the application of multilevel studies in oral health.

The case for more studies on population variations in oral health and its determinants

Geoffrey Rose's seminal work in 'The Strategy of Preventive Medicine' stressed the distinction between the risks for individual variations in health, and, the risks for population variations in health (Rose 1992). Rose's theorem' or the 'prevention paradox' states that "a large number of people exposed to a small risk may generate more cases than a small number exposed to a high risk". Therefore, when everyone is exposed to the risk within a population, it is not possible to measure the effect of the exposure without reference to a population that has a different level of exposure. Building on this, Rose established that the determinants of variations in health between populations differ from the determinants of variations in health within the population (Rose 1992). This is a key argument for studying population variations in health and its determinants. Differences in the magnitude of the influence of determinants of caries rates among children within and between Australia and Vietnam is one example of operationalization of Rose's theorem in oral epidemiology (Do 2012). The study reported that while individual social position was relevant for individual risk, country-level economic development and social inequality were more relevant for population risk (Do 2012).

Another epidemiologist, McMichael (1999) raised a relevant question that further underscores a key argument for conceptualizing and studying health outcomes at a population level that is relevant to oral health:

> "Are we, merely distinguishing between upstream social contexts and their downstream proximate manifestations? Or is there a category of risk factor that, in some collective way, influences the health of the population at large via processes that have no direct downstream manifestation?"

Evidence summarised below from the oral health literature reinforces the need to pursue this line of enquiry.

Growing evidence on the independent contribution of contexts in shaping oral health: A systematic review (Barbato and Peres 2015), and a scoping review (Singh et al. 2016), have separately confirmed poor oral health outcomes to be associated with less favourable contextual socioeconomic variables (high area-level social inequality, high area-level deprivation, low social capital, and, low access to dental healthcare). Socioeconomic inequalities in oral health outcomes according to contexts are expressed spatially based on the variations in area-level social, political, and economic characteristics. Therefore, population-level variations in oral health outcomes can finely capture the population-level impact of contextual societal disadvantage.

Population variations in oral health reveal underlying societal determinants: Investigating patterns of variation in oral health between populations is important in its own right. The observed population-level variations are important to understand the significance of specific contexts for oral health outcomes (Merlo et al. 2005a). Otherwise, similar individuals may have differences in their health dependent on where they live because of differing cultural, economic, political, geographic, climatic and historical contexts (Macintyre and Ellaway 2000). The more homogenous the oral health of individuals within a population, the higher the probability that determinants of oral health are directly related to the contextual environment or the population characteristics. Interventions, in this case, needs to be directed to contexts rather than individuals (Merlo et al. 2005b). From an equity perspective, population-variations in health outcomes, that are systematic, socially produced and unfair, are highly relevant (WHO(Europe) 2006). These inequities result from systematic differences in exposure to health risks and protective factors as well as to treatment services, based on social position ((CSDH) 2007). Therefore, the observation of population variations in oral health between societies reflects the need to understand the differences in characteristics of these societies.

Socio-political and multilevel nature of oral health determinants: Individual-level risk factors for most prevalent oral conditions include high sugar consumption, tobacco use, lack of access to fluoride, high levels of stress, lack of oral hygiene and favorable pattern of dental visiting (Rugg-Gunn and Do 2012; Sanders et al. 2006; Sheiham and Watt 2000). The distribution of these individual-level determinants both within and between societies can be influenced by societal determinants and policy decisions at multiple geographic and administrative levels. Variations in presence and intensity of policy implementation can also exist between the geographic and administrative levels. Key policy determinants that impact distribution of individual-level behavioural risk factors include federal, state and local level decisions on community water fluoridation (Peres et al. 2004); health care arrangements including provision and financing; tobacco control policies including ratification of Framework Convention of Tobacco Control (FCTC) at the national level to its compliance at different sub-national geographic and administrative levels (Liberman 2012); trade arrangements/agreements and marketing regulations impacting food demand and supply (Friel et al. 2013); and availability of local physical and social environments that improve social cohesion and physical activity (Bentley et al. 2010). Studying population variations in oral health can allow comparisons between societies and provide key insights about existing policies and the impact on population oral health of different political and administrative arrangements. Cross-national studies comparing countries with different policies, for example regarding taxation of sugar foods/beverages or their dental care systems, can contribute significantly in assessing the potential impact of upstream interventions on oral health. Additionally, natural experiments at the societal level that compare population oral health can serve as a useful tool. Natural experiments applied in oral health context from Brazil and Japan have improved the current understanding of the effectiveness of water fluoridation in reducing dental caries among adults, and the impact of socioeconomic disadvantage on tooth loss (Matsuyama et al. 2017; Peres et al. 2016).

Explanatory potential of individual-level studies for population oral health: Most epidemiological studies report measures of individual relative risk (odds ratio (OR), risk ratio (RR) rather than the population attributable risk (PAR) (Kunitz 2007). PAR describes how much of the condition within the population can be attributed to a particular risk factor, while the risk ratio (RR) informs the change in risk of an outcome among exposed individuals compared to unexposed individuals. Even with larger and statistically significant levels of RR, the PAR can be smaller and insignificant from a public health perspective, if the exposure is not widespread (Kunitz 2007). Alternatively, a low RR can accompany a high PAR when an exposure occurs frequently in the population. The study by Do (2012) on the differences between caries rates among Vietnamese and Australian children found an RR of 1.24 for dental caries among Vietnamese children who did not start brushing with toothpaste before three years of age. The RR for Australian children was similar with a value of 1.27. However, the Population Attributable Fraction (PAF - the proportion of the disease in the population attributable to a factor of interest) for Vietnamese children by introducing brushing with toothpaste before the age of three years was 18% compared to only 3% for Australian children for the prevention of caries. Lack of reporting of PAR along with measures of association in studies of individual-level outcomes limits the knowledge of the preventive capacity of interventions for population oral health.

Individual-level risk factors for oral diseases often do not vary enough within populations to permit quantification of their probability to increase risk at an individual level (Morgenstern 1995; Pearce 2000; Rose 1992). This issue further limits the value of individual-level studies in generating evidence for population-level prevention, even when PAR is reported. For instance, the WHO recommends that free sugars intake should be restricted to less than 10% of total energy. A conditional recommendation for further health benefits particularly with regard to dental caries includes restriction to less than 5% of total energy (ABS 2016). This recommendation is exceeded in most countries. A review of data on sugar intake from national surveys from Australia, Denmark, Ireland, Norway, and US showed that at a population level none of these countries met the recommendation of 5% limit (Wittekind and Walton 2014). Furthermore, evidence from Australia demonstrates the prevalence of exceeding the recommendations is high (52% for the 10% recommendation and 89% for the 5%

recommendation) (ABS 2016). Therefore, there may not be enough variation in the exposure within a population to the effects on dental caries to be determined. Ecological studies, which study between-population, rather than within-population variation in caries according to sugar availability, report larger variations in caries status according to sugar availability when compared to individual-level studies (Sheiham and James 2015). In cases where the individual risk factors do not vary within populations, evidence on population variations in oral health are likely to be more informative in making public health decisions.

Informing strategies for prevention for oral diseases: During the second half of the 19th and first half of 20th century, there was a shift in epidemiology away from studying societal causes of diseases and a move towards the individual and microbial causes (Honjo 2004; Kunitz 2006) and is identified as an epistemological revolution in understanding the causes of diseases (Kunitz 2006). Different approaches to disease causality have important political and medical implications as they mean a different locus of responsibility for prevention of diseases. A causal focus on microbial factors confers responsibility of prevention to health professionals, individual behaviours or lifestyle factors implies a personal responsibility for disease control, while a socio-environmental causal model places responsibility on authorities and general society for the prevention of disease and reduction of exposure (Tesh 1980). Prevention strategies for non-communicable diseases including oral diseases often suffer from a similar individually-focussed approach by promoting change in individual risk-factors. The population-based strategy, the high-risk strategy, and the directed population strategy are the three types of strategies applied towards prevention of oral diseases and promoting oral health. The population-based strategy for prevention starts with the recognition that the occurrence of common diseases and exposures reflects the behavior and circumstances of society as a whole (Rose 1992). Alternatively, the high-risk strategy targets individuals identified as having an elevated risk of some adverse health outcome (Rose 1992). The directed population strategy is a version of the population strategy but it is directed more towards vulnerable groups based on their social circumstances rather than elevated levels of risk (Frohlich and Potvin 2008; Watt 2005). The studies on the causes of individual variations in oral diseases generate evidence that may provide limited support to whole population approach for prevention. For instance, Holst and colleagues have reported that the occurrence of a carious lesion in individuals and the occurrence of caries in populations have different causal candidates and patterns. This exemplifies the distinction between the causes of cases and the causes of incidence in a population (Holst 2005; Holst et al. 2001). Individual-level approaches have remained as the dominant paradigm in understanding the production and prevention of oral diseases (Baelum 2011; Watt 2007). This approach is consistent with the ‘high-risk strategy’ (Rose 1992). and has evolved from both the biomedical nature of dentistry, and an individual ‘risk factor’ focus from clinical oral epidemiology (Watt 2007). The limitation of a ‘high-risk strategy’ in reducing variations in population levels of oral health is well established within the literature (Batchelor and Sheiham 2006; Watt 2007). This approach does not acknowledge the growing understanding of the multilevel nature of health determinants (Krieger 2008) and societal determinants in shaping the distribution of oral health (Marmot and Bell 2011; Watt 2002; 2007). Therefore, dominance of individual based approaches shifts attention from underlying societal determinants of health and encourages individual responsibility to maintain oral health rather improving environments to promote oral health (Schwartz 1994).

Advancing the multilevel study approach

An ecological design within epidemiology seeks to understand how contexts affect the health of groups through selection, distribution, interaction, adaption and other responses (Susser 1994). Multilevel studies investigate both groups and individuals as the unit of analysis. It allows the simultaneous investigation of between-group and within-group variability in individual-level outcomes (Diez Roux 2004). Therefore, multilevel studies can be applied to examine the associations between group level and individual level variables with individual-level outcomes. Additionally, it can be applied to examine between-group and within-group variability and the contributions of group-level and individual-level variables to variability at both levels -population variations in health and its determinants (Diez Roux 2002).

A key advantage of multilevel study is its potential to address confounding generated from variables at alternate levels of social organizations when simultaneously analyzing variables at two or more levels of social organization, multilevel studies allow addressing. This advantage of multilevel studies has been widely exploited in studies of area-level income inequality and health outcomes (Subramanian and Kawachi 2004). Early ecological studies on area-level income inequality and population health using single-level regression models have been criticized in the past. It is debated that the observed associations between area-level income inequality and average health status at the population level in ecological studies were due to the effect of individual income on individual health (compositional effect) rather than a true effect of income inequality (Judge et al. 1998). Multilevel studies offer the opportunity to separate the contextual effect of income inequality on individual health from the compositional effect of individual income by allowing to adjust for individual income within the same regression (Subramanian and Kawachi 2004). However, ecological studies analyzed population risk according to area-level income inequality, while the multilevel studies assessed individual risk according to area-level income inequality (Merlo et al. 2016). The population-level aspect of health outcome in multilevel studies is studied through investigating the share of individual-level variation in health outcomes that exist at the population level through decomposition of variance. (Merlo et al. 2016).

Methodological experts argue that multilevel modelling has not been used to its potential to answer questions on population-level variations in health status and its determinants in the field of social epidemiology (Larsen and Merlo 2005; Merlo 2003; 2014; Merlo et al. 2005a; Merlo et al. 2009; Merlo et al. 2016). Studies have mostly focussed on average associations between individual and societal determinants, and health outcomes, ignoring a thorough analysis of heterogeneity around average associations examined through the variance estimates obtained from multilevel studies (Merlo et al. 2016). The variance component informs to what extent individuals within a group are correlated with one another in relation to health. The extent of clustering has value in the context of ideas about considering interventions on places instead of people (Merlo et al. 2005b). One application of this logic is identified in a study where multilevel modelling is utilized to identify appropriate geographic levels for policy intervention (Castelli et al. 2013). Geographic levels at which the observed variations in outcomes are larger, there may be greater potential for policy intervention to have an impact on the outcomes of interest, compared with targeting policy at levels with relatively smaller variations (Castelli et al. 2013). Multilevel studies also provide a suite of measures based on average association between societal exposures and individual health outcomes (OR, RR), and measures of variation in individual health (variance) and its decomposition at the population level (variance partition coefficients (VPCs), intra-class correlation coefficient (ICC) for continuous outcomes and median odds ratio (MOR) for binary outcomes), that can be applied to understand societal causes of population variations in oral health. Two additional measures: 80% Interval Odds Ratio (IOR) and Proportion of Odds Ratio in Opposite Direction (POOR), can be quantified by combining regression coefficients obtained from averaged associations between societal determinants and individual oral health and the variance attributed to the contextual level. The two measures estimate the heterogeneity in the associations between societal exposures and individual health outcomes among contexts/population groups (Merlo et al. 2016). Measures of variation in individual health and its decomposition are critical for inferences on population-level variations in health. In addition to ICC, measures of discriminatory accuracy such as Area Under Curve (AUC) can be applied to understand the independent contribution of societal context in general, and of specific societal exposure, in determining oral health outcomes. (Merlo et al. 2016). Collectively, these measures can be exploited to provide a thorough and realistic assessment of the relationship between societal determinants and oral health within the same dataset.

Predominantly, multilevel studies on societal determinants of oral health are of two kinds. Some studies have simultaneously examined the role of multiple societal determinants (Human Development, access to fluoridated tap water, oral health coverage, and income inequality) and oral health outcome/s consistent with a more exploratory approach using the social determinant framework (Antunes et al. 2006; Chalub et al. 2016; Vettore and Aqeeli 2015). Others have tested specific associations between one societal determinant (for example: area-level income inequality, neighbourhood deprivation) (Aida et al. 2011; Bernabe and Marcenes 2011; Celeste et al. 2009; Goulart and Vettore 2015; Turrell et al. 2007) and oral health outcome/s consistent with a causal approach. The dominance of probabilistic risk factor epidemiology has limited the use of multi-level models to examine between-group and within-group variability through quantification of variance and its decomposition at different levels of social organizations (Merlo 2014; Merlo et al. 2009). The understanding of the social determinants of the societal determinants can substantially benefit from the application of multilevel models by examining between-group variability in individual-level oral health outcomes as a method to study population-level variations in oral health.

Methodological aspects relevant to application of multilevel approaches within oral health

Methodological considerations related to multilevel studies relevant to oral health are collated from the general health literature and discussed below under logical headings.

Wherever possible, published or hypothetical examples from oral health are used to illustrate their relevance.

Types of cross-level associations and arising fallacies

The simultaneous assessment of associations between societal and individual factors and individual health outcomes in multilevel studies has led to investigations of three main different types of associations (Blakely and Woodward 2000). A societal exposure can potentially impact oral health at an individual level through direct cross-level association, indirect cross-level association, and cross-level effect modification. A direct cross-level association occurs when a societal factor has a direct impact on the individual oral health outcome. For example, a person living in an area with community water fluoridation (exposed to fluoride) has lower risk of dental caries, than a person in non-fluoridated area (Bernabe and Marcenes 2011). Indirect cross-level association occurs when a societal factor results in a change in individual-level exposure, which consequently, increases or decreases risk of disease at an individual level. For instance, the presence of school policies on the availability of sugar sweetened beverages (SSBs) can discourage individual consumption of during the day, therefore, reduce the risk of dental caries (Wilder et al. 2016). Finally, cross-level effect modification occurs when a societal factor modifies the association between an individual level factor and individual health outcome. Some evidence exists to suggest that the associations between individual social position and oral health vary according to the welfare typology,(Guarnizo-Herreno et al. 2013; Sanders et al. 2009). in line with the cross-level effect modification. Clarity on these pathways when generating hypothesis is critical as the findings have consequences of the choice of policy intervention points for improving oral health.

Several fallacies are produced in a situation when the hypothesis generated in both conventional ecological studies and multilevel studies are not theoretically aligned with the potential mechanisms of how societal factors can impact oral health. These fallacies are called ecological, atomistic, sociologistic, and psychologistic, and are widely discussed in general health literature (Blakely and Woodward 2000; Diez Roux 2003). Each of these fallacies are described along with a suitable published or hypothetical example in Table 1.

Ecological variables: classification and constructs

Ecological variables represent group-level properties, including societal factors, which are relevant to oral health. Depending on their measurement or the construct they aim to capture, ecological variables have been classified in several ways within the literature. Classification of ecological variables reveals its degree and nature of dependency on individual-level factors. For instance, ecological variables can be integral or derived (Diez Roux 2004). Integral ecological variables are only group characteristics, and cannot be measured at an individual level, for example: community water fluoridation and air pollution. Conversely, derived ecological variables present as mathematical summary of individual characteristics within a group (Diez Roux 2004), for example: percentage of children with sugar consumption above the World Health Organization recommendation, or area-level mean income. However, derived ecological variables may or may not have their individual-level analogue. While area-level mean income has an individual income as its individual equivalent, area-level income inequality is solely a group property and does not have an individual equivalent.

Based on the constructs they capture; ecological variables can be categorized as:

i. aggregate/ contextual/ analytical,
ii. contagion,
iii. environmental,
iv. structural, and

v. global/ integral.

The description of these categories of ecological variables along with suitable examples is presented in Table 2. Clarifying the constructs that the ecological variable of interest aims to capture has implications on measurement issues and analytical approaches. For instance, global variables such as legislations and policies are likely to have a more diffused effect among populations rather than leading to an instant biological or bio-behavioural impact on ‘high-risk’ individuals. In such cases, ecologic inferences about effects on group rates or population-level variations may be more relevant than individual risks (Morgenstern 1995).

Meaningful population groups, scale, and unique characteristics

Specifying meaningful boundaries and identifying groups of interest for the ecological unit of interest is core to any multilevel study (Sampson et al. 2002; Subramanian 2004). Despite the use of ‘population’ across many disciplines analysing population data—for example, epidemiology, demography, sociology, ecology, population biology and population genetics, statistics and biostatistics, it is rarely defined, except in abstract statistical terms (Krieger 2012). Various criteria can be applied to define population groups of interest. For instance, the boundaries of a ‘neighbourhood’ can be defined based on historical or geographic criteria, the perception of the residents or the administrative boundaries used for policy delivery. Moreover, ‘neighbourhood’, ‘community’, and ‘area’ are often used loosely within the health literature to identify an individual’s immediate residential environment, and the three terms are not explicitly defined or distinguished (Diez Roux 2001). The population-level effectiveness of public policies such as community water fluoridation in reducing dental caries are more consistent with administratively defined boundaries, compared to interventions to improve opportunities for social interactions. Creating opportunities for social interaction in a community is likely dependent on what an individual perceives as the boundary for a community rather than the administratively defined limits. Recently, it was highlighted that a "residential" effect fallacy bias exists in most studies of neighbourhood and health studies that ignorantly capture non-residential environment effects, leading to overestimation of residential intervention effects (Chaix et al. 2017). These non-residential environment effects may be due to schools or workplaces depending on the health outcome, population density, and individual mobility (Chaix et al. 2017; Diez Roux 2008).

The selection of spatial scale for testing associations between ecological factors and health outcomes is both an important theoretical and methodological aspect. First, the societal processes that produces health may vary by geographic scale (Diez Roux 2007). Second, group-level characteristics do not occur randomly and are based on the social and political context that influence these characteristics. The spatial scale of assessment has been used consistently as one of the most important explanations for the lack of association income inequality and general health outcomes at a sub-national and/or small area level (Wilkinson and Pickett 2006). Studies have examined associations between income inequality and health outcome at different levels of aggregation within the same country and found significant variations (Rostila et al. 2012). The lack of association at a smaller level of geographic aggregation and the presence at the larger is attributed to the inability of income inequality as an exposure to reflect the social stratification within a society at a small area level. (Wilkinson and Pickett 2006). Medical geographers have also recognized the 'modifiable areal unit problem (MAUP)' and 'uncertain geographic context problem (UGCoP)' that need to be considered when selecting the relevant spatial scale (Duncan et al. 2014; Kwan 2012; Park and Kwan 2017; Sabel et al. 2013). MAUP relates to the fact that societal exposures vary based on the definition of the geographic scale selected as well as zonation areas even when one scale is selected (Duncan et al. 2014). Consequently, there is a possibility of spatial misclassification of exposure, and the likelihood of a spurious association between area-level factors and oral health outcome (Duncan et al.

2014; Sabel et al. 2013). Consistent with MAUP, exposure misclassification based on the selection of neighbourhood definition has been empirically shown for the exposure of youths' access to tobacco retailers in a study (Duncan et al. 2014). UGCoP identifies two sources of contextual uncertainty. These sources include spatial configuration of geographically defined contexts, and the timing and duration of exposure to those contexts (Kwan 2012; Park and Kwan 2017). However, the role of spatial aggregation and individual mobility has not been dealt in multilevel studies of oral health.

Explicit definitions of ecological factors are crucial when generating hypothesis on societal determinants of health. This applies also to the clarity on levels (societal or individual) at which ecological factors are measured. The level of measurement has consequences on theoretical pathways through which they impact oral health outcomes. Differences in definitions of concepts might exist according to levels. For instance, there is a lack of consensus on the meaning and definition of social capital (Rouxel et al. 2015). Lack of clarity on the definition makes the operationalization of social capital in epidemiological investigations challenging. Social capital is a contextual construct– a societal property. However, social capital is often measured at a societal level through deriving aggregates of individuals' perceptions of reciprocity, trust, and, engagements in civic activities. Social interactions among residents are rarely captured at the contextual level (Mackenbach et al. 2016). Individual perceptions of contextual social capital may potentially vary within the same context. Therefore, relying on aggregated measures of social capital that are unadjusted for individual-level variations in perceptions can lead to potential misclassification. This complexity in the measurement of social capital reflects the need for the explicit meaning of ecological measures at the contextual level. Additionally, recognizing the diversity of multiple mediating pathways (social capital or neo-material factors) for each and every oral health outcome and, at both individual and population levels can be helpful in a better understanding of causal relations and potential interventions (Singh et al. 2016). While social capital explained the association between income inequality and self-rated health in Japanese adults, it did not explain their dentition status (Aida et al. 2011).

