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Individual- and Area-level Factors of Access to Oral Healthcare Among Middle-Aged and Older adults in Ontario

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Abstract

Canada's aging population faces growing oral health challenges, with access to oral healthcare remaining uneven across individuals and regions. This thesis examines how both individual- and area-level oral healthcare care access factors shape oral health outcomes among middle-aged and older adults in Ontario. First, a geospatial analysis assessed dentist distribution across Forward Sortation Areas using spatial mapping and inequality measures, exploring inequalities by area-level income and geographic remoteness. Then, a cross-sectional multilevel analysis using data from the Canadian Longitudinal Study on Aging (2018-2021) evaluated the association between access to oral healthcare and three oral health outcomes: self-reported oral health, functional dentition, and frequency of dental visits. The geospatial analysis revealed the presence of inequalities in dentist distribution in Ontario, especially when stratified by area-level income and remoteness. The multilevel analysis showed the strong and consistent association of individual-level access to oral healthcare factors across all oral health outcomes in aging Ontarians. Further research should focus on incorporating other area-level access measures in both geospatial and multilevel studies.

Keywords

Access to oral healthcare, dentist-to-population ratio, inequalities, aging, socioeconomic factors, oral health, CLSA

Summary for Lay Audience

Oral health, encompassing healthy teeth and gums, is a vital component of overall well-being, particularly as people age. In Canada, older adults face growing oral health challenges, yet access to oral healthcare remains uneven. Poor oral health can lead to tooth loss, pain, and difficulties with eating and speaking, and is also linked to broader health issues such as poor nutrition, social isolation, and chronic diseases like diabetes and heart disease. This thesis explores how both individual-level factors of access to oral healthcare such as income, dental insurance, and education and area-level factors such as dentist availability, neighborhood income, and remoteness contribute to oral health outcomes among middle-aged and older Ontarians.

To begin, I conducted a geospatial analysis to examine the distribution of dentists across Ontario's Forward Sortation Areas (FSAs). The maps provided a broad overview, showing that Dentist-to-Population Ratios (DPRs) were generally higher in wealthier and urban FSAs. However, to better understand inequality within these groups, I applied the Lorenz Curve and Gini Coefficient. These measures revealed that dentist distribution was more unequal within lower-income quintiles and urban areas, indicating their influence on dentist distribution.

In the second part of the study, I used cross-sectional data from a national cohort to examine how individual and area-level factors relate to three oral health outcomes: self-reported oral health, functional dentition (having at least 20 natural teeth), and last dental visit. Individual-level factors such as lower income and lack of dental insurance were consistently linked to poorer outcomes, showing a clear social gradient. Having private dental insurance was especially protective, highlighting its role in enabling oral healthcare. Additionally, women generally had better oral health outcomes than men, and while older adults were more likely to have lost teeth, they tended to report better self-rated oral health, possibly reflecting adaptation over time. Additionally, there was no significant association observed between area-level access factors such as DPR, FSA-level income and geographic remoteness and oral health outcomes. These findings emphasize the strong influence of personal resources and social factors on oral health among aging Canadians.

Co-authorship Statement

This thesis includes two integrated articles, which will be submitted for publication in peer-reviewed journals. The co-author details for each article are presented below.

Chapter 2: Nair A., Wilk P., Gomaa N. Geographic and Socioeconomic Inequalities in Dentist Distribution in Ontario

Anusha P Nair was involved in the conception and design of the study, data acquisition and curation, coding and statistical analysis of data, and writing the first and subsequent drafts of the paper. Dr. Noha Gomaa acquired funding and was involved in the conception and design of the study, data acquisition, interpretation of data and critical revision of the article. Dr Piotr Wilk was involved in conception and design of the study, provided guidance on analysis, interpretation of data and critical revision of the article.

Chapter 3: Nair A., Wilk P., Gomaa N. Individual and Area-level Access to Oral Healthcare and Oral Health Outcomes Among Middle-aged and Older Adults in Ontario: A Data Linkage Analysis of the Canadian Longitudinal Study on Aging (CLSA)

Anusha P Nair was involved in the conception and design of the study, data acquisition and curation, coding and statistical analysis of data, and writing the first and subsequent drafts of the paper. Dr. Noha Gomaa acquired funding and was involved in the conception and design of the study, data acquisition, interpretation of data and critical revision of the article. Dr Piotr Wilk was involved in conception and design of the study, provided guidance on statistical concepts, interpretation of data and critical revision of the article.

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List of Abbreviations

CCHS	Canadian Community Health Survey
CDCP	Canadian Dental Care Plan
CHMS	Canadian Health Measures Survey
CI	Confidence Interval
CLSA	Canadian Longitudinal Study on Aging
CMA	Census Metropolitan Area
COHS	Community Oral Health Survey
CSD	Census Subdivision
DPR	Dentist-to-Population Ratio
FCS	Fully Conditional Specification
FD	Functional Dentition
FSA	Forward Sortation Area
HDI	Human Development Index
HPSA	Health Professional Shortage Area
ICC	Intraclass Correlation Coefficient
LDV	Last Dental Visit
MAR	Missing at Random
MAUP	Modifiable Areal Unit Problem
MICE	Multiple Imputation by Chained Equations

MOR	Median Odds Ratio
NIHB	Non-Insured Health Benefits
ODSCP	Ontario Seniors Dental Care Program
ODSP	Ontario Disability Support Program
OECD	Organization for Economic Co-operation and Development
OHRQOL	Oral Health-Related Quality of Life
OR	Odds Ratio
OW	Ontario Works
RCDSO	Royal College of Dental Surgeons of Ontario
SROH	Self-Reported Oral Health
WHO	World Health Organization