Most multilevel studies are a secondary analysis of already collected data. Consequently, researchers may be forced to use imperfect proxies for measuring group level constructs. This provides limited information and can further make inferences drawn from such analysis inaccurate (Diez Roux 2008). Caution is required particularly in identifying appropriate population groups, spatial scales and differentiating between the unique properties of ecological factors in interest.

Role of lag times

Failure to recognize and account for lag time between an ecological exposure and individual health outcome is a form of misclassification bias. The role of lag times between exposure and outcome has been paid less attention than other challenges in multilevel studies (Blakely and Woodward 2000). Usually, multilevel studies are conducted using cross-sectional data where the distinction between current and past exposures cannot be made. Societal factors are not likely to have an instantaneous effect on individual health, and therefore establishing appropriate lag period between the exposure and specific oral health outcome is necessary particularly when the exposure is not stable over time (Blakely and Woodward 2000). The lack of association between a societal exposure and an oral health outcome due to the inappropriate definition of lag times can be misleading as associations may be present when appropriate lag times are considered. Therefore, assessment of lag time is critical before dismissing the evidence on the impact of societal determinants on oral health based on findings where the exposure is non-stable and exposure and outcome are measured simultaneously.

Current challenges and limitations with multilevel statistical modelling

Multilevel models are still evolving. Issues such as appropriate sample size, methods for selecting and reporting appropriate measures of interest, and the reporting of diagnostic tests within multilevel studies are yet to be resolved (Subramanian 2004). Model diagnostics are also seldom reported within studies (Subramanian 2004). Assumptions of multilevel modelling regarding the hierarchical units being independent of each other are also rarely met. A lack of reporting of measures of variation in individual health and its decomposition is also identified within the literature (Merlo et al. 2009).

A more conceptual issue relevant to oral health needs further examination in the application of multilevel models in studying population variations in oral health. Compared to general health outcomes like mortality and health that are captured widely in census data and registration data, for oral health information data is obtained from oral health surveys that are not designed with a primary purpose to make inferences at smaller geographies, and are underpowered for this purpose. This limits the examination of average associations between an area-level societal determinant (area-level income inequality, area-level deprivation) and population oral health (rates of dental caries, rates of oral cancer) at small area level in multilevel studies. This restricts the assessment of theoretical pathways proposed to explain population-level variations in health/disease rates according to societal determinant when applied to explaining individual-level variations in oral health/disease. Some of the mediating pathways operate more strongly at an environmental level (legislation, policies, social capital, access to health services) while others at the individual level (stress, health behaviour, utilization of health services). Therefore, theoretical pathways need to be proposed and defended based on the level at which each oral health outcome is analysed. Potential differences in strengths of associations at the population level (population risk), and at the individual level (individual risk), may also demand separate prevention strategies and policy responses (Rose 1985). The extent to which studying population variations in oral health in multilevel studies through analysing variance share at population level informs these two policy-relevant issues needs further assessment.

Power and sample size calculations for multilevel hypotheses are complex as power depends both on a number of groups as well as the number of individuals per group (Diez-Roux 2000). Calculation of sample size in multilevel studies is dependent on the level at which inferences are to be made. When these are at the group level, there should be a sufficient number of groups rather than individuals. But, when the inference is to be made at the individual level, then both sufficient number of groups and individuals are required. Often multilevel studies are challenged due to the small size of groups. Simulation studies have shown that multilevel models with large numbers of groups (more than 459 groups) even with smaller group sizes remain stable, and neither fixed or random components are affected due to group sizes (Theall et al. 2011). Since most multilevel studies on societal determinants of oral health use secondary data, Monte Carlo simulation of the model should be applied to estimation post-hoc power and for sample size calculation (Snijders 2005).

Most multilevel studies analyse cross-sectional data where the temporal sequence between exposure and outcomes cannot be established. Multilevel studies on longitudinal datasets can help resolve this issue as temporal sequence between the societal exposure and oral health outcomes can be established. However, multilevel statistical modelling is mainly applied in longitudinal data to manage data imbalances due to loss to follow up, rather than to examine associations between societal determinants and oral health outcomes.

Final remarks

The challenges currently posed in population oral health highlight the need for more population focussed research and the use of ecological studies in the field or dental public health. The value in studying population-variations in oral health and its determinants has a rationale embedded in theory and is fundamental for policy assistance. This will likely contribute towards a better understanding of how exposures that affect all individuals in a population contribute to their oral health. There is a need for balancing the weight of individual-level studies with studies of population variations and societal determinants, not to replace the individual-level studies, but to complement them.

Ecological studies offer an opportunity to study average associations between societal determinants and population-level variations in oral health, but cannot account for potential confounding introduced by factors from alternate levels of social organization (Morgenstern 2008). Multilevel studies using individual and societal data collectively, overcome this limitation by simultaneously examining multiple hypotheses generated at different levels of social organization. Using multilevel models to quantify the share of individual-level variation in oral health outcomes that exist at a societal level, the contribution of societal and individual determinants on this share of variance, allows the investigation of population-level variations in oral health and its determinants (Merlo et al. 2016).

Multilevel studies of societal determinants of oral health require careful attention from the stage of conceptualization to design, analysis and reporting, as highlighted in this paper. These features are not unique to such studies and form the basis of any scientific enquiry. In addition to multilevel methods, studies on societal determinants of oral health can deal with inherent complexity by exploring methodological approaches from other disciplines such as social and political sciences including qualitative methods. Finally, studies with explicit theoretical bases (Singh et al. 2016) that draw on the strengths of multilevel modelling can provide a more enhanced understanding of societal determinants of oral health, and consequently lead to robust evidence for relevant policy solutions.

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Table 1. Description of fallacies along with suitable examples from oral health

Fallacy	Reason	Description	Example
Ecological	Construct and measurement issues	Associations at ecological level are used to make inferences on the association at an individual level due to absence of data at an individual level. The more heterogeneous the population, the higher is the fallacy	Association between water fluoridation and skeletal fractures (Rosen 2000):- Supportive evidence for the association came largely from ecological studies comparing rates of fracture between fluoridated and non-fluoridated communities. However, well designed studies that measured individual exposure to water fluoridation/fluoride intake and controlled for different confounders could not find an association between dentally optimal doses of fluoride and fracture. This indicates a case when ecological level associations were not held true at the individual level.
Atomistic	Construct and measurement issues	Associations at individual level are used to make inferences on the association at an ecological level due to absence of data at a population level. This fallacy ignores the fact that societal factors and population has independent characteristics	Individual income may be negatively associated with tooth loss and it is inferred that mean income of an area is associated positively with population rate of tooth loss. However, the mean income may not be associated or positively associated with population rate of tooth loss.
Sociologistic	Ignorance of variables from individual level	This fallacy is a consequence of ignoring the role of individual level factors in group level associations	Effects of fluoride intake on population-level differences in dental caries is determined by testing correlations between community-level water fluoridation and community levels of dental caries. Interpreting that community water fluoridation reduces every residents’ risk of dental caries within such studies can be prone to sociologistic fallacy as certain sub-groups may have

			preferences of bottled water over tap water.
Psychologistic	Ignorance of variables from population level	This fallacy is a result of ignoring the role of ecological level factors in individual level associations	Ignoring the fact that water fluoridation is an environmental factor, and its presence may modify the association between fluoride intake and dental caries at the individual level.

Table 2. Description of different categories of ecological variables according to their classification and examples

Category	Description	Example
Aggregate/contextual/analytical	Aggregate summary measure of individual characteristics in a group (similar to derived variables)	Area level mean income
Contagion	Aggregates of individual outcomes	Prevalence of dental caries and tooth loss rates of a group
Environmental	Physical characteristics with individual analogue	Environmental measure:- Residential access to water fluoridation Individual analogue:- Consuming fluoridated tap water
Structural	Patterns of relationship between individuals of a group	Social capital, social cohesion, social inequality as a product of power relations
Global	Attributes belonging to groups and not reduced to individuals	Legislations and policies

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5.3 Conclusions drawn from the chapter

This discussion paper emphasised the value of investigating population variations in oral health, and the need to examine its societal drivers. Multilevel studies that only report measures of associations between area-level income inequality and oral health outcomes at the individual level provide no evidence on the association between income inequality and population oral health. This gap is a critical limitation of multilevel studies from a policy perspective that does not incorporate a thorough assessment of population-level variation in the individual-level outcomes. The paper advocated the choice of a methodological approach that draws on strengths of multilevel methodology and ecological approaches to inform the evidence on societal determinants of oral health, such as income inequality.

Preparation of this review clarified the value in decomposing the inter-individual differences in oral health outcomes at a population level through decomposition of variance at the area level using a multilevel statistical approach. Additionally, the usefulness of various measures obtained from multilevel models in determining the heterogeneities between areas in the association between area-level income inequality and individual oral health outcomes were identified. This paper provided valuable methodological insights on operationalizing the research on area-level income inequality and oral health in the Australian context in terms of the required sample size, lag time, choice of the geographical unit of analysis and choice of statistical modelling.

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6. Area-level income inequality and oral health among Australian adults – A population-based multilevel study

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Name of Principal Author (Candidate)	Ankur Kumar Singh		
Contribution to the Paper	Conceptualized the study, requested data, conducted data cleaning and preparation, conducted analysis and interpreted the data, drafted the manuscript, and acted as a corresponding author		
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.		
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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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6.2 Rationale for the publication

Findings from the Literature Review and the scoping review showed that although evidence at the sub-national level exists on the association between income inequality and oral health, the evidence is limited to only three countries: the USA, Japan and Brazil. Considerable contextual variation in the association between income inequality and general health outcomes has been noted by a large review on income inequality and health (Lynch et al., 2004). The three countries in which the association between income inequality and oral health is examined are very different to each other in terms of their socio-political climate. Japan is more egalitarian compared to the USA, and while both countries are high-income, Brazil is an upper-middle income country. Furthermore, while only two studies on the association exist from USA (Bernabe and Marcenes, 2011; Moeller et al., 2017) and one study from Japan (Aida et al., 2011), the bulk of the literature at the sub-national level is limited to Brazil. Therefore, extrapolating the evidence from the USA and Japan to any other high-income country may not be appropriate.

Australia has unique geographic characteristics compared to all the three countries (USA, Japan and Brazil) in terms of its population density and remoteness. Income inequality within Australia has increased over the last three decades with an increase in the national estimates of Gini coefficients (measure of income distribution) from 0.27 in 1982 to 0.32 in 2011-12 (Fletcher and Guttmann, 2014). Additionally, geographic variations in the increase of income inequality within Australia during the last decade has also been reported (Fleming and Measham, 2015). Compared to the general health literature from other high-income countries, limited evidence exists on the associations between area-level income inequality and health outcomes within Australia (Dietze et al., 2009; Bechtel et al., 2012; Redig, 2014), and to our knowledge no study exists in oral health. None of the existing studies from Australia have applied the multilevel technique which has advantages of simultaneously accounting for area and individual-level confounding. Therefore, this paper addresses a significant gap in research from both the Australian and global perspective. The aims addressed in this paper include:

1. test associations between income inequality and oral health outcomes at the individual level after accounting for both area-level and individual-level confounders,
2. test the associations between income inequality and oral health according to area-level mean income,
3. compare the associations between household income and oral health outcomes under different levels of income inequality.

6.3 Methodology

A population-based multilevel study was conducted to address the objectives.

6.3.1 Data source and study population

Multiple data sources that contain nationally representative data on the oral health of Australians were considered and evaluated for the appropriateness and relevance to address the study objectives. Considered datasets included National Dental Telephone Interview Surveys 2001, 2005, 2010 and 2013 (NDTIS 2001, 2005, 2010 and 2013) and National Survey of Adult Oral Health 2004-2005 (NSAOH 2004-05). NDTIS 2013 was chosen considering its relevance to the current Australian population, timing with the Australian Census of Population and Housing 2011 – where the area-level socioeconomic data was available – and due to the possibility of geocoding individual-level information to multiple Australian Bureau of Statistics (ABS) geographical hierarchies. The lack of aggregate data on oral health at the LGA level due to the low sample size per LGA restricted from testing associations between LGA-level income inequality and average inadequate dentition or poor self-rated oral health at the population level.

NDTIS is a nationwide cross-sectional population-based survey administered to monitor population-levels of oral health across all states and territories conducted by the Australian Research Centre for Population Oral health (ARCPOH) every 2½ years since 1994. The survey involved a random sample of Australian residents aged five and over in all states and territories. An overlapping dual sampling frame design was adopted for the survey.

The first sampling frame was created from the electronic product 'Australia on Disc 2012 Residential' supplied by United Directory Systems. This product is an electronic listing of people/households listed in the White Pages Telephone Directory across Australia which is updated annually. Both landline and mobile telephone numbers were provided where applicable. A stratified two-stage sampling design was then adopted to select the sample from this sampling frame. Listed records on this frame were stratified according to State/Territory and region (Greater Capital City/ Rest of State). Systematic sample of the records was then selected from each stratum using specified sampling fractions. Once a telephone contact was made with a selected household, one person aged ≥18 years was selected for the interview. A second sampling frame was used so as to include households that were not listed in the White Pages. This sampling frame was supplied by Sampleworx who supplied 20,000 mobile telephone numbers by appending randomly generated suffix numbers to all known Australian mobile prefixes. More information on survey methodology is reported elsewhere (AIHW, 2016).

Population

Dentate adults aged ≥18 years (5,169 out of 6,340) within the survey were included in the analysis. This age-group was chosen for two reasons. First, provision of dental health services differs among individuals above and below the age of 18 years. Only children 17 years and below are eligible for Child Dental Benefits (Luzzi and Harford, 2014). Second, studies have reported that the magnitude of income inequality and health associations varies according to age groups (Dorling et al., 2007).

Data collection

Data was collected between May 2013 and March 2014 via telephone interview. Trained interviewers conducted telephone interviews using WinCATI® software. The collected data included measures of self-reported number of teeth and self-rated oral health status, use of and access to dental services, social impact of oral health, the financial burden of dental care, and private health insurance that covered dental expenses.

Level of Geographic Aggregation

Individual information for adults from NDTIS was allocated to multiple geographic levels through geocoding residential addresses obtained from the electronic white pages and self-reported questionnaire. For the purposes of analysis, Local Government Areas (LGAs) were considered as an appropriate level of geography. LGAs represent the administrative boundaries for local government councils for the provision of a broad range of infrastructure, economic and community services to residents (Association, 2014). Local government councils provide social and welfare services to communities and also represent the decision-making body for policies at the local area level. The level of geographic aggregation of income inequality also needs to be consistent with the mediating pathways relevant to the health outcomes (Celeste and Nadanovsky, 2010). Neo-material pathway for the association between high income inequality and poor health outcomes emphasizes on health policies as a key aspect of neo-material infrastructure (Lynch et al. 2004). Variations in the presence of community water fluoridation (an important oral health policy) exists at the LGA level in Queensland

(Akers and Foley, 2012). An ecological study on income inequality and health outcome from Australia has also confirmed a positive association between LGA-level income inequality and alcohol attributed harm (Dietze et al. 2009).

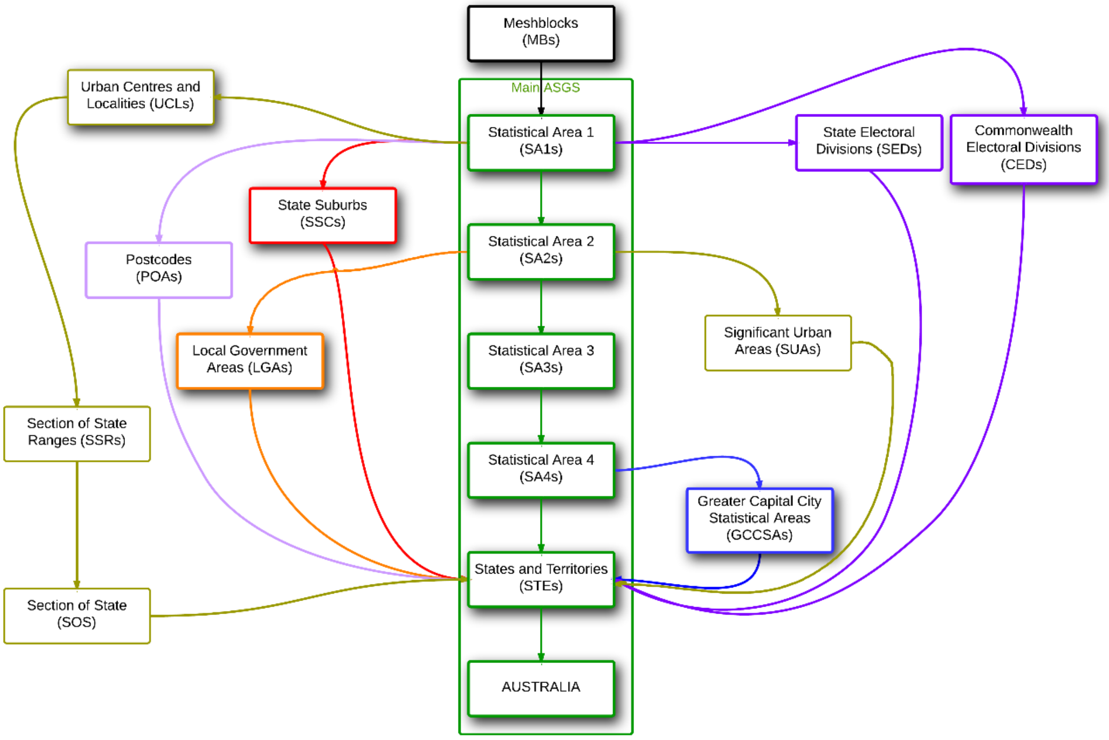

Figure 1. Geographic structure by Australian Standard Geographic System (ASGS) (AURIN, 2017)

There are a total of 561 LGAs in Australia (Association, 2014). In the absence of information on residential addresses, individuals were allocated to LGAs using concordance files for postcodes to LGAs provided by the ABS (ABS, 2012).

6.3.2 Data request, cleaning and preparation

A data request form was submitted and approved by ARCPOH Executive Committee, and de-identified data was made available with the variables listed above. An additional request was made to the data custodians to provide sampling and self-reported street addresses of 6,340 adult respondents after obtaining permissions from Adelaide University's Human Research and Ethics Committee to geocode the available addresses to ABS and non-ABS geographies. Using two methods 98% of the NDTIS sample was allocated to appropriate LGAs:

1) Geocoded sampling or self-reported street addresses of 93.1% respondents (n=5,797/6,340)
2) Postcodes aligned with more than 90% of the boundaries of LGA (n=430/6,340; 7%) based on ABS concordance files for the remaining 10.7% of the respondents (http://www.abs.gov.au/websitedbs/D3310114.nsf/home/Correspondences)

After this process, a total of 6,227 (98%) respondents from the NDTIS 2013 survey were allocated to 458 LGAs. However, the number of respondents was not uniform across all the LGAs. On an average all the LGAs had 14 individuals while the range of individuals within the LGAs were from 1 – 447 (Table 1).

Table 1. Number of LGAs and distribution of sample

Individuals per LGA	Count of LGAs	%	Cumulative %
1	82	17.9	17.9
2-5	122	26.6	44.5
6-9	68	14.9	59.4
10-20	101	22.1	81.4
21-50	72	15.7	97.2
51-100	8	1.8	98.9

101-200	3	0.7	99.6
201-300	1	0.2	99.8
447	1	0.2	100
Total:- (n= 6,227)	Total:- 458	Total 100%	

Individual-level variables:- Variables with individual level information provided in NDTIS included number of teeth, self-rated dental health, number of extractions in last year, age, sex, country of birth, educational attainment, household annual income and area remoteness. Based upon the objectives and outcome definitions individual-level variables were then categorised.

Area-level variables:- Three variables were derived from the Census 2011 at the area level (ABS, 2011a). These included Gini coefficients for household income at the LGA level, weekly mean household income, and Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) scores at the LGA level. After allocating LGA names and codes to individuals within NDTIS 2013, the corresponding values of area-level variables were added to the individual level dataset. For the analysis LGAs were grouped into tertiles for each area-level variable.

6.3.3 Study measures

Outcomes

Only self-reported oral health measures are available for NDTIS. One objective outcome of tooth loss and a subjective outcome of self-perception of oral health were selected. The two included outcomes were: inadequate dentition and poor self-rated oral health. Inadequate dentition was defined as having fewer than 21 teeth (Hobdell et al., 2003) and is reported to be associated with poor quality of life in a systematic review (Hobdell et al., 2003; Gerritsen et al., 2010). Individuals were asked ‘do you have any of your own natural teeth?’, and ‘there are 16 teeth, including wisdom teeth in the upper/lower jaw. How many teeth do you have remaining in your upper/lower jaw?’. Adult proxy interviewees were not asked about the number of teeth, hence were excluded from the analysis. Self-rated oral health is a subjective marker of oral health linked to the general state of health and functional ability which contributed independently to long-term well-being and satisfaction (Locker et al., 2005). For the outcome of self-rated oral health, dentate participants were asked: ‘how would you rate your own dental health. Would you say that it is: excellent, very good, good, fair or poor.’

Exposure

The primary exposure was area-level income inequality measured by Gini coefficient for LGAs with a range of 0 to 1. A value closer to 1 represents higher inequality compared to a value closer to 0. The values of Gini coefficients for each LGA were obtained from published estimates (Fleming and Measham, 2015) based on household incomes reported in the Australian Census of Population and Housing 2011. The estimated Gini coefficients for LGAs were based on estimations with income data provided in intervals with an unbounded topmost interval, i.e. no information about maximum income in a region is available. More details on the estimation of the Gini coefficients at the LGA level are provided in the Appendices of the original source (Fleming and Measham, 2015). For the analysis of this paper, LGAs were grouped into tertiles by their Gini coefficients.

Covariates

Based on the evidence on the association between area-level income inequality and health (Subramanian and Kawachi, 2004), the individual and LGA covariates were included in the analysis. Individual covariates were age, sex, household income and educational attainment (specifically for aim 3). For LGAs, equivalised mean household income, area remoteness and Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) scores were included. Age was categorised as 18 to 34, 35 to 54, 55 to 74 and, 75 years and above. Household income in Australian dollars was collected as a categorical variable and was further re-categorised in five groups. The new categories were: households having an annual income of less than \$20,000; \$20,000 to less than \$50,000; \$50,000 to less than \$80,000; \$80,000 to less than \$100,000; and \$100,000 and above. LGA-level weekly mean equivalised household income was obtained from the Australian Census of Population and Housing 2011 and was converted into tertiles (ABS, 2011a). IRSAD score is a measure of Socio Economic Indexes for Areas (SEIFA), an area-level composite index that summarises information about economic and social conditions of people and households within an LGA including both relative advantage and disadvantage measures. IRSAD scores were obtained from the Australian Census of Population and Housing 2011 and converted into tertiles. Remoteness was measured by using postcode information collected in NDTIS 2013 data using Accessibility/Remoteness Index of Australia (ARIA+) by ABS. Categories for remoteness included: major city areas, inner regional areas, outer regional areas and remote/very remote areas.

6.3.4 Analytical approach

Statistical analysis: Associations between LGA-level income inequality and oral health at the individual level were tested using the multilevel multivariable logistic regression models. This approach is consistent with other studies in oral health that have tested associations between income inequality and oral health at the individual level (Celeste et al., 2009; Celeste and Nadanovsky, 2010; Aida et al., 2011; Bernabe and Marcenes, 2011; Celeste et al., 2011; Vettore et al., 2013). The analytical approach specific to each aim is described below.

1. <u>Test associations between income inequality and oral health outcomes at the individual level after accounting for both area-level and individual-level confounders.</u>

Associations between tertiles of LGA-level income inequality and individual oral health outcomes were modelled using multivariable multilevel logistic regression models with random intercepts and fixed slopes. The adequacy of random intercepts and fixed slopes were determined by comparing models with random intercepts and random slopes using a maximum likelihood estimation technique. Random intercepts and fixed slopes were preferred due to the observation of no significant differences in the models ($p>0.05$) and a better model fit. Model 1 was the null model with no explanatory variables. Model 2 estimated the unadjusted association between the tertiles of the Gini coefficients for LGAs and the two outcomes. A sequential adjustment of covariates was then carried out as follows: model 3 adjusted for age and sex, model 4 for LGA-level weekly mean household income, and model 5 for household income and geographic remoteness.

Odd ratios (fixed parameter) obtained from the models informed the strength and the direction of association between LGA-level income inequality and oral health outcomes at the individual level. Median Odds Ratio (MOR) and Intra-class correlation coefficients (ICC) informed the unexplained share of inter-individual variance that was found at the LGA level in the two oral health outcomes (Merlo et al., 2006). Collinearity between LGA-level variables (income inequality, mean weekly household income and IRSAD) scores was examined by testing correlations through the estimation of Pearson's correlation coefficients.

Five separate sensitivity analyses were performed to test the robustness of findings from the multilevel multivariable regression models:

i) *Variations in the association according to cluster sizes*: The first sensitivity analysis was performed to investigate if differences in associations exist according to cluster sizes (low observations in each LGA). Due to the presence of 18% of the LGAs with only one individual each (Table 1), a sensitivity analysis was run to test if the variation in cluster sizes made any difference to observed associations. Two cut offs for sample sizes were tested following suggestions from the literature (Rabe-Hesketh and Skrondal, 2008; Theall et al., 2011) – minimum of two individuals per LGA (excluding singletons– LGAs with only one individual) and a minimum of five individuals per LGA.

ii) *Variations in the association between area-level income inequality and individual oral health outcomes among LGAs*: The second sensitivity analysis tested whether the observed associations between area-level income inequality and oral health outcomes at the individual level varied among LGAs. Combining regression coefficients from fixed parameters and the unexplained variance attributed at the area level from random parameters, measures such as 80% Interval Odds Ratio (IOR-80) and Proportion of Opposite Odds Ratio (POOR) were estimated. These measures obtained from the multilevel model inform the degree of heterogeneity among areas in the association between an area-level exposure and the individual-level outcome (Merlo et al., 2016). If the 80% Interval Odds Ratio (IOR-80) includes one then some areas have the association in the opposite direction to the overall odds ratio. Values of POOR extend from 0% to 50%. A POOR of 0% means all odds ratios across the areas have the same sign. A POOR of 50% means that half of the odds ratios are of the opposite sign and the association is very heterogeneous (Merlo et al., 2006; Merlo et al., 2016).

iii) *Variations in the associations after adjusting for educational attainment and tertiles of LGA-level IRSAD:* There is a lack of clarity on the role of the three variables (education and IRSAD) in the association between income inequality and the two oral health outcomes in the Australian context. The Literature Review of this thesis discussed the lack of consensus on the inclusion of educational attainment as a confounder when testing the association between income inequality and health (Muller, 2002; Subramanian and Kawachi, 2004; Wilkinson and Pickett, 2006). While one study has considered education as a confounder, others have argued that it is likely to be on the causal pathway between income inequality and health outcomes and should not be adjusted when the objective is to test association between income inequality and health outcomes (Subramanian and Kawachi, 2004; Wilkinson and Pickett, 2006). IRSAD captures a range of measures reflecting social advantage and disadvantage, one of which includes percentage of people with stated household equivalised income greater than $52,000 per year (ABS, 2011b). Therefore, a potential of collinearity exists between LGA-level IRSAD scores and weekly mean household income. This was also confirmed with a significantly high correlation coefficient (ρ=0.79, p<0.001) between the two measures. Due to the lack of theoretical evidence on the role of the three variables (education, remoteness and IRSAD), these variables were not adjusted in the main analyses. As an alternative, sensitivity analysis was run to examine whether the observed associations were robust to a further adjustment of educational attainment, remoteness and tertiles of IRSAD scores.

iv) *Potential of residual confounding by LGA-level and household-level income:* A sensitivity analysis was performed to examine the association between LGA-level income inequality and inadequate dentition under different categories of LGA-level mean income (deciles) and 8 categories of household income. This analysis examined the potential of residual confounding by area-level, and household-level, measures of income.

v) *Different categorization of Gini coefficients:* Due to varying ranges of Gini coefficients within the tertiles of LGA-level income inequality, the final sensitivity analysis examined the associations with the categorization of LGA-level Gini coefficients derived through k-cluster analysis.

2. Test the associations between income inequality and oral health according to area-level mean income.

This objective was addressed in two stages. First, an interaction between tertiles LGA-level income inequality and LGA-level weekly mean household income was tested for the two oral health outcomes in multilevel multivariable regression models after accounting for age, sex and household income. When the interaction term was significant, stratified analyses were conducted to examine the variations in the associations between income inequality and oral health according to tertiles of area-level mean income.

3. Compare the associations between household income and oral health outcomes under different levels of income inequality.

To address the last objective of the study, associations between household income and the two oral health outcomes were estimated after adjusting for age, sex, educational attainment and LGA-level weekly mean income using multilevel multivariable regression models. The prevalence of both oral health outcomes by household income was estimated from separate models for each of the high, medium and low tertiles of the Gini coefficient.

PAPER 4

Area-level income inequality and oral health among Australian adults – A population-based multilevel study

Title: Area-level income inequality and oral health among Australian adults – A population-based multilevel study

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Abstract

Background: A lack of evidence exists on the association between area-level income inequality and oral health within Australia. This study examined associations between area-level income inequality and oral health outcomes (inadequate dentition (<21 teeth) and poor self-rated oral health) among Australian adults. Variations in the association between area-level income inequality and oral health outcomes according to area-level mean income were also assessed. Finally, household-income gradients in oral health outcomes according to area-level income inequality were compared.

Methods: For the analyses, data on Australian dentate adults (n=5,165 nested in 435 Local Government Areas (LGAs)) was obtained from the National Dental Telephone Interview Survey-2013. Multilevel multivariable logistic regression models with random intercept and fixed slopes were fitted to test associations between area-level income inequality and oral health outcomes, examine variations in associations according to area-level mean income, and examine variations in household-income gradients in outcomes according to area-level income inequality. Covariates included age, sex, LGA-level mean weekly household income, geographic remoteness and household income.

Results: LGA-level income inequality was not associated with poor self-rated oral health and inversely associated with inadequate dentition (OR: 0.64; 95% CI: 0.48, 0.87) after adjusting for covariates. Inverse association between income inequality and inadequate dentition at the individual level was limited to LGAs within the highest tertile of mean weekly household income. Household income gradients in both outcomes showed poorer oral health at lower levels of household income. The household income gradients for inadequate dentition varied according to the LGA-level income inequality.

Conclusion: Findings suggest that income inequality at the LGA-level in Australia is not positively associated with poorer oral health outcomes. Inverse association between income inequality and inadequate dentition is likely due to the contextual differences between Australia and other high-income countries.

Background

Over 300 studies have investigated associations between area-level income inequality and outcomes of mortality and morbidity at global, national and sub-national levels (Pickett and Wilkinson 2015). Reviews on the hypothesized association between high income inequality and worse health outcomes have reported conflicting findings/conclusions (Kondo et al. 2009; Lynch et al. 2004; Macinko et al. 2003; Subramanian et al. 2003; Wilkinson and Pickett 2006). Earlier reviews indicated that the association between high area-level income inequality and worse health outcomes is not universal, and limited to a few outcomes (Lynch et al. 2004; Macinko et al. 2003). However, recent reviews have found more support for a detrimental impact of area-level income inequality on health (Kondo et al. 2009; Wilkinson and Pickett 2006). A scoping review on area-level social inequality and oral health also reported that the collective evidence was suggestive of associations between high income inequality and worse oral health (Singh et al. 2016).

Oral diseases such as dental caries and periodontal disease and consequent loss of teeth are widely prevalent (Kassebaum et al. 2017), associated with high economic costs, impact labor productivity (Listl et al. 2015), and negatively impact the quality of life (Haag et al. 2017; Sheiham 2005). Inadequate dentition (having fewer than 21 teeth) is associated with poor quality of life (Gerritsen et al. 2010; Hobdell et al. 2003). Self-rated oral health is a subjective marker of oral health linked to the general state of health and functional ability contributing independently to long-term well-being and satisfaction (Locker et al. 2005). At a sub-national level, higher area-level income inequality has been associated with worse individual oral health outcomes in USA at state level (Bernabe and Marcenes 2011a), in Brazil at municipal level (Celeste et al. 2009; Goulart Mde and Vettore 2016; Vettore et al. 2017), and in Japan at the district level (Aida et al. 2011). Variations in the presence of associations according to oral health outcomes are found (Singh et al. 2016). No associations were reported for the outcomes of dental caries (Peres et al. 2003), periodontal disease (Celeste et al. 2011), and lack of functional dentition (Chalub et al. 2016).

Theoretical explanations (material, behavioural, psychosocial, structural and neo-material) are proposed to explain how high area-level income inequality leads to poor oral health outcomes. Leading explanations include psychosocial and neo-material theories (Kondo et al. 2009; Lynch et al. 2004; Macinko et al. 2003; Subramanian et al. 2003; Wilkinson and Pickett 2006). According to the psychosocial theory, high levels of income inequality leads to poor oral health outcomes through depletion of psychosocial assets (social capital) and increase in psychosocial stressors (increased social evaluative threats) at the societal level. On the other hand, neo-material theorists postulate that the harmful effects of income inequality on health outcomes are due to the combined lack of material resources and healthy public policies at the societal level (Singh et al. 2016).

Increasing income inequalities within and between countries has become a global concern as a range of detrimental consequences on social and economic indicators including inequality of opportunity, negative impacts on economic growth and its sustainability, negative impacts on labour productivity, underinvestment in education, and political instability and conflict are well described (Wilkinson and Pickett 2009; Piketty T 2014; Dabla-Norris et al. 2015). Gini coefficients, derived from the Lorenz curve, measures the extent to which the distribution of income (or, in some cases, consumption expenditure) deviates from a perfectly equal distribution among individuals or households within an economy. Its value ranges from ranging from 0 (perfect equality) to 1 (Kawachi and Kennedy 1997). Income inequality within Australia has increased over the last three decades with an increase in the national estimates of Gini coefficients from 0.27 in 1982 to 0.32 in 2011-12 (Fletcher and Guttmann 2013). Compared to the general health literature from other high-income countries, limited and inconclusive evidence exists on the associations between area-level income inequality and health outcomes within Australia (Bechtel et al. 2012; Dietze et al. 2009). No associations were reported between area-level income inequality and the outcomes of mental health at neighborhood and city level (Bechtel et al. 2012). An ecological study reported positive associations between area-level income inequality and alcohol-related harms at the Local Government Area (LGA) level, while inverse associations were reported for the outcome of alcohol-attributable hospitalization (Dietze et al. 2009).

Studies of the association between area-level income inequality and health are complicated by the known association between individual income and health (Rambotti 2015) as well as that between area-level income and health (Sanders et al. 2008). Both may themselves be associated with the level of inequality. Thus, larger inequalities could result in poorer health overall because (at the same average income) it results in more people on low incomes – a compositional effect of inequalities (Subramanian and Kawachi 2004) rather than, greater inequalities impacting on health at any level of individual income. These complications contribute to the ongoing debate about the pathways through which area-level income inequality may potentially affect health status (Muntaner and Lynch 1999) and to methodological developments, including multilevel analysis intended to account for potential confounding by both area and individual level factors (Judge et al. 1998).

Consequently, many studies both in general and oral health have applied the multilevel technique to investigate the associations between area-level income inequality and individual health outcomes as shown in literature reviews (Singh et al. 2016; Wilkinson and Pickett 2006). A systematic review of multilevel studies on the associations between area-level income inequality and mortality, and self-rated health reported inverse association (odds ratio of 1.08) between high income inequality and poor self-rated health (Kondo et al. 2009).

Recently, there has been a call to also investigate the impact of area-level income inequality on health inequalities within societies, not only average health (Truesdale and Jencks 2016). To our knowledge, no study exists within Australia that examines associations between area-level income inequality and oral health outcomes. Additionally, none of the existing studies of general health outcome within Australia (Bechtel et al. 2012; Dietze et al. 2009) have applied a multilevel statistical analytical technique, despite its advantages, or explored the impact of area-level income inequalities on health inequalities.

Therefore, this study aimed to:

1. test associations between area-level income inequality and oral health outcomes of inadequate dentition and poor self-rated oral health at the individual level after accounting for both area and individual level confounders,
2. test the associations between area-level income inequality and oral health according to area-level mean income,
3. compare the associations between household income and the two oral health outcomes under different levels of area-level income inequality.

Methods

Study population

To address the objectives of the current study, a secondary analysis was conducted on the data available for dentate adults from National Dental Telephone Interview Survey (NDTIS) 2013. NDTIS is a nationwide cross-sectional population-based survey administered to monitor population levels of oral health across all states and territories conducted by the

Australian Research Centre for Population Oral health (ARCPOH) every 2 ½ years since 1994. The survey involved a random sample of Australian residents aged five and over in all states and territories. An overlapping dual sampling frame design was adopted for the survey.

The first sampling frame was created from the electronic product 'Australia on Disc 2012 Residential' supplied by United Directory Systems. This product is an electronic listing of people/households listed in the White Pages telephone directory across Australia and is updated annually. Both landline and mobile telephone numbers were provided where applicable. A stratified two-stage sampling design was then adopted to select the sample from this sampling frame. Once a telephone contact was made with a selected household, one person aged ≥18 years was selected for the interview. A second sampling frame was used so as to include households that were not listed in the White Pages. This sampling frame was supplied by Sampleworx who supplied 20,000 mobile telephone numbers by appending randomly generated suffix numbers to all known Australian mobile prefix. More information on survey methodology is reported elsewhere (AIHW 2016).

Dentate adults aged ≥18 years (5,169 out of 6,340) within the survey were included in the analysis. This age-group was chosen for two reasons. First, provision of dental health services differs among individuals above and below the age of 18 years. Only children 17 years and below are eligible for Child Dental Benefits (Luzzi and Harford 2014) in accordance with the Australian government policy. Second, a study reports that the magnitude of income inequality and health associations varies according to age groups, and the negative impact is predominantly observed among young adulthood (Dorling et al. 2007).

Individual information for adults from NDTIS was allocated to multiple geographic levels through geocoding residential addresses obtained from the electronic white pages and self-reported questionnaire. For the purposes of analysis, LGAs were considered as an appropriate level of geography. LGAs represent the administrative boundaries for local government councils for the provision of a broad range of infrastructure, economic and community services to residents (Association 2014). There are a total of 561 LGAs in Australia (Association 2014). In the absence of information on residential addresses, individuals were allocated to LGAs using concordance files for postcodes to LGAs provided by the Australian Bureau of Statistics (ABS) (ABS 2012).

Data collection

Data was collected between May 2013 and March 2014 via telephone interview. Trained interviewers conducted telephone interviews using WinCATI® software. The collected data included measures of self-reported number of teeth and self-rated oral health status, use of and access to dental services, social impact of oral health, the financial burden of dental care, and private health insurance that covered dental expenses.

Outcomes

Two outcomes were included in the study: inadequate dentition and self-rated oral health. Inadequate dentition was defined as having fewer than 21 teeth (Hobdell et al. 2003). Individuals were asked 'do you have any of your own natural teeth?', and 'there are 16 teeth, including wisdom teeth in the upper/lower jaw. How many teeth do you have remaining in your upper/lower jaw?'. Combining the responses to the two questions, a derived binary variable for each dentate individual was created to identify individuals with/without inadequate dentition. Adult proxy interviewees were not asked about the number of teeth, hence were excluded from this analysis. For the outcome of self-rated oral health, dentate participants were asked: 'how would you rate your own dental health. Would you say that it is: excellent, very good, good, fair or poor.' Responses of 'fair' and 'poor' were grouped as poor self-rated oral health, and 'excellent', 'very good' and 'good' were grouped together as better self-rated oral health.

Exposure

The primary exposure was area-level income inequality measured by the Gini coefficient for LGAs with a range of 0 to 1. A value closer to 1 represents higher inequality compared to a value closer to 0. The values of Gini coefficients for each LGA were obtained from a published estimates (Fleming and Measham 2015) based on household incomes reported in the Australian Census of Population and Housing 2011. For this analysis LGAs were grouped into tertiles by their Gini coefficients (range: first tertile (0.292, 0.369); second tertile (0.370, 0.387); third tertile (0.388, 0.489)).

Covariates

Based on the evidence on the association between area-level income inequality and health (Subramanian and Kawachi 2004), the individual-level and LGA-level covariates were included in the analysis. Age, sex and household income were included to address for confounding. Additionally, educational attainment was included to address for confounding specifically for aim 3. For LGAs, equivalised mean household income and geographic remoteness were included. The theorized relationship between LGA-level income inequality, oral health outcomes at the individual level, and covariates are shown through a Directed Acyclic Graph (DAG) (fig 1). Age was treated as a continuous variable for analysis but categorized as 18 to 34, 35 to 54, 55 to 74 and, 75 years and above for descriptive purpose. Household income in Australian dollars was collected as a categorical variable and was further re-categorized in five groups. The new categories were: households having an annual income of less than \$20,000, \$20,000 to less than \$50,000, \$50,000 to less than \$80,000, \$80,000 to less than $100,000, and $100,000 and above. Geographic remoteness was recorded at the individual level and the categories included those residing in major city areas, inner regional areas, outer regional areas, and remote/very remote areas. LGA-LGA level weekly mean equivalised household income was obtained from the Australian Census of Population and Housing 2011. Values were converted into tertiles for relative comparison between LGAs investigating potential social gradients in individual-level outcomes according to area-level income inequality. Tertiles were preferred over higher number of categories as the objective 2 of the study required examination of potential interactions between LGA-level income inequality and LGA-level weekly mean equivalised household income (ABS 2011).

Statistical Analysis

The associations between LGA-level income inequality and individual oral health outcomes were modelled using multivariable multilevel logistic regression models with random intercepts and fixed slopes. Model 1 estimated the unadjusted association between the tertiles of Gini coefficients for LGAs and the two outcomes. Model 2 adjusted for age, sex, LGA-level weekly mean household income, household income and geographic remoteness. The direction and strength of association between LGA-level income inequality and the outcomes were estimated with a fixed parameter (odds ratio). Area-level heterogeneity in the outcomes and the variance explained by the inclusion of variables were estimated with random parameters (intra-class coefficient and median odds ratio) (Merlo et al. 2006). Stratified analyses of the association between LGA-level income inequality and the outcomes were conducted according to the tertiles of LGA-level weekly mean household income. The prevalence of both outcomes by household income was estimated from separate models for each of the high, medium and low tertiles of Gini. These models were adjusted for age, sex, educational attainment, LGA-level weekly mean household income and geographic remoteness. Survey commands (svy prefix) were used to account for the complex survey design and to perform the weighted descriptive analysis. All analyses were performed in Stata, v14. Five different sensitivity analyses were performed to confirm the robustness of the current findings. The rationale, method and results for each are presented in the supplementary file.

Results

Overall 6,340 adults were interviewed within NDTIS survey, with a participation rate of 34.3% (AIHW, 2016). A complete case analyses of 4,768 dentates nested in 428 LGAs for inadequate dentition, and 5,165 dentate adults nested in 435 LGAs for self-rated oral health were possible after excluding edentates (n=307), and missing values for household income (n=781), non-allocation to LGAs (n=83), self-rated oral health (n=4), and number of teeth (n=401). Descriptive characteristics of the dentate adults from NDTIS 2013 is presented in Table 1. The sample had similar proportions of males and females and had relatively more individuals below the age of 54 years compared to those above. Comparisons between the characteristics of interviewed 5,978 dentates, full cases and demographic characteristics from Australian population census 2011 are presented in S1. Table 1. A flowchart is presented to explain the sample flow in S1. Fig 1.

The estimates obtained null models showed that the share of variance at the LGA level was higher for inadequate dentition (ICC: 4.3%, MOR: 1.44) than for the outcome of poor-self rated oral health (ICC: 1.05%, MOR: 1.20) (not reported in tables).

Unadjusted estimates obtained from model 1 showed that individuals in the most unequal LGAs had relative odds of 0.59 for inadequate dentition compared to individuals in the least unequal LGAs (Table 2). After adjusting for individual age, sex, household income, LGA mean household weekly income, and geographic remoteness, individuals in most unequal LGAs had relative odds of 0.64 of having inadequate dentition, with LGAs in the lowest tertile of Gini at reference. There were no differences between the low and middle inequality LGAs for inadequate dentition (Table 2). The median odds ratio (MOR) obtained from model 1 showed that median odds of inadequate dentition increased by 1.30 times with a move to an area with a higher probability of inadequate dentition. The inclusion of age, sex, household income and LGA-level mean income in model 2 reduced the MOR to 1.09 (Table 2). Results from the stratified analysis indicate that the lower odds of inadequate dentition in the highest tertile of income inequality were limited to LGAs with higher mean weekly household incomes (Table 2).

Model 1 showed that individuals in LGAs with the highest tertile of Gini had relative odds of 0.77 for having poor self-rated oral health compared to those in LGAs of lowest tertile of Gini (Table 3). This association did not remain significant after inclusion of covariates age, sex, LGA-level mean household weekly income, and household income (Model 2, Table 3). The MOR for poor self-rated oral health was close to 1, and after inclusion of age, sex, household income, and LGA level mean income in the final model MOR was 1.04. Residents of middle income, medium inequality LGAs had relatively lower odds (OR: 0.80; 95% CI: 0.61, 1.05) of poor self-rated oral health than their counterparts living in low inequality LGAs. While residents of middle income, high inequality LGAs had relatively higher odds (OR: 1.35; 95% CI: 0.91, 2.01) (Table 3).

The adjusted prevalence of inadequate dentition by household income and LGA level income inequality showed that although there was an overall lower prevalence of inadequate dentition within the LGAs with highest tertile of Gini, a clear stepwise gradient with household income was observed in this group. On the other hand, a marked increase in the prevalence of inadequate dentition within the groups of low and medium inequality was observed at the household income levels of less than $20,000 and $20,000 - $50,000 groups, respectively (fig 2a). There were no differences in household income according to inequality for the outcome of poor self-rated oral health (fig 2b).

Changes in estimates on sequential adjustment of covariates (age, sex + LGA-level mean is also presented in Supplementary file 2. Findings from the sensitivity analyses confirmed the robustness of findings (Supplementary file 3).

Discussion

Higher area-level income inequality was found to be associated with lower inadequate dentition at the individual level among Australian adults, but no association was present for poor self-rated oral health. The share of the individual-level variation in the outcome of inadequate dentition was higher at the LGA-level compared to the outcome of poor self-rated oral health. Stratified analysis confirmed that the association between higher income inequality and lower inadequate dentition was limited to areas with high mean income. Oral health was poorer at lower levels of household income. Differences in gradients of oral health by household income were observed across levels of LGA income inequality for inadequate dentition, but not for self-rated oral health.

This study has several strengths. It is the first assessment of the association between area-level income inequality and oral health within Australia using a robust methodology on a nationally representative dataset; weighted according to Australian Census of Population and Housing 2011 (AIHW 2016). The multilevel analytical technique has advantages in testing associations between area-level income inequality and health outcomes as it allows accounting for potential confounding at both area and individual level (Subramanian and Kawachi 2004).

To the best of our knowledge this study is the first within Australia to apply the multilevel technique to test the association between income inequality and health. The data from NDTIS 2013 had a wide coverage with individuals from 78% (n=435/561) of LGAs in Australia. This is recognized as an advantage when conducting the multilevel analysis (Rabe-Hesketh and Skrondal 2008; Snijders 2005; Theall et al. 2011). Due to the difference of timing between Australian Census 2011, and NDTIS 2013, a natural lag time of two years between the exposure area-level income inequality and the oral health outcomes was present. It is stated within the literature that societal factors such as income inequality may not have an instantaneous effect on health (Blakely and Woodward 2000), and therefore this was an added strength of the study. Multiple sensitivity analyses were performed to confirm the robustness of our findings in Australian context. Testing associations of area-level income inequality with both a subjective (self-rated oral health) and objective measure (inadequate dentition) of oral health was an additional strength of this study (Locker et al. 2005). Finally, this study tested both the independent and combined associations of area-level income inequality and mean income on oral health outcomes at the individual level as well as the differences in income gradients in these outcomes according to area level income inequality in the Australian context following recent suggestions within the literature (Rambotti 2015; Truesdale and Jencks 2016). Therefore, the study adds to the empirical evidence on the theorized interdependencies between different dimensions of income at an individual and societal level on health, raised within the literature (Rambotti 2015; Truesdale and Jencks 2016).

Some limitations were also there. Given that the information regarding the temporal sequence between oral health outcomes and the exposure of income inequality was not available, causal inferences cannot be made from the current study. There were missing values for the outcomes and co-variates due to which all dentate participants within NDTIS 2013 could not be analyzed leading to a reduction in sample size. Majority of the missing values were identified for the variable of household income that can potentially lead to selection bias and affect the generalizability of the findings. Only dentates were analyzed in the current study and edentates may present as the most severe form of tooth loss. However, a continuing trend of fall in edentulism in Australia has been reported and a low prevalence of edentulism (4.7%) was confirmed in the NDTIS 2013 (AIHW 2016). Tertiles of LGA-level Gini coefficient were used in the analysis to draw relative comparisons among individuals according to area-level income inequality. However, the intervals of these tertiles were not equal in size. A sensitivity analysis confirmed that the observed associations between LGA-level income inequality and inadequate dentition was present when categorization of Gini coefficients were alternatively derived from k-cluster analysis (Supplementary file: S3, table 5).

Most studies on area-level income inequality and health have either shown no associations or that higher income inequality is associated with worse health outcomes (Pickett and Wilkinson 2015; Wilkinson and Pickett 2006). The finding of higher area-level income inequality to be associated with lower inadequate dentition at the individual level is conflicting with this literature. However, this study is not the first to report the association in the direction opposite to proposed hypothesis. An Australian ecological study has also reported that higher income inequality at the LGA level was associated with lower alcohol-attributed deaths and hospitalization (Dietze et al. 2009). Higher income inequality at a small area level has also been shown to be associated with lower mortality in Belgium (Lorant et al. 2001) and Switzerland (Clough-Gorr et al. 2015), lower adverse birth outcomes and better self-perceived health in Canada (Auger et al. 2009; Hou and Myles 2005), and USA (Wen et al. 2003), and better mental health outcomes in Wales (Fone et al. 2013). No previous study on oral health outcomes has reported higher area-level income inequality to be associated with better oral health outcomes (Singh et al. 2016). A study from Wales reported an association between higher area-level income inequality and lower common mental disorders only in low deprivation neighborhoods (Fone et al. 2013), which is consistent with our findings of an inverse association between area-level income inequality and inadequate dentition limited to LGAs with the highest mean income.

Number of possible explanations exist for the differences in the presence and direction of associations between income inequality and the two outcomes in the Australian context. There is a strong potential of residual confounding due to both measured and unmeasured covariates. A detailed examination of spatial characteristics of income inequality among working age males at the Statistical Local Area (SLA) level (similar in geography to LGAs) in Australia has revealed two interesting patterns. First, income inequality at the LGA level is positively correlated with average income within major Australian cities. Therefore, residual confounding due to LGA-level mean weekly household income can possibly drive the counterintuitive findings for inadequate dentition. A sensitivity analysis showed attenuation in odds ratio for inadequate dentition (OR 0.68; 95% CI: 0.50, 0.92) when LGA-level mean weekly household income and household income were alternatively included on a continuous scale for adjustment in multilevel multivariable logistic regression model (S3 table 4). However, the 95% confidence intervals did not include null. Second, in most Australian cities, income inequality is much higher in the more heterogeneous inner city areas compared to the outer regions of the cities that are more homogenous areas with low average incomes (Bradbury 2017). The current study also found that the inverse association between area-level income inequality and inadequate dentition was limited to areas with high mean income. Inadequate dentition is an outcome of tooth loss that is a cumulative outcome of an individual's lifetime exposure to dental disease and utilization of dental care. At a country level studies have shown that utilization of dental care is inversely associated with income inequality (Bhandari et al. 2015); however, at the LGA level within Australia, it is more likely that area-level mean income rather than inequality is likely to drive access to dental care. The dental care system in

Australia comprises a combination of private and public sectors and the majority of dental services for adults are provided through the private sector. The state and territory governments provide free or subsidized dental care to those who hold an Australian Government concession card. Studies have examined access to dental care as mediators between the area-level income inequality and oral health outcomes in the USA and Brazil consistent with the neo-material pathway (Bernabe and Marcenes 2011b; Celeste et al. 2009; Singh et al. 2016). Due to the lack of available data on dentist to population ratio at the LGA level within Australia, the role of access to dental services in the association between LGA level income inequality and inadequate dentition could not be examined in this study. Therefore, potential unmeasured/residual confounding may explain the counterintuitive findings for inadequate dentition.

A geographic phenomenon may also explain the findings for inadequate dentition. The association between income inequality and health outcomes is sensitive to the level of geographic aggregation at which the association is tested (Wilkinson and Pickett 2006). Modifiable areal unit problem is a phenomena where societal exposures likely vary based on the definition of the geographic scale selected as well as zonation areas even when one scale is selected (Duncan et al. 2014). Therefore, the observed association can vary at other levels of geographic aggregation and future studies should confirm the current findings at different levels of geographic aggregation. Additionally, socio-epidemiologic theoretical pathways that are proposed to explain the association between area-level income inequality and health outcomes hinge upon income inequality as a marker of social inequality (Goldthorpe 2010; Muntaner and Lynch 1999). Large differences are reported in wealth inequality (Gini for household net worth in 2013-14 was 0.605) and income inequality (Gini=0.333 for equivalised disposable household income) at the national level (ABS 2015). Therefore, structural differences between small areas in Australia and other countries could lead to the observation of lower inadequate dentition at higher levels of LGA-level income inequality. It is beyond the scope of the current study to examine whether income inequality at LGA level can well capture underlying class relations and the degree of social stratification (Muntaner and Lynch 1999; Wilkinson 1999). Future studies could also investigate associations with area-level income inequality and oral health among adolescents and children as the rates of child poverty are high in Australia. It may be possible the income inequality has different impacts on different population groups according to age (Dorling et al. 2007).

The current study found differences in income gradients in the prevalence of inadequate dentition between LGAs at different levels of income inequality. Overall, the prevalence of both the oral health outcomes (poor self-rated oral health and inadequate dentition) was higher with decreasing household income in each group. While there was a clear stepwise gradient in the prevalence of inadequate dentition in the LGAs with high Gini reflecting overall susceptibility towards inadequate dentition across income groups, individuals at lower household incomes were more vulnerable towards inadequate dentition in LGAs with low and medium Gini. This finding substantiates the need to investigate slope effects of area-level income inequality on the association between individual income and health in conjunction with the average effects that examine overall effect of income inequality on health (Truesdale and Jencks 2016).

In conclusion, current findings highlight important contextual differences at small area level between other countries and Australia. Hence, generalization of evidence on the negative impact of a societal determinant (income inequality) on health from one context to other is inappropriate.

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Tables and Figures

Table 1. Descriptive characteristics of the sample according to the oral health outcomes (Weighted Percentages)

		Inadequate Dentition (n: 4,768; LGAs 428)		Self-Rated oral health (n: 5,165; LGAs: 435)	
Characteristics	Categories	% of sample	Inadequate dentition (%)	% of sample	Poor SROH (%)
Sex	Male	48.5	11.3	50.6	21.2
	Female	51.5	10.8	49.4	19.7
Age	18-34	28.7	0.4	30.1	14.6
	35-54	39.1	5.8	38.7	23.1
	55-74	26.0	21.9	25.1	23.2
	75 and above	6.1	47.7	6.1	21.5
Household Income	$100K and above	33.0	2.5	33.8	12.5
	80K < 100k	11.3	7.2	11.6	17.5
	50k < 80k	20.5	8.5	20.5	20.8
	20k < 50k	26.5	19.5	25.9	27.8
	Less than 20k	8.7	28.4	8.3	33.9
Educational attainment	Tertiary[a]	24.3	3.0	23.3	12.5
	Vocational[b]	47.6	12.6	47.3	22.7
	Student[c]	5.5	1.7	6.2	8.1
	Secondary[d]	22.7	18.6	23.2	27.3
Geographic remoteness	Major city	70.8	9.4	70.5	19.6
	Inner regional	18.7	15.4	18.8	21.1
	Outer regional	8.3	15.7	8.5	24.3
	Remote/Very remote	2.2	10.8	2.2	30.2
Inadequate dentition	No	89.0		89.0	18.5
	Yes	11.0		11.0	39.7
Self-rated oral health	Excellent/Very Good/Good	79.2	8.4	79.5	
	Poor/Very Poor	20.8	21.0	20.5	
Local Government Areas (LGAs)				Median	Range
Gini Coefficient 2011 household				0.377	0.292, 0.489
Mean weekly household income (2011) (Australian Dollars)				1577.6	823.6-3886.2
NDTIS Sample Size				7	1-446
		Categories	%	Gini Median	Gini Range
Gini Tertiles		Low	35.6	0.359	0.292, 0.369
		Medium	32.1	0.378	0.370, 0.387
		High	32.3	0.402	0.388, 0.489
Mean weekly household income2011 Australian Dollars (Range)		High (1750.2, 3886.2)	33.2	0.391	0.292, 0.472
		Medium (1420.8, 1748.6)	33.4	0.377	0.330-0.478
		Low (823.5, 1420.3)	33.4	0.370	0.312, 0.489

a: Bachelor/honors degree or more; b: Advanced diploma, diploma, associate degree, certificate level, and other qualifications; c: None completed but studying at university, TAFE apprentice, secondary school; d: No post-secondary qualification & not currently studying

Table 2: Multilevel logistic regression analysis for the association between LGA level income inequality and inadequate dentition (No. of Areas= 428; N of individuals=4,768)

		Model 1		Model 2	
	Categories	OR	95% CI	OR	95% CI
Income Inequality (Gini)	Low	1		1	
	Medium	1.10	0.89, 1.37	0.88	0.70, 1.11
	High	0.59	0.46, 0.75	0.64	0.48, 0.87
Mean weekly household income	High			1	
	Medium			1.44	1.12, 1.86
	Low			1.37	1.00, 1.88
Age	1-year change			1.07	1.06, 1.08
Sex	Male			1	
	Female			0.79	0.65, 0.96
Household Income	$100K and above			1	
	80K < 100k			1.79	1.13, 2.87
	50k < 80k			2.56	1.76, 3.73
	20k < 50k			3.97	2.78, 5.66
	Less than 20k			6.56	4.42, 9.72
Remoteness	Major city			1	
	Inner regional			1.10	0.84, 1.43
	Outer regional			1.04	0.75, 1.44
	Remote/Very remote			1.55	0.98, 2.44
Random parameters		Est.		Est.	
ICC (%)		2.2%		0.2%	
MOR		1.30		1.09	
P-value for the interaction between LGA level income inequality and LGA level mean weekly household income (p<0.001)					
Mean weekly household income		Income Inequality		OR	95% CI
	High	Low		1	
		Medium		0.81	0.51, 1.29
		High		0.58	0.37, 0.91
	Medium	Low		1	
		Medium		0.86	0.59, 1.26
		High		1.05	0.59, 1.88
	Low	Low		1	
		Medium		0.92	0.60, 1.39
		High		0.56	0.18, 1.74

Model 1: Unadjusted; Model 2: Adjusted for age, sex, LGA level mean income, household income and remoteness; ICC: Intra-class Coefficient, MOR: Median Odds Ratio, Est.: Estimate; OR: Odds ratio

Table 3: Multilevel logistic regression analysis for the association between LGA level income inequality and poor self-rated oral health (N of Areas =435; N of individuals=5,165)

		Model 1		Model 2	
	Categories	OR	95% CI	OR	95% CI
Income Inequality (Gini)	Low	1		1	
	Medium	0.93	0.79, 1.10	0.95	0.80, 1.13
	High	0.77	0.65, 0.91	0.92	0.74, 1.14
Mean weekly household income	High			1	
	Medium			1.10	0.91, 1.33
	Low			1.29	1.02, 1.65
Age	1-year change			1.00	0.99, 1.00
Sex	Male			1	
	Female			0.79	0.68, 0.91
Household Income	$100K and above			1	
	80K < 100k			1.39	1.07, 1.81
	50k < 80k			1.78	1.44, 2.21
	20k < 50k			2.62	2.12, 3.22
	Less than 20k			4.08	3.13, 5.31
Remoteness	Major city			1	
	Inner regional			0.87	0.71, 1.06
	Outer regional			0.94	0.74, 1.19
	Remote/Very remote			1.46	1.06, 2.01
Random parameters		Est.		Est.	
ICC (%)		<0.1%		0.4%	
MOR		~1.00		1.04	
P-value for the interaction between LGA level income inequality and LGA level mean weekly household income (p=0.15)					
Mean weekly household income		Income Inequality		OR	95% CI
	High	Low		1	
		Medium		1.33	0.95, 1.87
		High		1.04	0.75, 1.45
	Medium	Low		1	
		Medium		0.80	0.61, 1.05
		High		1.35	0.91, 2.01
	Low	Low		1	
		Medium		0.97	0.66, 1.44
		High		1.66	0.67, 4.10

Model 1: Unadjusted; Model 2: Adjusted for age, sex, LGA level mean income, household income and remoteness; ICC: Intra-class Coefficient, MOR: Median Odds Ratio, Est.: Estimate; OR: Odds ratio

Figures

Fig 1: Directed Acyclic Graph (DAG) to represent the relationship between area-level income inequality and individual-level oral health outcomes

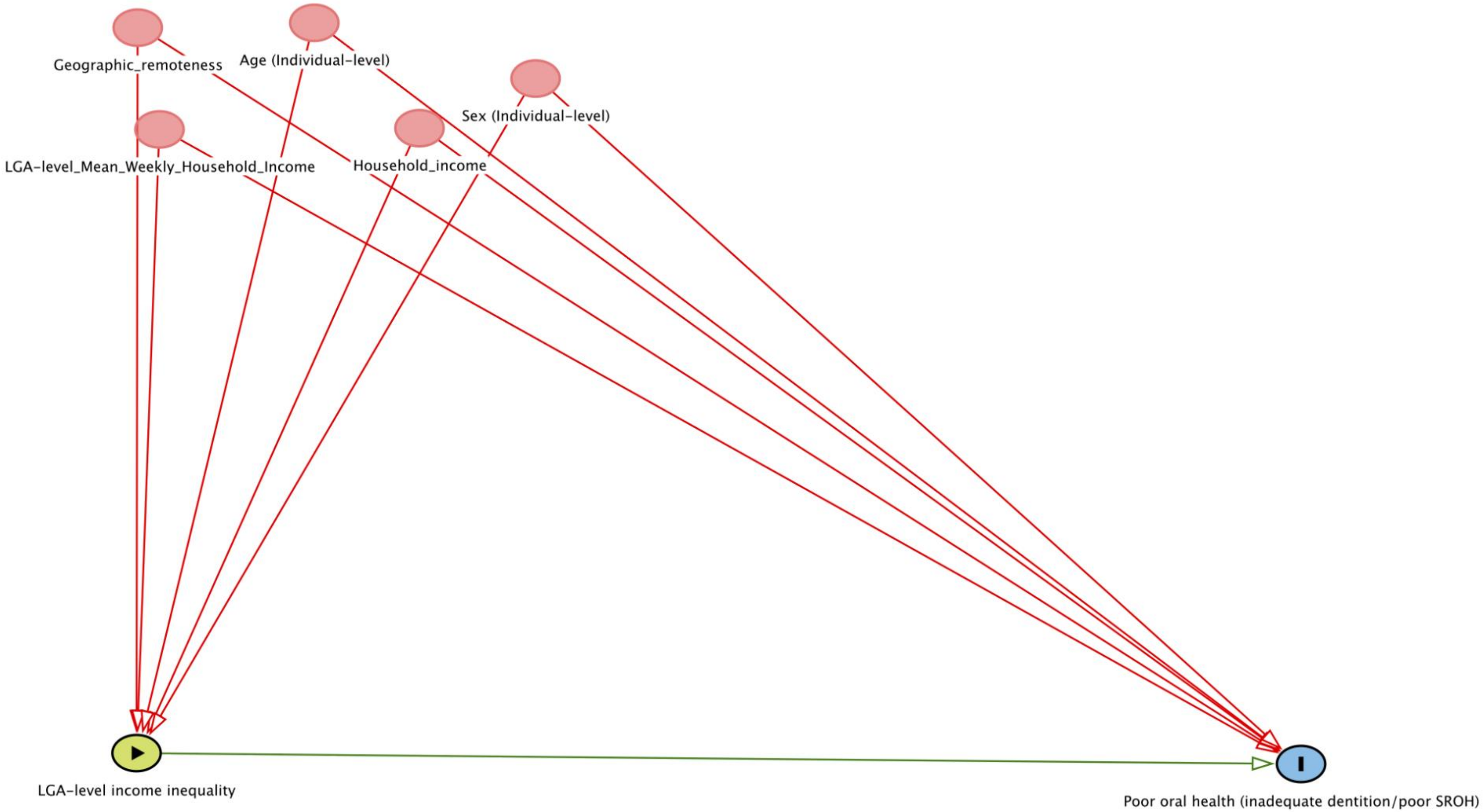
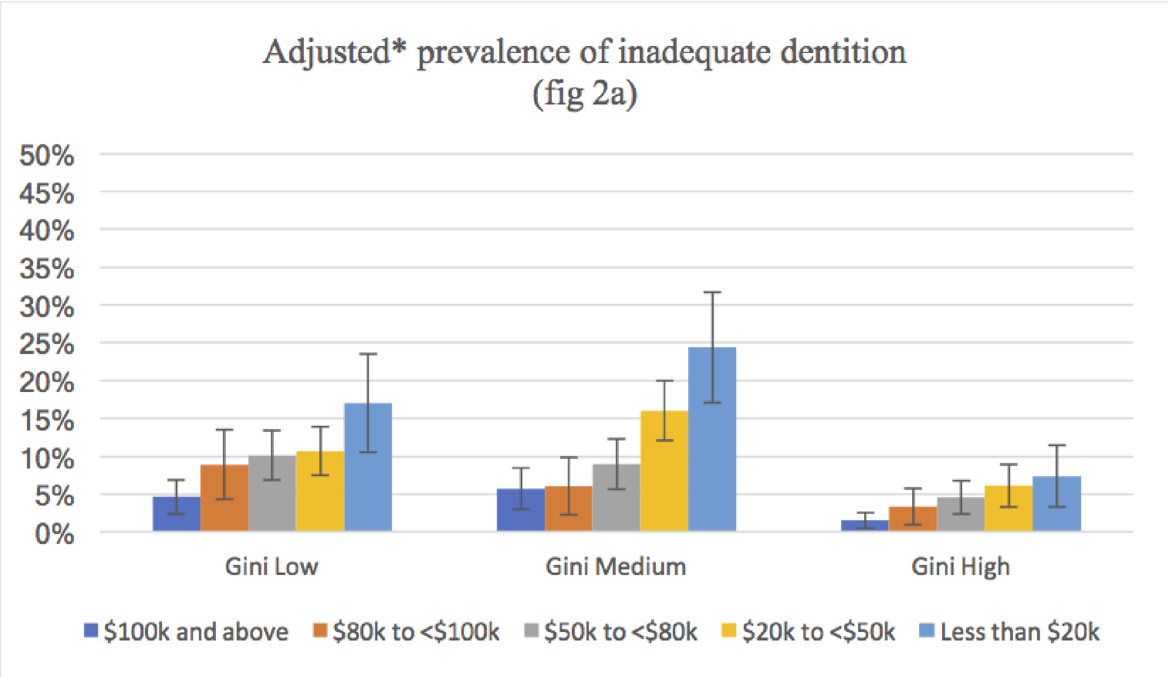
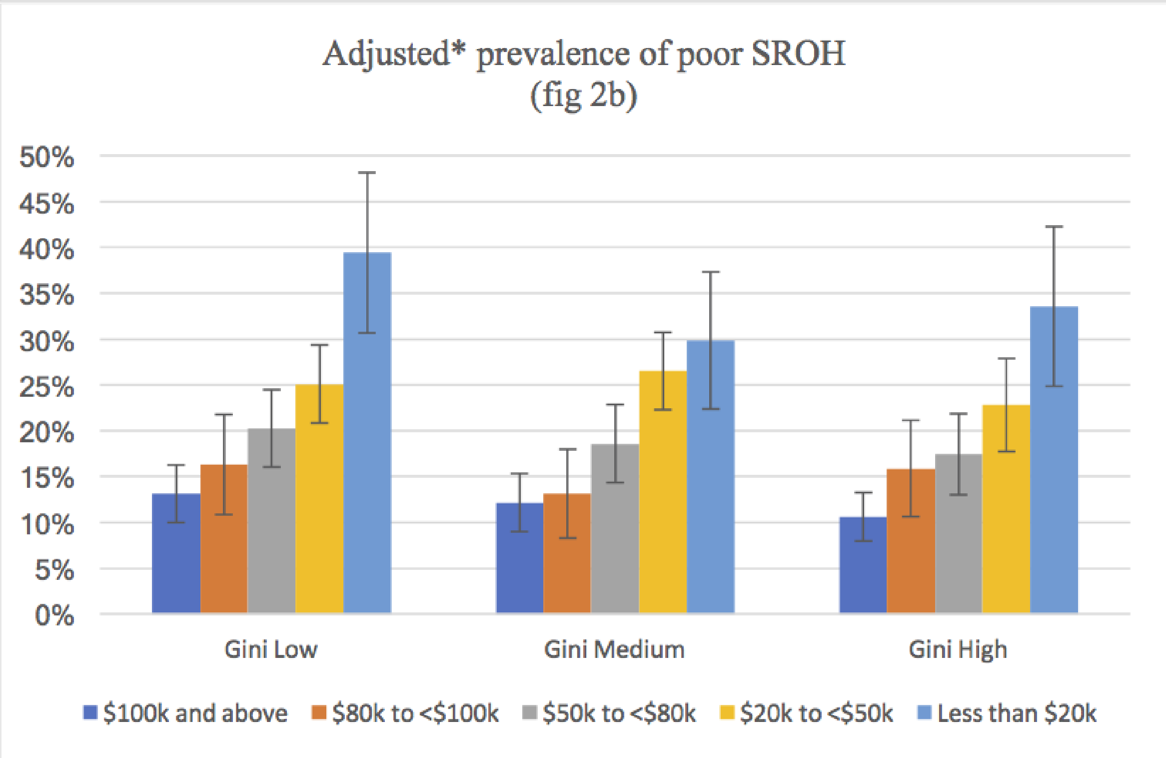


Fig 2: Adjusted prevalence of inadequate dentition (fig 2a), and poor self-rated oral health (fig 2b) according to household income and LGA level income inequality (*adjusted for age, sex, educational attainment, LGA level mean weekly household income and remoteness).





6.4 Conclusions drawn from the chapter

Findings from this population-based study reflected important differences in the association between area-level income inequality and oral health outcomes at the individual level between the Australian context and other examined contexts (USA, Japan and Brazil) where associations between income inequality and oral health outcomes are also reported. While no associations were observed between area-level income inequality and poor self-rated oral health, contrary to the hypothesis, inverse associations between area-level income inequality and inadequate dentition at the individual level were found. The finding of inverse association between income inequality and inadequate dentition at the individual level was robust to multiple sensitivity analyses. Additionally, the finding of an inverse association between income inequality and inadequate dentition at the individual level was only limited to areas with high mean income. These findings allude to the need for caution in generalising the evidence on income inequality hypothesis from one context to the other.

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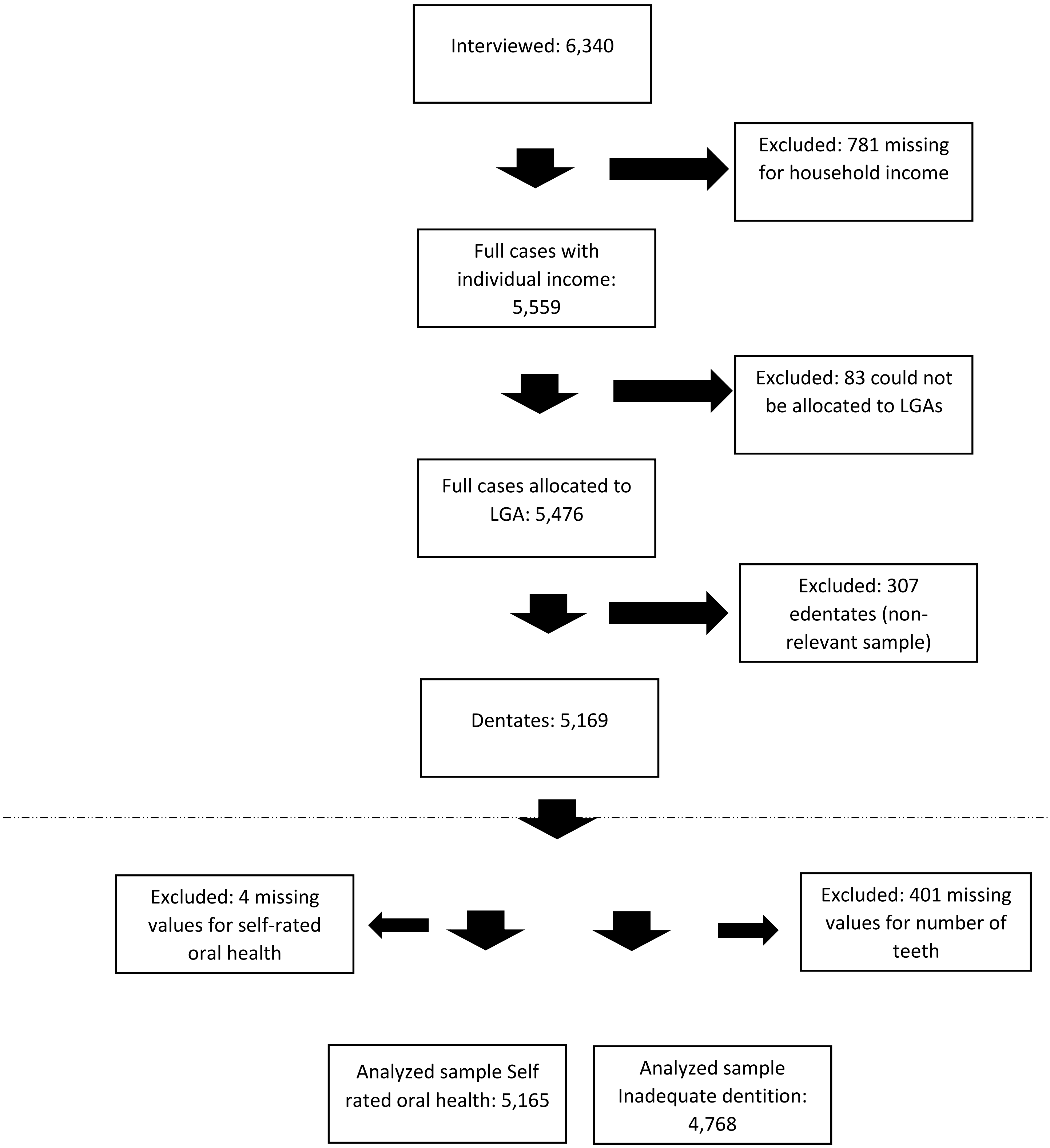
6.5 Appendices for Paper 4

S1. Fig 1. Sample flowchart



S1. Table 1. Descriptive characteristics of the sample according to different sample groups

Characteristics	Categories	Australian Population Census (2011)	Interviewed-NDTIS (n=6,340) (%)	Dentates (n=5,978)	Full Case SROH (n=5,165)	Full Case Inadequate Dentition (n=4,678)
Sex	Male	49.7	49.3	49.6	50.6	48.5
	Female	50.3	50.7	50.4	49.4	51.5
Age	18-34	28.04 (15-34 years)	31.5	33.0	30.1	28.7
	35-54	27.8	35.2	36.5	38.7	39.1
	55-74	19.01	25.1	24.2	25.1	26.0
	75 and above	6.3	8.2	6.3	6.1	6.1
Household Income	$100K and above		27.4	28.6	33.8	33.0
	80K < 100k		9.8	10.1	11.6	11.3
	50k < 80k		16.8	17.4	20.5	20.5
	20k < 50k		23.3	22.1	25.9	26.5
	Less than 20k		8	7.0	8.3	8.7
	Missing		14.8	14.8	0.0	0.0
Educational attainment	Tertiary[a]		22.4	23.3	23.3	24.3
	Vocational[b]		45.5	45.7	47.3	47.6
	Student[c]		7.3	7.7	6.2	5.5
	Secondary[d]		24.8	23.3	23.2	22.7
Inadequate dentition	No		77.2	81.0	89.0	89.0
	Yes		9.6	10.1	11.0	11.0
	Missing/ Edentate[$]		13.2	9.0 (Missing)	0.0	0.0
Self-rated oral health	Excellent/Very Good/Good		75.9	79.6	79.5	79.2
	Poor/Very Poor		19.3	20.2	20.5	20.8
	Missing		4.8	0.1		
Remoteness	Major city		70.5	71.0	70.8	70.5
	Inner regional		18.7	18.4	18.7	18.8
	Outer regional		8.4	8.2	8.3	8.5
	Remote/Very Remote		2.0	2.0	2.2	2.2
	Missing		0.5	0.5		
LGA Allocation	Yes		96.2	96.0	100	100
	No		3.8	4.0	0	0

Weighted Percentages; a: Bachelor/honors degree or more; b: Advanced diploma, diploma, associate degree, certificate level, and other qualifications; c: None completed but studying at university, TAFE apprentice, secondary school; d: No post-secondary qualification & not currently studying

S2. Supporting information for multilevel multivariable regression models

Collinearity

Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) score is a measure of Socio Economic Indexes for Areas (SEIFA), an area-level composite index that summarises information about economic and social conditions of people and households within an LGA including both relative advantage and disadvantage measures. IRSAD scores were obtained from the Australian Census of Population and Housing 2011 and converted into tertiles. Pearson's correlation coefficients were obtained to check for collinearity between LGA-level Gini coefficients and LGA-level weekly mean household income and IRSAD scores. LGA-level Gini and LGA-level mean household weekly income had significant but weak correlations ($\rho=0.29$, $p<0.001$). Similarly, significant but weak correlations ($\rho=0.12$, $p=0.008$) were observed between LGA-level Gini and IRSAD scores. Significantly strong correlations were noted between LGA-level mean household weekly income and IRSAD scores ($\rho=0.79$, $p<0.001$).

Sequential adjustment for covariates

Analysis

Multilevel multivariable regression models with random intercept and fixed slopes were fitted to test associations between income inequality (tertiles of Gini coefficient) and the two oral health outcomes at individual level. Model 1 represented null model with no explanatory variables. Model 2 estimated the unadjusted association between the tertiles of Gini coefficients for LGAs and the two outcomes. A sequential adjustment of covariates was then carried out as follows: model 3 adjusted for age and sex, model 4 for LGA-level weekly mean household income, and model 5 for household income and geographic remoteness. All the models are presented below while only fully adjusted models are presented in the text of the manuscript.

Results

Unadjusted estimates obtained from model 1 showed that individuals in the most unequal LGAs had relative odds of 0.59 for inadequate dentition compared to individuals in the least unequal LGAs (Table 2). Adding age and sex in model 2 reduced the relative odds to 0.43, while the inclusion of LGA-level mean household weekly income increased it to 0.58. After adjusting for individual age, sex and household income, and LGA-level mean household weekly income, individuals in most unequal LGAs had relative odds of 0.64 of having inadequate dentition, with LGAs in the lowest tertile of Gini at reference. (Table 2).

Model 1 showed that individuals in LGAs with the highest tertile of Gini had relative odds of 0.77 for having poor self-rated oral health compared to those in LGAs of lowest tertile of Gini (Table 3). The inclusion of age and sex in model 2 attenuated the odds ratio, but not markedly. LGA-level mean household weekly income attenuated this association and the odds ratio was 0.89 and non-significant (model 3).

S2. Table 2: Multilevel logistic regression analysis for the association between LGA level income inequality and inadequate dentition (No. of Areas= 428; N of individuals=4,768)

		Null Model		Model 1		Model 2		Model 3		Model 4		Model 5	
	Categories	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95%CI
Income Inequality (Gini)	Low			1		1		1		1		1	
	Medium			1.10	0.89, 1.37	0.87	0.69, 1.09	0.87	0.69, 1.08	0.86	0.69, 1.09	0.88	0.70, 1.11
	High			0.59	0.46, 0.75	0.43	0.33, 0.56	0.58	0.43, 0.77	0.60	0.45, 0.81	0.64	0.48, 0.87
Mean weekly household income	High							1		1		1	
	Medium							1.59	1.24, 2.05	1.43	1.11, 1.85	1.44	1.12, 1.86
	Low							1.73	1.30, 2.31	1.40	1.04, 1.87	1.37	1.00, 1.88
Age	1-year change					1.09	1.08, 1.10	1.09	1.08, 1.10	1.07	1.06, 1.08	1.07	1.06, 1.08
Sex	Male					1		1		1		1	
	Female					0.91	0.75, 1.09	0.91	0.76, 1.10	0.79	0.65, 0.96	0.79	0.65, 0.96
Household Income	$100K and above									1		1	
	80K < 100k									1.79	1.12, 2.86	1.79	1.13, 2.87
	50k < 80k									2.55	1.75, 3.71	2.56	1.76, 3.73
	20k < 50k									3.91	2.75, 5.58	3.97	2.78, 5.66
	Less than 20k									6.49	4.38, 9.61	6.56	4.42, 9.72
Remoteness	Major City											1	
	Inner Regional											1.10	0.84, 1.43
	Outer Regional											1.04	0.75, 1.44
	Remote/Very Remote											1.55	0.98, 2.44

Model 1: Unadjusted; Model 2: Adjusted for age and sex; Model 3: Adjusted for age, sex, LGA level mean income; Model 4: Adjusted for age, sex, LGA level mean income and household income; ICC: Intra-class Coefficient, MOR: Median Odds Ratio, DIC: Deviance Information Criterion

S2. Table 3. Multilevel logistic regression analysis for the association between LGA level income inequality and poor self-rated oral health (N of Areas =435; N of individuals=5,165)

		Null Model		Model 1		Model 2		Model 3		Model 4		Model 5	
	Categories	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Income Inequality	Low			1		1		1		1		1	
(Gini)	Medium			0.93	0.79, 1.10	0.92	0.78, 1.09	0.93	0.78, 1.10	0.92	0.77, 1.10	0.95	0.80, 1.13
	High			0.77	0.65, 0.91	0.76	0.64, 0.90	0.89	0.73, 1.08	0.90	0.73, 1.10	0.92	0.74, 1.14
Mean weekly	High							1		1		1	
household	Medium							1.20	1.01, 1.44	1.06	0.88, 1.28	1.10	0.91, 1.33
income	Low							1.48	1.20, 1.83	1.19	0.95, 1.49	1.29	1.02, 1.65
Age	1-year change					1.01	1.00, 1.01	1.00	1.00, 1.01	1.00	0.99, 1.00	1.00	0.99, 1.00
Sex	Male					1		1		1		1	
	Female					0.86	0.74, 0.98	0.86	0.75, 0.99	0.79	0.68, 0.91	0.79	0.68, 0.91
Household	$100K and above									1		1	
Income	80K < 100k									1.39	1.06, 1.81	1.39	1.07, 1.81
	50k < 80k									1.78	1.43, 2.20	1.78	1.44, 2.21
	20k < 50k									2.59	2.10, 3.19	2.62	2.12, 3.22
	Less than 20k									4.06	3.12, 5.29	4.08	3.13, 5.31
Remoteness	Major City											1	
	Inner Regional											0.87	0.71, 1.06
	Outer Regional											0.94	0.74, 1.19
	Remote/Very Remote											1.46	1.06, 2.01

Model 1: Unadjusted; Model 2: Adjusted for age and sex; Model 3: Adjusted for age, sex, LGA level mean income; Model 4: Adjusted for age, sex, LGA level mean income and household income; ICC: Intra-class Coefficient, MOR: Median Odds Ratio, DIC: Deviance Information Criterion

S3. Sensitivity Analyses

Five different sensitivity analyses were performed to confirm the robustness of findings:

i) The first sensitivity analysis was performed to investigate if differences in associations exist according to cluster sizes (low observations in each LGA). Two cut offs for sample sizes were tested following suggestions from the literature –minimum of two individuals per LGA (excluding singletons– LGAs with only one individual) and a minimum of five individuals per LGA (Table 1).

ii) The second sensitivity analysis tested whether the observed associations between area-level income inequality and oral health outcomes at the individual level varied among LGAs. Measures of 80% Interval Odds Ratio (IOR) and Proportion of Opposite Odds Ratio (POOR) that are estimated using the specific regression coefficient and variance attributed to LGAs from each regression model informed the degree of variations in the associations (Table 2).

*80% IOR (If includes 1 then some areas have association in opposite direction to overall odds ratio)	$exp(\beta_4 \pm \sqrt{2\sigma_u^2}\Phi^{-1}(0.9))$
#Proportion of Opposite Odds Ratio (POOR) (Values extend from 0% to 50%. A POOR of 0% means all ORs have the same sign. A POOR of 50% means that half of the ORs are of the opposite sign and so the association is very heterogeneous.)	$\Phi\left(-\frac{\beta_4}{\sqrt{2\sigma_u^2}}\right)$

iii) The third sensitivity analysis confirmed if the observed associations between income inequality and oral health outcomes were robust to adjustment of variables (education and tertiles of LGA-level IRSAD) where there is a lack of clarity and consensus on their role in the association between income inequality and the two oral health outcomes in the Australian context (Table 3).

iv) A sensitivity analysis was performed to examine the association between LGA-level income inequality and inadequate dentition under different categories of LGA-level mean income (deciles) and 8 categories of household income. This analysis examined the potential of residual confounding by area-level, and household-level, measures of income (Table 4).

v) The final sensitivity analysis examined the association between LGA-level income inequality and inadequate dentition with the categorization of LGA-level Gini coefficients derived through k-cluster analysis (Table 5).

S3. Table 1. Sensitivity analysis (sensitivity analysis -1) to investigate differences in the associations of income inequality and oral health outcomes after excluding:

i) Singletons for inadequate dentition (13.08%) and poor self-rated oral health (14.3%). Remaining sample: Inadequate dentition (n=4,712; LGAs= 372) Poor self-rated oral health (n=5,103; LGAs= 373).
ii) Applying a minimum cutoff of 5 individuals per LGA: Remaining sample: Inadequate dentition (n=4,510; LGAs= 280) Poor self-rated oral health (n=4,882; LGAs= 280)

Inadequate Dentition										
			Model 1		Model 2		Model 3		Model 4	
			OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Full cases	Income Inequality	Low	1		1		1		1	
		Medium	1.10	0.89, 1.37	0.87	0.69, 1.09	0.87	0.69, 1.08	0.86	0.69, 1.09
		High	0.59	0.46, 0.75	0.43	0.33, 0.56	0.58	0.43, 0.77	0.60	0.45, 0.81
Excluding singletons		Low	1		1		1		1	
		Medium	1.08	0.87, 1.35	0.85	0.68, 1.07	0.85	0.68, 1.07	0.85	0.68, 1.07
		High	0.58	0.45, 0.75	0.43	0.33, 0.56	0.58	0.44, 0.78	0.61	0.46, 0.82
Minimum 5 per LGA		Low	1		1		1		1	
		Medium	1.08	0.87, 1.35	0.84	0.67, 1.06	0.84	0.67, 1.05	0.85	0.67, 1.07
		High	0.58	0.45, 0.74	0.42	0.32, 0.55	0.57	0.42, 0.76	0.60	0.45, 0.82
Poor Self-rated oral health										
Full cases	Income Inequality	Low	1		1		1		1	
		Medium	0.93	0.79, 1.10	0.92	0.78, 1.09	0.93	0.78, 1.10	0.92	0.77, 1.10
		High	0.77	0.65, 0.91	0.76	0.64, 0.90	0.89	0.73, 1.08	0.90	0.73, 1.10
Excluding singletons		Low	1		1		1		1	
		Medium	0.92	0.78, 1.09	0.91	0.77, 1.08	0.92	0.77, 1.09	0.92	0.77, 1.09
		High	0.77	0.65, 0.91	0.76	0.64, 0.91	0.90	0.74, 1.10	0.91	0.74, 1.12
Minimum 5 per LGA		Low	1		1		1		1	
		Medium	0.94	0.79, 1.11	0.92	0.78, 1.10	0.93	0.78, 1.10	0.93	0.77, 1.11
		High	0.77	0.65, 0.92	0.76	0.64, 0.91	0.89	0.72, 1.09	0.90	0.72, 1.11

Model 1: Unadjusted; Model 2: Adjusted for age and sex; Model 3: Adjusted for age, sex, LGA level mean income; Model 4: Adjusted for age, sex, LGA level mean income and household income

S3. Table 2. Sensitivity analysis (sensitivity analysis-2) to investigate variations in the associations between area-level income inequality and inadequate dentition and poor self-rated oral health among LGAs within Australia

Inadequate dentition (n: 4,768; LGAs 428)											
		Null Model		Model 1		Model 2		Model 3		Model 4	
	Categories	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Income Inequality (Gini)	Low			1		1		1		1	
	Medium			1.10	0.89, 1.37	0.87	0.69, 1.09	0.87	0.69, 1.08	0.86	0.69, 1.09
	80% IOR*			0.67, 1.82		0.60, 1.27		0.68, 1.10		0.68, 1.10	
	POOR#			40%		32%		22%		22%	
	High			0.59	0.46, 0.75	0.43	0.33, 0.56	0.58	0.43, 0.77	0.60	0.45, 0.81
	80% IOR*			0.36, 0.97		0.30, 0.63		0.46, 0.74		0.48, 0.77	
	POOR#			9%		0%		0%		0%	
Poor self-rated oral health (n: 5,165; LGAs: 435)											
Income Inequality (Gini)	Low			1		1		1		1	
	Medium			0.93	0.79, 1.10	0.92	0.78, 1.09	0.93	0.78, 1.10	0.92	0.77, 1.10
	80% IOR*			0.93, 0.93		0.92, 0.92		0.93, 0.93		0.77, 1.12	
	POOR#			0%		0%		0%		30%	
	High			0.77	0.65, 0.91	0.76	0.64, 0.90	0.89	0.73, 1.08	0.90	0.73, 1.10
	80% IOR*			0.77, 0.77		0.76, 0.76		0.89, 0.89		0.74, 1.09	
	POOR#			0%		0%		0%		23%	

Model 1: Unadjusted; Model 2: Adjusted for age and sex; Model 3: Adjusted for age, sex, LGA level mean income; Model 4: Adjusted for age, sex, LGA level mean income and household income

S3. Table 3. Sensitivity analysis (sensitivity analysis-3) to investigate variations in the associations between area-level income inequality and inadequate dentition and poor self-rated oral health after adjusting for educational attainment, tertiles of IRSAD scores and area-remoteness, results from multilevel multivariable logistic regression models

Inadequate dentition (n: 4,768; LGAs 428)													
		Null Model		Model 1		Model 2		Model 3		Model 4		Model 5	
	Categories	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Income Inequality (Gini)	Low			1		1		1		1		1	
	Medium			1.10	0.89, 1.37	0.87	0.69, 1.09	0.87	0.69, 1.08	0.86	0.69, 1.09	0.90	0.72, 1.13
	High			0.59	0.46, 0.75	0.43	0.33, 0.56	0.58	0.43, 0.77	0.60	0.45, 0.81	0.64	0.47, 0.86
Poor self-rated oral health (n: 5,165; LGAs: 435)													
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Income Inequality (Gini)	Low			1		1		1		1		1	
	Medium			0.93	0.79, 1.10	0.92	0.78, 1.09	0.93	0.78, 1.10	0.92	0.77, 1.10	0.94	0.78, 1.12
	High			0.77	0.65, 0.91	0.76	0.64, 0.90	0.89	0.73, 1.08	0.90	0.73, 1.10	0.95	0.76, 1.19

Model 1: Unadjusted; Model 2: Adjusted for age and sex; Model 3: Adjusted for age, sex, LGA level mean income; Model 4: Adjusted for age, sex, LGA level mean income and household income; Model 4: Adjusted for age, sex, LGA level mean income and household income; Model 5: Adjusted for education, remoteness, and Index of Relative Socio-economic Advantage and Disadvantage (IRSAD)

S3. Table 4. Sensitivity analysis (sensitivity analysis-4) to investigate for residual confounding by LGA-level mean household income and household income in the association between LGA-level income inequality and inadequate dentition. Values of LGA-level mean household income and 16 categories of household income were included on continuous scale

Income inequality	Odds Ratio (95% CI) for inadequate dentition compared to no inadequate dentition
Low	1
Medium	0.91 (0.72, 1.14)
High	0.68 (0.50, 0.92)

Adjusted for age, sex, LGA-level equivalised weekly mean household income, household income and geographic remoteness.

S3. Table 5. Sensitivity analysis (sensitivity analysis-4) to investigate for variation in the association between LGA-level income inequality and inadequate dentition according to a categorization of LGA-level income inequality derived through k-cluster analysis.

Income inequality	Odds Ratio (95% CI) for inadequate dentition compared to no inadequate dentition
Low (0.292 – 0.370)	1
Medium (0.371 – 0.402)	0.85 (0.69, 1.05)
High (0.403 – 0.474)	0.54 (0.36, 0.81)

Adjusted for age, sex, LGA-level equivalised weekly mean household income and household income

7. Thesis Conclusion

Outline of the conclusion chapter

This chapter discusses the conclusions drawn from the papers included in this thesis. As each paper itself includes a discussion of its findings, this section takes a more general approach towards explaining the overarching findings across the included papers. First, an overall summary of the findings is presented according to each research question. Next, the strengths and limitations of this thesis are highlighted. Implications for research and policy are discussed in the following section. The last section includes overall conclusion of this thesis.

7.1 Summary of findings

This Ph.D. thesis aimed to address two research questions. Findings specific to each research question are summarised below.

Summary of findings for research question (I): Which socio-epidemiologic theories can be used to explain the linkages between social inequalities and population oral health?

The presumed theoretical underpinnings of empirical relationships between income inequality and health were not upheld in studies on social inequality and population oral health. While multiple theories are detailed in general health literature that may explain the association between social inequality and general health outcomes, their application in oral health needs to be outcome-specific and contextually relevant. The extent to which socio-epidemiologic theories have been applied in the literature between income inequality and oral health varied significantly between studies in terms of comprehensibility and their degree of integration in analytical framework. Neither any particular socio-epidemiologic theory, nor a combination of theories, were found to explain the association between income inequality and oral health when the explanatory potential of socio-epidemiologic theories were tested empirically.

Summary of findings for research question (II): Is area-level income inequality inversely associated with population oral health in the Australian context?

Examination of the association between area-level income inequality and oral health outcomes at the individual level in the Australian context revealed counterintuitive finding of an inverse association between area-level income inequality and inadequate dentition at the individual level. Observation of the inverse association between area-level income inequality and inadequate dentition being limited to areas with high mean income, reflected contextual differences in areas of high income inequality in Australia compared to other countries like the USA, Japan and Brazil. No association between area-level income inequality and poor self-rated oral health at the individual level showed that within the same context associations between area-level income inequality and oral health outcomes can vary according to the outcomes examined.

Key insights on the findings

Findings from this thesis challenged the practice of generalisation of theoretical pathways used to explain the relationship between area-level income inequality and general health outcomes for oral health outcomes. The lack of sufficient and robust evidence on the relative explanatory potential of theories in empirical studies on oral health outcomes in the scoping review substantiates this position. Similarly, the evidence on the associations between high income inequality and poor oral health reported from the USA, Japan and Brazil was not confirmed in the Australian context. Superficially, the two findings can be interpreted as being non-supportive of the voluminous literature on negative impacts of income inequality on outcomes of population health. However, the findings from this thesis must be interpreted carefully due to the theoretical and methodological points highlighted in the Literature Review and the theoretical papers that can shift the interpretation from one end of the scale to another. The potential theoretical and methodological points that shape the findings observed in the Australian context are described below

Contextual and temporal dependency of theoretical pathways: Psychosocial and neo-material theories are claimed to explain the pathways through which income inequality impacts on health outcomes. There is a contextual and temporal dependency in these two main theoretical explanations. For instance, psychosocial theory has been challenged on the grounds that although income inequality is lower in Japan, the Japanese society is a significantly hierarchical and patriarchal society (Goldthorpe, 2010). Paradoxically, social cohesion has been noted to be high in some of the unhealthiest societies (Muntaner and Lynch, 1999). Similarly, neo-material theory places emphasis on nature and availability of health supportive infrastructure (Lynch et al., 2000). Dependency of public health policies and social spending on the political climate of societies is well recognised. At the national level, the welfare typology has been shown to impact on population health as well as oral health outcomes (Guarnizo-Herreño et al., 2017).

Another aspect to consider is temporal variations in the availability of a health supportive infrastructure. In most democratic societies, priorities of political parties are different, and consequently so is their stand on social spending and availability of a health supportive infrastructure. The dynamic nature of health policies can impact on the distribution of health resources at different time points within and between countries. Depending on the nature of the health outcome analysed, there is a large possibility that the health resources relevant to that outcome may be shaped by national and local political climate at a particular time and by the expectation of voters. Therefore, it is important to understand the contextual and temporal nature of the different pathways between income inequality and health outcomes that may shape the income inequality-health associations differentially in different contexts and at different time points.

Income inequality as a measure of social inequality: A lack of consensus on the underlying aspects of social inequality that income inequality captures leaves income inequality only as a mathematical summary of income distribution in a geographically defined population. This limitation is reflected by the finding of an inverse association between area-level income inequality and inadequate dentition in the Australian context. Spatial variations in area-level income inequality has been confirmed within and between Australian cities (Bradbury 2017). Therefore, it is unclear whether income inequality at small area level in Australia captures dimensions of social class, distribution of social resources (Muntaner et al., 1999), and the overall scale of stratification (Wilkinson, 1999), similar to USA, Japan and Brazil. Otherwise, the exposure to income inequality with same magnitude may have different sociological meanings in different contexts.

Modifiable Areal Unit Problem and the role of geographic aggregation: The level of geographic aggregation at which the association between area-level income inequality and oral health outcome is tested can be a factor in driving both the direction and strength of observed association (Soobader and LaClere, 1999; Franzini et al., 2001; Chen and Crawford, 2012; Rostila et al., 2012). MAUP is a well-recognised methodological problem in studies of ecological exposures and health outcomes introduced due to the level of geographic aggregation by medical geographers (Flowerdew, 2011). The observed associations between exposures and outcomes may vary according to the geographic level at which variables are aggregated and associations are tested. LGAs were chosen as the appropriate level of geographic aggregation for income inequality in this thesis due to the theoretical reasons and its policy relevance. However, it is possible that LGAs may not capture the underlying sociological phenomenon in high resolution as other different levels of geographic aggregation used by the Australian Bureau of Statistics (ABS), such as SA1, postal areas or the SLAs. Therefore, MAUP can potentially be driving the counterintuitive findings observed at the LGA level in Australian context and association may differ in presence, strength and direction at different levels of geographic aggregation.

An alternative to choose the level of geographic aggregation could be a more data-driven approach. The share of variance in inadequate dentition and poor self-rated oral health was quantified using the measures of ICC and MOR on the geocoded NDTIS 2013 data as a post-hoc exercise (Appendix 5). The geographic level which has the highest level of share of variance in the oral health outcomes qualifies as the relevant level for examination on the association between area-level income inequality and oral health at the individual level (Castelli et al. 2013). SA1 level appeared as the most appropriate level for the outcome of inadequate dentition while postcodes for the outcome of poor self-rated oral health using this criterion. However, data on household income at these geographic levels are not released in the

Australian Population Census 2011 due to potential confidentiality issues. Therefore, measures of income inequality could not be allocated at these levels. Additionally, individuals per area at each level of the geographic aggregation will differ within NDTIS 2013 and needs to be considered particularly at levels lower than LGAs.

Boundaries of theoretical framework: Discussion around the neoliberal framework and inclusion in the neo-material theory (Coburn, 2000; Lynch, 2000; Coburn, 2004) demanded the need to extend the theories to consider the reasons that led to income inequality in the first place, rather than those originating from income inequality. Findings from this thesis underscore this demand. Unless there is clarity about how social inequality differentially impacts on different health outcomes, the contextual and outcome wise variations in the association between income inequality and health outcomes are likely. This is particularly important at sub-national level as it is easier to identify differences in socio-political climate relevant to health outcomes at the national level, but it is more difficult to identify these influences at smaller geographies. These influences may include the interplay of factors such as physical geography, local politics, population composition, level of implementation of public policies, and migration.

Strengths and Limitations

This thesis applied a comprehensive approach to understanding the relationship between income inequality and oral health, and its examination in the Australian context at a sub-national level. Given the criticism on the theoretical and methodological aspects related to the research on income inequality and health, this project faced similar operational challenges that appear as its limitations. However, the thesis has approached the methodological and operational challenges through theoretical support and research. The overarching strength of this project lies in its inherent feedback mechanism from theory to methods, and then its application. Subramanian et al. (2003) debating on whether income inequality as a public health concern, in a review of multilevel studies on income inequality and health mentioned:

> ‘Like any debate that hinges on the analyses of empirical data, this one warrants a close look at questions such as how the researchers defined income inequality (e.g., at what level of geographical aggregation?), what variables they controlled for, and how they analyzed the inherently multilevel nature of the research question. The devil, as they say, is always in the details’

Identifying the value in details, this project’s strength lies in explaining the theoretical and methodological aspects inherent in the contextual variation at the sub-national level in the association between income inequality and health outcomes. More specific strengths and limitations are summarised below.

7.1.1 Strengths

Evidence on the association between income inequality and health outcomes in Australia

There is a considerable amount of limited evidence on income inequality and general health outcomes at the sub-national level in Australia (Dietze et al., 2009; Bechtel et al., 2012; Redig, 2014). Among the three existing studies, two have investigated the association between income inequality and health outcomes (mental health and self-rated health) using the same panel data from Household, Income and Labour Dynamics in Australia (HILDA) Survey (Bechtel et al., 2012; Redig, 2014). These studies conducted econometric modelling with individuals nested in time rather than individuals nested in areas. The purpose of the two studies were to test competing hypotheses proposed to explain possible association between income inequality and health (Wagstaff and Doorslaer, 2000) rather than to test associations between area-level income inequality and health outcomes from a social-epidemiological perspective. The only study that remains is the one investigating the ecological association between income inequality and harms related to alcohol use, and it reported conflicting findings for the two examined outcomes (Dietze et al., 2009). Compared to the three empirical studies, this thesis investigated the evidence on income inequality and health within Australia, with the theoretically informed methods that are consistent with global literature on income inequality and health. This allows comparison of evidence between Australia and other countries. Therefore, this project adds valuable evidence towards understanding income inequality and health relationship within the Australian context.

Innovative, robust and theoretically grounded research approach

This project has made advances in the field of social epidemiology by applying a novel methodology (integrating deductive content analysis in a scoping review) to examine the theoretical use in a body of literature on a specific research question. The need to integrate theory in studies of social epidemiology has been raised consistently. However, a lack of consistent methodology to address this gap was observed. The approach applied in the scoping review of this thesis is reproducible and applicable to similar questions in social epidemiology. Similarly, the value in investigating contextual variation with the application of multilevel modelling to understand population variations in health outcomes has been constantly suggested (Merlo, 2003; Larsen and Merlo, 2005; Merlo et al., 2005a; b; Merlo et al., 2005c; Merlo et al., 2006; Merlo et al., 2009; Merlo et al., 2016). Consistent with such suggestions, the multilevel modelling applied in this thesis simultaneously estimated and reported the measures of associations between income inequality and oral health outcomes at the individual level, and quantified the share of variance that existed in outcomes at the LGA level. Furthermore, limited studied have used measures such as 80% IOR and POOR measures that link measures of variance and association to quantify heterogeneity across areas in the observed associations between area-level factors and individual health outcomes (Merlo et al., 2016). The population-based study applied 80% IOR and POOR measures in a sensitivity analysis to examine the degree to which the associations between LGA-level income inequality and oral health outcomes varied between LGAs. Therefore, the project applied innovative and robust methodologies to address the research questions framed in this thesis comprehensively.

Data quality and information

The Australian National Dental Telephone Interview Surveys are periodic, nationwide, cross-sectional, population-based surveys administered across all states and territories conducted by the Australian Research Centre for Population Oral health (ARCPOH) every 2 ½ years since 1994. This survey aids in monitoring population levels of oral health, and estimates obtained from this survey guide the planning of oral health services at the national and state levels within Australia. The survey follows strict protocols to monitor the confidentiality and quality of data. In order to provide reliable estimates to policy makers for the oral health status of the Australian population, the survey is weighted against the most recent Australian Census of Population and Housing conducted by the Australian Bureau of Statistics. Data used in this thesis were derived from the most recent NDTIS conducted in 2013 and the Australian Census of Population and Housing conducted in 2011. The geocoding of residential addresses in the NDTIS 2013 data to identify their geographic boundaries, as defined by ABS, was additionally a further key quality of this research. The lowest matching percentage of 70% informs the geographic accuracy of the administrative boundary of LGA used in the empirical component of this thesis. This also provides a one- of-its-kind databank for future research on geographic variations in oral health within Australia, which will aid in the investigation of the unresolved issues on income inequality and oral health among Australian population highlighted in this thesis.

Evidence on the impact of income inequality on household income-oral health relationship

Globally, the evidence on income inequality and oral health relationship is limited to testing only the associations between area-level income inequality and oral health outcomes at the individual and population level. Only one study exists that has examined the impact of income inequality on the sugar and dental caries relationship, and that too is at the country level (Masood et al., 2012). No study has investigated the impact of area-level income inequality on the individual level association between income and health. Following the recent suggestions from the literature to examine the slope effects of income inequality on health outcomes (Truesdale and Jencks, 2016), this thesis assessed the variations in the household income-oral health gradients according to levels of income inequality within Australia. Variations observed between the shapes of gradients according to levels of income inequality indicated that above and beyond the impact of income inequality on individual oral health, as a system-level factor income inequality plays an important role in shaping individual level associations between income and oral health. This is an important finding for policy implications within Australia and a valuable addition to oral health literature.

7.1.2 Limitations

Restrictive interpretation of findings

This thesis aimed to address the gap in evidence on the association between income inequality and oral health in the Australian context. Given the lack of evidence on the association in the Australian context and the limited evidence with varying methodological approaches in the Australian literature on general health, findings should be inferred cautiously. Within the limited time frame of the Ph.D. thesis, only certain operational aspects of the research on income inequality and oral health in Australia could be addressed. These aspects relate to the choice of LGAs as the level of geographic aggregation, use of the Gini coefficient as a sole measure of income inequality, assessment of association with self-reported oral health outcomes and restricting the application of this research to adult population. Within these operational boundaries, findings from this thesis provide an important contribution. However, this limits the generalisability of this research across different measures of income inequality, association of income inequality with clinical oral health outcomes of dental caries and periodontal disease, as well as other general health outcomes; and presence or absence of association at other levels of geographic aggregation within Australia that has not been examined in this thesis. In particular, an important basis of the current findings is the accuracy of household income, reported in the census to estimate the Gini coefficient, and particularly the inclusion of those at very high levels of income. Therefore, despite a comprehensive approach there are clear operational boundaries that limit the generalisability of the association between income inequality and health within Australia, as apparent in from the current findings of this thesis.

Deviations from original ideas due to operational challenges

The thesis aimed to provide evidence on the association between area-level income inequality and population oral health based on the hypothesis that areas with higher income inequality will have poorer oral health on average compared to areas with lower levels of income inequality in the Australian context. Additionally, following the literature gaps identified in the scoping review, a supplementary aim was planned to quantify the explanatory potential of different theoretical pathways in explaining the association between area-level income inequality and population oral health. The first operational roadblock to addressing the lack of evidence on the association between area-level income inequality and population oral health, was that data from oral health surveys are not designed to make inferences at a small area level, and consequently are underpowered for that task. It is usually possible to obtain population levels estimates of general health outcomes even at smaller levels of geographic aggregation – such as outcomes like mortality rates can be derived from registration data. Therefore, consistent with most oral health studies, and observing the lack of evidence on income inequality and oral health in Australia, the thesis tested the association between area-level income inequality and oral health at the individual level in Australia. Nevertheless, the theoretical papers included in this thesis critically investigated the distinction between conceptualising oral health at the population and individual level and evaluated its policy and research implications. Second, the lack of data on the theoretical pathways particularly at the LGA level restricted the quantification of the explanatory potential of different theoretical pathway in explaining the association between area-level income inequality and oral health in the Australian context.

Limitations on the choice of variables

The finding of the inverse association between area-level income inequality and inadequate dentition was unique in the context of global oral health literature. While the last study in this thesis aimed only to test associations between area-level income inequality and oral health outcomes, it would have been most appropriate to empirically test the explanations for the observed inverse association. However, the lack of data on the availability of dental care at the LGA-level did not permit this exercise. This is also a limitation of most secondary analyses that apply multilevel methods to investigate the determinants of health at different levels of social organisation as they have to rely on available data for analysis.

7.2 Implications for research and policy

Research Implications

Variations in the association with clinical outcomes and the child population:

This project has only examined the association between area-level income inequality and self-reported outcomes of tooth loss and self-rated oral health among Australian adults. Both the outcomes of tooth loss and self-rated oral health occur later in the causal chain compared to disease measures like dental caries and periodontal disease. Variations in the associations of income inequality with disease measures, compared to the outcomes of tooth loss and self-rated oral health, can inform whether mechanisms specific to tooth loss (access and utilisation of dental care) are linked differentially to income inequality within the Australian context. Furthermore, future studies can also inform whether differences in association between income inequality and tooth loss differs among adolescents and children, because different dental healthcare arrangements in Australia differ for children and adults (Luzzi and Harford, 2014).

Variations according to different lag times:

Research has shown that consideration of lag times are important when testing the association between income inequality and oral health outcomes. Although, a natural lag of two years was present between the exposure of income inequality and the oral health outcomes in Paper 5, there is only one study in oral health that has tested the impact of lag times for this association (Celeste et al., 2011). Future research could explore the role of different lag times between income inequality and oral health outcomes in Australian context.

Role of availability of dental care:

Due to lack of data on the availability of dental care at the LGA-level, this thesis could not examine its speculated role in the inverse association between area-level income inequality and inadequate dentition at the individual level. This research will have important policy implications because it informs the value in investment in equitable dental healthcare in a context where dental and general healthcare are treated differentially for different population sub-groups.

Linkages between income inequality and other dimensions of social inequality:

Income inequality is a growing social and public health concern as observed in political and public debates in Australia over the last few years. Addressing income inequality for reasons not limited to its implications on oral health are justified. However, the contextual variation in the association between income inequality and oral health in Australia reflects the need for future research to clarify the link between income inequality and other dimensions of social inequality. Within Australia, the contextual variation in area-level income inequality from a spatial perspective, and from the perspective of the mining boom has been reported in the literature (Fleming and Measham, 2015; Bradbury, 2017). Bradbury (2017) reported variations in income inequality both between major cities of Australia and among their Statistical Local Areas. Fleming and Measham (2015) reported that over the decade 2001-2011, income inequality increased by 4.8% in mining regions compared to 8.7% in the average non-mining region. However, there is a considerable lack of evidence on its consequences on health outcomes. Future research with inter-disciplinary team and expertise should address this important gap that these current findings from the thesis have implicitly revealed.

Impact of change in income inequality on oral health outcomes:

The current study evaluated the association between area-level income inequality and oral health outcomes at one point of time. However, a study from Brazil has shown that changes in income inequality over time are also associated with poor oral health at the individual level (Goulart and Vettore, 2015). This gap in evidence is identified. Given the increase in income inequality over time within Australia (Fletcher and Guttmann, 2014; Fleming and Measham, 2015), future studies should examine whether such changes impact on the oral health of the Australian population.

Confirmation across different measures of income inequality:

Due to operational challenges such as a lack of available measures of income inequality and the limited time frame of the Ph.D., analysis was restricted to the use of the Gini coefficients as a measure of income inequality. Given the spatial variations in characteristics of income inequality within Australia, it is possible that other measures of income inequality such as the Theil and Atkinson Index may better capture the sociological dimensions of income inequality. However, a previous study from Australia did not find any differences in the lack of association between income inequality with mental health, according to the use of income inequality measures (Bechtel et al., 2012). Future studies can confirm if any variations in associations with oral health exist according to different measures of income inequality in the Australian context.

Assessment at different levels of geographic aggregation:

The current study investigated the association between income inequality and oral health outcomes at the LGA level. As identified in the Literature Review and the theoretical Papers in this thesis, the association between income inequality and health outcomes can vary across levels of geographic aggregation, particularly at the sub-national level (Wilkinson and Pickett, 2006). Variations in the association at different levels of geographic aggregation suggests that social, political and administrative processes unique to the level of examination may have consequences for the association between area-level income inequality and oral health. There is also a lack of evidence on the role of different geographic aggregation in the association between income inequality and oral health and future studies can address this gap.

Policy Implications

Findings from the thesis revealed that the evidence on income inequality and oral health from other high-income countries cannot be generalised to Australia due to its unique contextual characteristics. The current findings of an inverse association between area-level income inequality and inadequate dentition should be interpreted cautiously from a policy perspective as it is likely to be due to the spatial distribution of income inequality and oral health resources within the Australian context. Additionally, variations in household-income gradients in inadequate dentition according to area-level income inequality reveal a more systematic role of income inequality in defining oral health inequalities within Australian society. Therefore, reducing income inequality and increasing equitable access to oral healthcare resources can benefit in improving individual and population oral health.

7.3 Conclusion

Overall, this thesis identified variations in the association between area-level income inequality and oral health outcomes in the Australian context compared to other countries. Rather than challenging the evidence on ill-effects of income inequality on health outcomes, this lack of generalisability reflects the need to understand contextual variations that shape the associations between income inequality and health outcomes.

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Thesis Appendices

APPENDIX 1. Conference abstracts and poster presentation

- Appendix 1.1: Singh, A., Harford, J., Watt, R.G., & Peres, M.A. (2014). Role of theories in explaining the association between social inequalities and population oral health – Protocol of a Scoping Review. (Poster presentation at the 8th Annual Florey International Postgraduate Research Conference, 25th September 2014, Adelaide, Australia).
- Appendix 1.2: Singh, A., Harford, J., Schuch, H.S., Watt, R.G. & Peres, M.A. (2015). Theories for socio-inequalities in oral health – Scoping Review. International Association for Dental Research (IADR) Australia & New Zealand Conference (23rd – 26th August, Dunedin, New Zealand)
- Appendix 1.3: Singh, A., Harford, J. & Peres, M.A. (2016). Testing associations between area level social inequality and population oral health within Australia – similar, yet different. (Oral presentation at the 2016 SA Population Health Conference, 22nd October 2016, Adelaide, Australia).
- Appendix 1.4: Singh, A. (2017). The conundrum of analytical unit when testing the income inequality hypothesis. (Oral presentation at the Behavioral, Epidemiological and Health Services Research Group (BEHSR) Epi-forum at the IADR/AADR/CADR General Session & Exhibition, San Francisco, California, USA - March 21, 2017).
- Appendix 1.5: Singh, A., Harford, J., Antunes, J.L.F. & Peres, M.A. (2017). Associations between area income inequality and oral health within Australia. (Oral presentation at the IADR/AADR/CADR General Session & Exhibition, San Francisco, California, USA - March 22-25, 2017).

- Appendix 1.6: Singh, A., Harford, J., Antunes, J.L.F. & Peres, M.A. (2017). Area-level income inequality and individual-level inadequate dentition among Australian adults. (Abstract submitted for consideration at the International Association for Dental Research (IADR) Australia & New Zealand Conference (25^{th} – 27^{th} September, Adelaide, Australia)).

APPENDIX 2. Data request forms for the population-based study and permission from research ethics body

- Appendix 2.1. Data request for the population-based study
- Appendix 2.2. Data request for requesting de-identified addresses from NDTIS 2013
- Appendix 2.3. Permission from Human Research Ethics Committee to geocode addresses

APPENDIX 3. Communication from journals for submission of papers 3, 4 and 5

- Appendix 3.1. Communication from the journal Community Dentistry and Oral Epidemiology confirming submission of the article
- Appendix 3.2. Communication from the journal Community Dentistry and Oral Epidemiology confirming submission of the article
- Appendix 3.3. Communication from the journal PLOS One confirming submission of the article

APPENDIX 4. Source for measures of Gini Coefficient

APPENDIX 5. Intra-class Correlation Coefficients and Median Odds Ratios for inadequate dentition and poor self-rated oral health at different levels of geographic aggregation in Australia

Appendix 1.1

Poster presented at Florey International Postgraduate Conference, Adelaide, 2015

ARCPOH Australian Research Centre for POPULATION ORAL HEALTH

THE UNIVERSITY of ADELAIDE

Role of theories in explaining the association between social inequalities and population oral health – Protocol of a Scoping Review

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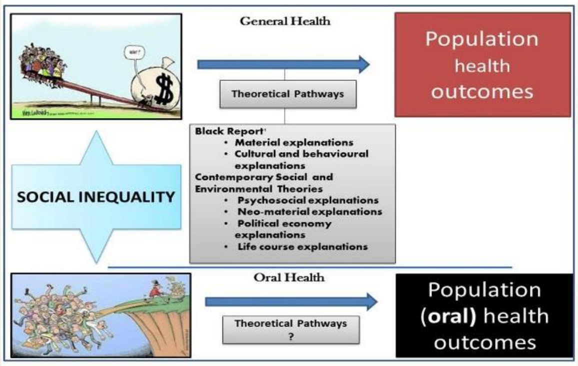
BACKGROUND



Studies report direct effects of social inequalities on a range of population health outcomes such as mortality, life expectancy, self-rated health, hypertension, suicides among others[2,3,4,5,6]. Some studies suggest such results cannot be generalized[4,7]. Several studies have also investigated direct effects of social inequalities on population oral health outcomes and have reported mixed findings [8,9,10,11]. In social epidemiology the most debated issue around the evidence surrounding social inequalities and it's implication on population health is regarding the theoretical pathways through which they are related[2,4,6]. There is considerable uncertainty in the dental literature regarding the theoretical pathways and mechanisms through which they may be related.

RATIONALE

Considering the uncertainty regarding the use of theories in explaining the association between social inequality and population oral health in the existing literature, a systematic review may not be the appropriate methodology to assess the evidence on role of theories. A **scoping review** is conducted with a purpose to examine the extent, range and nature of any research activity; to determine the possibility of conducting a full systematic review; to summarize, disseminate research findings and finally to identify research gaps in the existing literature[12]. Hence, a **scoping review** will be conducted in order to assess the gap regarding role of social theories in the evidence.

AIM/ OBJECTIVES

Research Question

What is the nature and extent of social theories being used as a basis to explain the associations between social inequalities and population oral health?

Research Hypothesis

Literature on the associations between social inequalities and population oral health has focussed largely on building empirical evidence on the association between social inequalities and population oral health rather than giving importance to the role of theories in leading to social inequalities and its implications on population oral health.

Aim

To gauge and explore the evidence on theoretical explanations for pathways and mechanisms through which social inequalities affects population oral health.

Objectives

1. To synthesize the evidence on the association between social inequalities and population oral health according to the social theories used as an explanation.
2. To identify and categorize conceptual and measurement alternatives used in the existing evidence to measure social class or socioeconomic inequalities according to either stratification or relational approach.
3. To highlight the gap in evidence for future research implications in this field.

METHODS

Methodological framework for conducting a scoping review[12,13]:-

STAGE I

Population Studies restricted to assessing the association in a clearly defined population in terms of age group and geography

Concept Social theories as explanations for pathways through which social inequalities affects population oral health

Exposure Measurements of Social inequality: Income Inequality:- GINI Index, Income share, Robinhood index, Slope index of inequality, Relative concentration index

Social Inequalities:- Occupational measurements, Employer-Employee Relationship; Ethnicity, Gender, Caste, Power relations

Context Area level, Country level or Multi-country studies (within countries and between countries)

Outcome of Interest: Widely used self-reported and clinically measured population oral health outcomes: Dental caries, Tooth loss, Self-rated oral health, Oral Health Related Quality of Life, Periodontitis, Periodontal Pockets and Dental Pain

STAGE II

Databases: Pubmed, Medline (Ovid), EMBASE, Web of Science, SciElo, Lilacs, ERIC (EDUCATION RESOURCES INFORMATION CENTER), Sociological Abstracts, Social Work Abstracts, Google search, reference lists, book chapters and contact with experts; Thesis (Proquest) and Conference abstracts. Further editorials, library thesis, opinions and letters will be searched to identify relevant studies.

OUTCOME	EXPOSURE	PHENOMENON
Oral Health[TW] OR Tooth Loss*[TW] OR Decayed Missing and Filled Teeth[TW] OR DMF*[TW] OR Edent*[TW] OR Dental Status*[TW] OR Periodontitis [MH] OR Periodont* [TW] OR Caries [TW] OR Toothach* [TW] OR Dental pain [TW]	Psychosocial Deprivation* [TW] OR Family characteristics [MH] OR Hierarchy, Social [MH] OR Social Hierarch* [TW] OR Minority Group [MH] OR Social Class [MH] OR Social class* [TW] OR Social Mobilit* [TW] OR Caste* [TW] OR Social Condition* [TW] OR Sociology [MH] OR Poverty [TW] OR Socioeconomic Factors [MH] OR Socioeconomic*[TW] OR Income* [TW] OR Wage* [TW] OR Remuneration* [TW] OR Occupation* [TW] OR Unemploy* [TW] OR Labour* [TW] OR Labor* [TW] OR Educational Status[TW] OR Educational Achievement*[TW] OR Educational attainment* [TW] OR Ethnic Groups [MH] OR Race* [TW] OR Raci* [TW] OR Sexism [MH] OR Sexis* [TW] OR Gender Identity [MH] OR Gender* [TW] OR Social stratif* [TW] OR Political Systems [MH]	Inequalit*[TW] OR Disparit* [TW] OR Inequit* [TW] OR Difference* [TW] OR Discriminat* [TW]

And ⟷ And

Table 1: Preliminary search on Pubmed: No of hits = 3358

STAGE III

In order to reduce individual bias, after removal of all duplicates the titles will be screened for eligibility by two researchers on the basis of pre decided inclusion and exclusion criteria. Disagreements will be resolved with discussions with an expert or a third reviewer. Subsequently, abstract screening and full text review will be conducted.

STAGE IV

i) Data extraction using standardized data extraction forms
ii) Data synthesis using narrative review along with systematic and descriptive mapping

STAGE V

i) Analysis:- Numerical description on the association and thematic framework analysis for nature, extent of theories and measurements alternatives for social inequalities.
ii) Reporting under logical categories and headings.
iii) Discussing results and highlighting gaps for research and policy implications.

FUTURE PROSPECTS

The proposed scoping review will be submitted as a Conference abstract and a manuscript for suitable journal publication targeting social epidemiologists and dental public health researchers as an audience. The results from the review will highlight the existing gap in the evidence in order to inform future research studies in this area. Clarifying the mechanisms by which social inequalities impact population oral health will provide evidence for policymakers on potentially effective strategies to reduce the impact of social inequalities on population oral health.

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Appendix 1.2
ABSTRACT FOR IADR ANZ REGIONAL MEETING, Dunedin, 2015

Title (Abstract titles are limited to 10 words or less):

Theories on social inequalities and oral health: a scoping review

Authors:

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Abstract Text (300 or less):

Aims: To review the evidence on the association between area-level social inequalities and population oral health according to type and extent of social theories.

Methods: A scoping review was conducted on the studies which assessed association between any area level social inequality measure and population oral health outcomes such as self-rated oral health, number of teeth, dental caries, periodontal disease, tooth loss, Oral Health related Quality of Life (OHRQoL) and dental pain. A search strategy was applied to identify evidence on PubMed, Medline (Ovid), EMBASE, Web of Science, ERIC, Sociological Abstracts, Social Services Abstracts, references of selected studies, and further grey literature. A qualitative content analysis of the selected studies using Nvivo software was conducted.

Results: A total of 2647 hits were identified and 11 studies were included in the review. Income inequality was measure of area-level inequality amongst all studies and Gini Index as the preferred measure of income inequality in selected studies There were 31 uses of 7 types of social theories in the selected studies including psychosocial (9), behavioural (6), neo-material (6), social capital (5), social cohesion (2), social support (2) and material (1). Amongst the selected studies 4 used theories for post-hoc explanation, only 2 explicitly tested social theories as pathways from inequalities to population oral health outcomes, 2 had some conceptual basis, 2 used a theoretical construct, and 1 had no theoretical basis. All the studies used income inequality as the area-level measure of social inequality. All studies reported significant associations and detrimental effects of area level inequality on oral health outcomes.

Conclusions: Few studies have assessed the association between an area-level social inequality and oral health outcomes. Psychosocial theories are applied most frequently. Social theories were not explicitly tested in the majority of the studies.

Keywords: Inequality, Oral health, Ecological, Scoping review

Scientific group/Network: Global Oral Health Inequalities Research

Appendix 1.3

Abstract for SA Population Health Conference, Adelaide, 2016

Testing associations between area level social inequality and population oral health within Australia – similar, yet different

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PRESENTER DETAILS

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Abstract

Introduction: Weight of global evidence suggests that area level social inequality is detrimental to population oral health. This association is reported at both country and small area levels. However, there is a lack of evidence on this association within Australia. Using global evidence the current study aimed to identify conceptual and methodological issues requiring careful consideration when testing this association within Australia.

Methods: Three sources of evidence were used to collate the relevant methodological and conceptual characteristics for operationalizing this research in Australia. First, a published scoping review informed the theoretical basis and pathways through which social inequality may affect population oral health. Second, global literature on income inequality hypothesis was carefully assessed to identify key characteristics related to the context (country/area) where the hypothesis is to be tested. Finally, published literature on methodological characteristics of ecological and multi-level studies informed the factors which need additional consideration when testing the associations within Australia

Results: Methodological issues identified which require special attention when testing associations between area level social inequality and population oral health within Australia include: meaningful definition of ecological unit, appropriate spatial scale, appropriate lag times, contextual differences in theoretical pathways, importance of individual factors, data sources with appropriate statistical techniques.

Conclusion: Associations between area level social inequality and population oral health are highly dependent on the context where tested. The lack of studies on this association within Australia necessitates a closer attention to the identified conceptual and methodological characteristics which may differently operate within Australia.

Implications for policy and/ or practice: Amplifying concerns about increasing income and wealth inequality in Australia over time added with global evidence pointing towards detrimental effects on population oral health necessitates well-designed studies to generate robust evidence and inform policies.

Keywords: Inequality; oral health; societal determinants; ecological studies

Appendix 1.4

Abstract for Epiforum, IADR Conference, San Francisco, 2017

Presentation Title: The conundrum of analytical unit when testing the income inequality hypothesis

Background: A theoretical debate in epidemiology persists regarding the differences between conceptualizing health at the population and individual levels due to the exclusivity of their risks. An inverse association between income inequality and population health (including oral health) is reported at multiple geographic levels in different settings. Earlier studies on income inequality and health tested associations between income inequality and average health outcomes (population level); while more recent multilevel studies have tested associations at the individual level. A clarity on the analytical unit is necessary both for understanding theoretical pathways and to find relevant methodological approaches.

Objective(s): The study aims to discuss the methodological challenges related to multilevel studies when testing associations between area level income inequality and population health.

Methods: The presentation will use evidence from global literature on income inequality studies and the published literature on methodological characteristics of ecological and multi-level studies to apply on the data of dentate adults from National Dental Telephone Interview Survey (NDTIS) 2013 (n=5,978; Local Government Areas (LGA)=435) for illustrating methodological discussions.

Findings-to-Date: Earlier studies on income inequality and population health tested associations using single level regressions and correlations. Due to the advantages of multilevel technique in permitting accounting for potential confounding at multiple levels, recent studies have predominantly applied multilevel models. However, majority of these studies have evaluated associations between income inequality and individual health, not population health. In the absence of aggregated health outcomes (disease rates and prevalence) at an area level, multilevel models have limited application in testing associations between area level income inequality and population health. Small area estimation technique can potentially help in addressing this limitation by obtain synthetic population estimates.

Summary: Multilevel analytical technique has limitations in estimating associations at the population level in absence of aggregated health outcomes.

Appendix 1.5
Abstract for IADR Conference, San Francisco, 2017

Scientific Group/Network: GOHIRN

Title (10 words limit):- Associations between area income inequality and oral health within Australia

Ankur Singh,[1*] Jane Harford,[1] José Leopoldo Ferreira Antunes,[2] Marco A Peres[1]

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Abstract (300 words limit)

Objectives: To test associations between area-level income inequality and oral health outcomes among Australian adults.

Methods: Data was obtained from National Dental Telephone Interview Survey (NDTIS) 2013 (n=6,340;LGAs=458). Income inequality of Local Government Areas (LGAs) were measured by Gini index from Australian Census 2011. Outcomes included inadequate dentition (<21 teeth) and self-rated oral health (SROH) (poor/very poor vs excellent/very good/good). Multilevel logistic regression models were applied to test associations. Covariates included age, sex, area mean household income and individual income. Interactions between Gini and area mean household income were assessed for both outcomes. Heterogeneities among areas in the associations were estimated with Proportion of Odds Ratios in Opposite Direction (POOR) and Interval Odds Ratios (IOR).

Results: After accounting for covariates; one standard deviation increase in LGA Gini was associated with 0.85 (95%CI:0.79,0.92) relatively lower odds of having inadequate dentition among individuals. POOR indicated that 16% of the time an individual from LGA with higher Gini had greater rather than lower likelihood of inadequate dentition, compared to a person from LGA with lower Gini. Unadjusted inverse association between area level income

inequality and poorer SROH was explained by area mean household income. POOR of 34% demonstrated heterogeneity among LGAs in the direction of this association. IORs substantiated heterogeneities among areas for both outcomes. Significant interactions ($p<0.001$) were observed between Gini and area mean household income for both outcomes. For the tertiles of Gini and area level mean household income; individuals within areas with highest Gini and medium mean household income had 1.66 (95%CI:1.04,2.66) and 1.61 (95%CI:1.05,2.46) relatively higher odds of inadequate dentition and poor SROH respectively, compared to the individuals within areas with lowest Gini and highest mean household income.

Conclusion: Higher income inequality was associated with lower inadequate dentition at the individual level. However, this association was heterogeneous among areas.

Appendix 1.6
Abstract for IADR Conference, Adelaide, 2017

Scientific Group/Network: GOHIRN

Title (10 words limit):- Area-level income inequality and individual-level inadequate dentition among Australian adults

Ankur Singh,[1*] Jane Harford,[1] José Leopoldo Ferreira Antunes,[2] Marco A Peres[1]

Affiliations:-

5. Australian Research Centre for Population Oral Health (ARCPOH), Adelaide Dental School, The University of Adelaide, Adelaide, Australia
6. Departamento de Epidemiologia, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil

Abstract (300 words limit)

Objectives: A previous analysis found area-level income inequality to be inversely associated with inadequate dentition (<21 teeth) at the individual level among Australian adults after adjusting for age, sex, household income and area-level mean income. Current study aimed to identify possible explanations for this counterintuitive finding. Additionally, this study tested whether household income-inadequate dentition gradients vary according to area-level income inequality in the Australian context.

Methods: Evidence on theoretical and methodological aspects critical to testing associations between income inequality and health were applied to understand the contextual characteristics of Australia that lead to counter-intuitive finding on income inequality and inadequate dentition. To examine variation in household income-inadequate dentition gradients according to area-level income inequality, data on dentate adults was obtained from National Dental Telephone Interview Survey (NDTIS) 2013 (n=5,169; Local Government Areas=435). Associations between household income and inadequate dentition were estimated after adjusting for age, sex, educational attainment and LGA-level weekly mean income using multilevel multivariable regression models. The prevalence of inadequate dentition by household income was estimated from separate models for each high, medium and low tertiles of Gini coefficient.

Results: Geographic variations in area-level income inequality and its potential impact on availability and distribution of oral health resources at LGA level in Australia presented as the possible explanation for the inverse association between area-level income inequality and inadequate dentition among Australian adults. Household income gradients in inadequate dentition showed more inadequate dentition among individuals at lower levels of household income. The household income gradients for inadequate dentition varied according to LGA-level income inequality.

Conclusion: Finding of an inverse association between area-level income inequality and inadequate dentition should be interpreted cautiously. Variation in household-income gradients in inadequate dentition according to area-level income inequality reveal systematic role of income inequality in defining socioeconomic inequalities in tooth loss within Australian context.

Appendix 2.1 Data request form

Australian Research Centre for Population Oral Health (ARCPOH)

School of Dentistry

Student request for de-identified data

Submit to ARCPOH Executive Committee

1. Date submitted:	2/ 2 / 2016

2. Applicant:	
a. Name:	**Ankur Kumar Singh**
b. Contact details:	**ankur.singh@adelaide.edu.au** **0883132549**
c. Affiliation:	**Australian Research Centre for Population Oral Health**
d. Course:	**PhD in Dentistry**
e. Period of candidature:	**27th April 2014 to 27th April 2017**
3. Scholarship?	☐ No ☒ Yes (please specify) International Postgraduate Research Scholarship (IPRS) and Australian Postgraduate Award (APA)

4. ARCPOH supervisor	**Prof. Marco A Peres and Dr. Jane Harford**
5. Other supervisor(s) *(include affiliation if not from ARCPOH)*	

Page 1

6. Working title of the project: **Theoretical and empirical explanations for the association between social inequalities and population oral health**

- **Specific aims of the project** *(please provide as much detail as possible)*

Paper 1

1. To test an association between income inequality and population oral health within Australia (for a range of measures)
2. To assess whether income inequality has a contextual effect on population oral independent of a compositional effect of individual level income (tooth loss, untreated decay, self-rated oral health and recent extraction)

Paper 2

3. To assess whether the level of geographic aggregation used influences the association between income inequality and oral health within Australia

Paper 3

4. To test whether the existing theoretical explanations (neo-material, psychosocial and behavioural) for the associations between area level social inequalities and population oral health potentially explain the relationship if evident within Australia

7. Background for the project

It is argued that social inequality (inequality within a society or within a group to which the individual belongs) affects the average population health (Kondo et al., 2009; Pickett and Wilkinson, 2015; Wilkinson, 1992; Wilkinson and Pickett, 2006) within a society. Income inequality is examined as a determinant of population health. It is postulated that more egalitarian societies have better population health when compared to the unequal societies. There is a significant gap in the literature on the association between income inequality and population oral health within Australia. Oral health is an integral part of general health and poor oral health affects quality of life. There are considerable healthcare costs associated with the treatment of oral diseases. Untreated dental caries is most prevalent non communicable disease despite that it is largely preventable. Similarly, premature loss of teeth has been shown to be an independent risk factor for mortality. Apart from the associated public health burden of oral diseases, considering that their pathophysiology is more or less well known; they serve as important population health outcomes to test the income inequality hypothesis (Celeste et al., 2011; Celeste and Nadanovsky, 2010; Celeste et al., 2009). Considering the lack of evidence in Australia on the effects of inequality on population health, and the public health importance of oral diseases, the proposed study will test the association between income inequality and population oral health within Australia. The proposed study will also inform on some key issues associated with testing this hypothesis within Australia:

1) Role of geographical aggregation level

2) Independent contextual effect of inequality on population health beyond the compositional relationship between individual income and oral health
3) Potential explanatory power of existing socio-epidemiologic theories in explaining the association between inequality and population oral health within Australia

8. Data required	
a. Name of dataset(s)	NDTIS 2002 & NSAOH 2004-2006 & NDTIS 2013
b. Specific variables required (please provide as much detail)	**<u>Specify</u>** **Please also see attached Table (Variable names and details mentioned in excel sheet).**
	Paper 1 & 2 **Outcome variables:** Extraction in the last year (NDTIS 2002; NSAOH 2004-2006), Self-reported tooth loss (NDTIS 2002; NSAOH 2004-2006), Self-rated oral health (NDTIS 2002; NSAOH 2004-2006) and Untreated dental caries (NSAOH 2004-2006) **Main explanatory variables:** Gini Coefficient (Census 2002), Postcode identifier (NDTIS 2002; NSAOH 2004-2006) **Covariates:** Individual income (NDTIS 2002, NSAOH 2004-2006), Age (NDTIS 2002, NSAOH 2004-2006), Sex (NDTIS 2002, NSAOH 2004-2006), Country of birth (NDTIS 2002, NSAOH 2004-2006), Educational attainment (NDTIS 2002, NSAOH 2004-2006), area remoteness (NDTIS 2002, NSAOH 2004-2006) **Other variables:** Individual Id and Survey Weights (NDTIS 2002, NSAOH 2004-2006)
	Paper 3 **Outcome variables:** Extraction in the last year (NDTIS 2013), Self-reported tooth loss (NDTIS 2013), Self-rated oral health (NDTIS 2013) **Main explanatory variables:** Gini Coefficient (Census 2002), Postcode identifier (NDTIS 2013) **Covariates:** Individual income (NDTIS 2013;

	NSAOH), Age (NDTIS 2013), Sex (NDTIS 2013), Country of birth (NDTIS 2013), Educational attainment (NDTIS 2013), tobacco use (NDTIS 2013, NSAOH 2004-2006), dental attendance (NDTIS 2013, NSAOH 2004-2006), area remoteness (NDTIS 2013) **Other variables:** Individual Id and Survey Weights (NDTIS 2013, NSAOH 2004-2006); Postcode identifier (NSAOH 2004-2006)
9. Date data required	12th February 2016

10. Chief Investigators (CIs) on originating grant (if applicable):

a. **Have the originating grant CIs been contacted regarding collaborating/co-supervision on this project?**

☐ Yes ☐ No ☒ N/A

b. **Have the originating grant CIs agreed to collaborate on this project?**

☐ Yes ☐ No ☒ N/A

c. **If the originating grant CIs cannot, or do not wish to collaborate, please provide details:**

11. Who will take responsibility for the data?

a. Name:	**Ankur Kumar Singh**
b. Email address:	**ankur.singh@adelaide.edu.au**
12. Where will the data be stored?	**ARCPOH computers**

Appendix 2.2

Requirement of additional information from NDTIS – 2013

Requested information:- Individual addresses of the participants in NDTIS 2013

Purpose:- To allocate individuals to appropriate Local Government Areas (LGAs) and other ABS hierarchies

Justification:- The remaining part of my PhD thesis aims to quantify the association between area level income inequality and population oral health within Australia. Furthermore, it aims to test this association at different levels of geographic aggregations. The only geographic information recorded within NDTIS is postcodes, which limits us from proceeding with the analysis as income inequality has not been reported at the postcode level, and the boundaries of postcodes do not always align with the boundaries of ABS and other non-ABS geographical units.

In order to address this, individual level data from NDTIS needs to be geocoded to appropriate geographical units for two purposes:-

1) To allocate corresponding levels of income inequality (Gini coefficients) which are already reported at different geographic units except postcodes
2) To avoid potential misclassification of individuals to geographical units. Particularly, when the boundaries of postcodes do not align completely with the corresponding geographic units

Process:- Based upon the discussions held with Managing Director of Omnilink Pty Ltd., they require a spreadsheet of de-identified addresses, which they will validate and then geocode to the different geographical units.

This will need to be provided in the following format (example):-

Temporary ID	Addresses
1	ARCPOH, The University of Adelaide, 122 Frome Street (Cnr Pirie St)
2	--------
3	--------
----	---------

This temporary id can be just a number series which can be separately stored in a file with the NDTIS id within a restricted folder that ensures that no specific information from the NDTIS dataset is sent to the external body. The temporary id will only be later used to merge the geographic information received after geo-coding.

After geocoding, the external organization (Omnilink Pty Ltd (http://www.omnilink.com.au/)) will provide us with the codes for the different ABS hierarchies and the LGAs for each of the addresses.

Temporary ID	Addresses	LGA	SLA	SA-2	SA-3	SA-4	State/Territories
1	ARCPOH, The University of Adelaide, 122 Frome Street (Cnr Pirie St)						
2	--------						
3	--------						
----	---------						

After the geocoding is done, this spreadsheet will be returned to ARCPOH data custodian, and then this information can be merged with NDTIS 2013 data using the temporary IDs which was shared. For the PhD analysis, a de-identified dataset with the previously requested and approved variables along with the geographic units without the addresses will be sufficient.

Appendix 2.3. Permission from Ethics Committee for geocoding

Ankur Kumar Singh

From:	Human Research Ethics Committee HREC
Sent:	Tuesday, 10 May 2016 9:25 AM
To:	Ankur Kumar Singh
Subject:	RE: Query

Dear Ankur

Thank you for your enquiry and detailed description of the work you wish to conduct. As the data from ARCPOH that you will be receiving has no personal identifiers and the addresses you want to link are publicly available, this work does not require ethical approval. Thank you for clarifying that the geo-coding will be conducted by an external agency who will not be using it for any other purposes and have also signed a confidentiality agreement.

Kind regards
Sabine

Sabine Schreiber
Secretary, Human Research Ethics Committee
Office of Research Ethics, Compliance and Integrity
Level 4 Rundle Mall Plaza, 50 Rundle Mall
The University of Adelaide, AUSTRALIA 5000
Ph : 8313 6028
Fax: 8313 3700
HREC e-mail: hrec@adelaide.edu.au
e-mail: sabine.schreiber@adelaide.edu.au
http://www.adelaide.edu.au/ethics/human

Days of Work: Monday to Thursday

From: Ankur Kumar Singh
Sent: Wednesday, 4 May 2016 10:51 AM
To: Human Research Ethics Committee HREC <hrec@adelaide.edu.au>
Subject: Query

Dear Officer,

I am a PhD student at the Australian Research Centre for Population Oral Health (ARCPOH) at the School of Dentistry. I am currently in the third year of my PhD candidature and have two studies remaining before the submission of my thesis. These studies aim to test the associations between income inequality and population oral health within Australia (Details hypotheses, objectives and data sources are at attachment 1 to this letter). I am writing to seek your guidance regarding the requirement for ethical approval and the level of review which is required for one aspect of my proposed work.

The sampling frame for National Dental Telephone Interview Survey (NDTIS) 2013 was created from the electronic product 'Australia on Disc 2012 Residential' supplied by United Directory Systems. This product is an electronic listing of people/households listed in the White Pages across Australia and includes addresses and telephone

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numbers. This product is updated annually from publicly available information. This product is publicly available for purchase.

The NDTIS dataset is de-identified and does not include participant identifying information such as name, address or date of birth. Currently the only geographical information stored in the dataset is postcode. This is insufficient to accurately allocate ABS geographical categories. Completion of the proposed work requires that the residential addresses be geocoded and then allocated to ABS categories. To maintain confidentiality of NDTIS participants within our dataset, these addresses will only be coded to Statistical Area Level 2 (SA-2), LGAs (http://www.abs.gov.au/websitedbs/D3310114.nsf/home/Australian+Statistical+Geography+Standard+(ASGS) and above.

There is not currently the expertise in ARCPOH to geo-code addresses. Thus, the process of geo-coding requires sending the addresses to an external organisation, who will return the ABS geographic categories to the ARCPOH data custodian. The data custodian will provide the dataset with ABS geographic categories to the student for the data analysis. The external organisation will be required to sign a confidentiality agreement protecting it from using the shared address for any other purposes.
Our concern is to ensure that we maintain appropriate ethical safeguards in providing these (publicly available) addresses to an external party.

Before proceeding with this process, we are writing to seek your advice about whether any form ethics review is required, and if so, what level of review is appropriate and the corresponding time-frame.

Kind regards,
Ankur Singh

....
Ankur Singh BDS, MSc Dental Public Health
PhD Candidate
Australian Research Centre for Population Oral Health (ARCPOH)
The University of Adelaide (CRICOS Provider Number 00123M)
Location: Ground Floor, 122 Frome Street (Cnr Pirie Street)
Adelaide SA 5000, Australia
Tel: +61 8 8313 2549 Fax: +61 8 8313 3070
Email: ankur.singh@adelaide.edu.au
Webpage: http://www.adelaide.edu.au/directory/ankur.singh

Appendix 3.1. Communication from Community Dentistry and Oral Epidemiology

Ankur Kumar Singh

From:	onbehalfof+n.brown+otago.ac.nz@manuscriptcentral.com on behalf of Community Dentistry and Oral Epidemiology <onbehalfof+n.brown+otago.ac.nz@manuscriptcentral.com>
Sent:	Monday, 29 May 2017 4:13 PM
To:	Ankur Kumar Singh; Jane Harford; Marco Peres
Subject:	Community Dentistry and Oral Epidemiology - Manuscript ID CDOE-17-219

29-May-2017

Dear Author of "Investigating population oral health and its societal determinants: The value of ecological approaches",

The manuscript entitled "Investigating population oral health and its societal determinants: The value of ecological approaches" has been submitted by Mr Ankur Singh to Community Dentistry and Oral Epidemiology and is presently being given full consideration for publication.

You have been listed as author for the manuscript. IF THIS IS NOT THE CASE, please reply to this email.

Sincerely,

Miss Natalie Brown
Community Dentistry and Oral Epidemiology Editorial Office n.brown@otago.ac.nz

Appendix 3.2. Communication from Community Dentistry and Oral Epidemiology

Ankur Kumar Singh

From:	onbehalfof+n.brown+otago.ac.nz@manuscriptcentral.com on behalf of Community Dentistry and Oral Epidemiology <onbehalfof+n.brown+otago.ac.nz@manuscriptcentral.com>
Sent:	Monday, 29 May 2017 4:07 PM
To:	Ankur Kumar Singh; Jane Harford; Marco Peres
Subject:	Community Dentistry and Oral Epidemiology - Manuscript ID CDOE-17-218

29-May-2017

Dear Author of "Methodological aspects related to ecological and multilevel studies of societal determinants of oral health",

The manuscript entitled "Methodological aspects related to ecological and multilevel studies of societal determinants of oral health" has been submitted by Mr Ankur Singh to Community Dentistry and Oral Epidemiology and is presently being given full consideration for publication.

You have been listed as author for the manuscript. IF THIS IS NOT THE CASE, please reply to this email.

Sincerely,

Miss Natalie Brown
Community Dentistry and Oral Epidemiology Editorial Office n.brown@otago.ac.nz

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Appendix 3.3. Communication from PLOS One

Ankur Kumar Singh

From:	em.pone.0.5452c4.f9ebd14f@editorialmanager.com on behalf of PLOS ONE <em@editorialmanager.com>
Sent:	Wednesday, 5 July 2017 2:32 PM
To:	Ankur Kumar Singh
Subject:	Submission Confirmation for PONE-D-17-25280 - [EMID:a11abbc0645b5325]

PONE-D-17-25280
Area-level income inequality and oral health among Australian adults - A population-based multilevel study PLOS ONE

Dear Dr Singh,

Thank you for submitting your manuscript entitled 'Area-level income inequality and oral health among Australian adults - A population-based multilevel study' to PLOS ONE. Your assigned manuscript number is PONE-D-17-25280.

We will now begin processing your manuscript and may contact you if we require any further information. You will receive an update once your manuscript passes our in-house technical check; you can also check the status of your manuscript by logging into your account at http://pone.edmgr.com/. If you have any inquiries or other comments regarding this manuscript please contact plosone@plos.org.

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I have not seen publicly posted peer reviews before.
http://surveys.plos.org/s3/pONEAuReadPosted?answer=NeverSeen

Thank you for your support of PLOS ONE.

Kind regards,
PLOS ONE

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Appendix 4.1. Source of Gini Coefficients

Gini coefficients for LGAs were obtained from the 2011 estimates of Gini Coefficients published for public use by Fleming, David; Measham, Tom (2015): Income Inequality (Gini Coefficients) for Australian regions. v1. CSIRO. Data Collection. http://doi.org/10.4225/08/55093772960E4

The data is publicly available for use at the following webpage: https://data.csiro.au/dap/landingpage?pid=csiro%3A12312

Appendix 5.1. ICC and MOR values for oral health outcomes

Values of ICC and MOR for the two oral health outcomes at different levels of geographic aggregation within the NDTIS 2013 data obtained from null models

	ICC – Inadequate dentition (%)	MOR – Inadequate dentition	ICC- Poor Self-rated oral health (%)	MOR – Poor Self-rated oral health
Local Government Area (LGAs)	4.45	1.45	1.60	1.25
Postcodes	5.57	1.52	4.28	1.44
Statistical Local Areas (SLAs) (2006)	3.88	1.42	3.68	1.40
SA 1	15.4	2.09	1.63	1.25
SA 2	5.17	1.50	2.62	1.33
SA 3	4.18	1.44	2.43	1.31
SA 4	3.64	1.40	2.53	1.32

Note: Only geocoded data 4,071 dentates for inadequate dentition and 4,436 for poor self-rated oral health from NDTIS 2013 used for this exercise