Chapter 1

1 Introduction

1.1 Overview of Oral Health in Canada

1.1.1 Introduction to Oral Health and Aging

According to the World Health Organization (WHO), the year 2020 marked a milestone where the global population aged 60 years and older exceeded that of children, and this proportion is projected to nearly double by 2050. [1] Canada is undergoing a similar demographic transition.[2,3] In 2019, older adults in Canada constituted around 6.6 million individuals, making up 17.5% of the national population. This number is projected to rise to approximately 10.7 million by 2040, comprising nearly 25% of the total population.[3] While this growth in the older adult population is multifactorial, it has been partially attributed to improvements in public health and healthcare such as access to medical services and enhanced quality of care, which are determinants of increased life expectancy.[4]

However, aging brings with it a range of health challenges, including a higher prevalence of chronic diseases with oral health being no exception.[4,5] Oral diseases remain highly prevalent and affect billions of people globally, despite being largely preventable.[6] Among older adults, age-related physiological changes in tooth structure are common.[4] While improved oral healthcare and preventive strategies have enabled many seniors to retain their natural teeth, oral health problems continue to be one of the most commonly reported health concerns in those over 60 years of age. [2,5,7] Common oral diseases, such as periodontal disease and dental caries, are major contributors to poor oral health.[5,7] In turn, poor oral health can impair chewing and speaking functions, leading to nutritional deficiencies, reduced self-esteem, limited social participation, cognitive decline, exacerbation of systemic conditions, and a diminished overall quality of life.[5,8–10]

Maintaining at least 20 natural teeth is considered essential for adequate oral function.[11] Findings from the Canadian Health Measures Survey (CHMS) indicated that 6.4% of adults aged 20 to 79 were edentulous (loss of all natural teeth), with the highest prevalence observed among those aged 60 to 79. [12] Additionally, 26% of edentulous adults reported avoiding certain foods due to oral health problems, and among edentulous older adults in the 60 to 79 age group,

23% avoided specific foods for the same reason.[7,12] A more recent report from the Canadian Oral Health Survey (COHS) estimated that approximately 11% of individuals aged 60 and above had lost all of their natural teeth.[13] In Nova Scotia, about 18% of middle-aged and older adults were edentulous, including 8% in community settings and 41% in long-term care.[2] Findings from three Canadian Community Health Survey (CCHS) cycles showed that poor self-reported oral health increased with age.[14] According to analyses of 2022 CCHS data, more than one in three Canadians had not visited a dental professional within the previous year.[15] In Ontario, just 67.2% of individuals aged 12 and older reported a dental visit during the same period.[15] Among seniors in Canada, this proportion was even lower, with only around 60% reporting a dental visit in the last 12 months.[15]

1.1.2 Inequalities in Oral Health Outcomes Among Canadian Middle-aged and Older adults

While aging inherently increases vulnerability to oral health problems, these issues are not uniformly experienced across geographic regions or population groups. Oral health outcomes are dependent on factors such as income, education, occupation, sex, race, immigrant status and place of residence. In Canada, middle-aged and older adults with lower income, males, and individuals without post-secondary education were more likely to report fair or poor oral health.[16] Additionally, a study found that older and female immigrants were increasingly likely to report poor oral health over time, indicating a decline in oral health the longer they resided in Canada compared to native-born individuals.[17] In Ontario, individuals in the lowest income group, as well as established immigrants and those of Chinese origin, have consistently reported higher odds of poor oral health over the past decade than higher-income individuals, native-born residents, and White and Black subpopulations.[14,18]

Inequalities in oral health outcomes have also been observed across international, provincial, and local levels. At the international level, comparative research has shown that Canada exhibits the highest inequality in edentulism relative to the United States and the United Kingdom, signaling a substantial inequality affecting lower-income individuals.[19] Within Canada, studies have reported that conditions such as toothache, tooth sensitivity, and jaw pain vary across metropolitan areas particularly in Ontario and British Columbia, and tend to be

more prevalent in cities with greater income inequality, as indicated by higher Gini coefficients.[20] Evidence from provincial studies highlights the impact of rural residence on oral health among middle-aged and older adults in Canada. In Nova Scotia, in spite of having better oral health, community-dwelling middle-aged adults reported more oral health impacts than seniors, while dental visits were lower specifically among community-dwelling rural seniors compared to their urban counterparts.[2] Similarly, in Quebec, middle-aged adults living in rural areas experienced significantly poorer oral health-related quality of life (OHRQoL) and were more affected by negative oral health outcomes than those in urban settings.[21] Additionally, older adults in metropolitan Ontario have been reported to receive more dental services than those in non-metropolitan areas, pointing to the disproportionate distribution of oral health services.[22]

Oral health inequalities among middle-aged and older adults arise from a combination of individual-level factors, such as income, education, and demographics, and area-level factors, including the availability of dental services, urban–rural context, and regional socioeconomic conditions. Recognizing the joint influence of individual characteristics and area-level context provides a foundation for examining how both individual- and area-level factors of access to oral healthcare shape oral health outcomes.

1.2 Access to Oral Healthcare

Access to healthcare is widely recognized as being multidimensional, with varying definitions and dimensions used across the literature.[23,24] Some authors conceptualize access as being determined by the attributes of individuals (e.g., income and insurance) and the healthcare system (e.g., provider availability and infrastructure) while others by looking at outcomes such as frequency of service use and satisfaction.[23,24] Another perspective considers access as an interaction between supply and demand factors.[24] A study by Tzenios argued that the determinants of access to healthcare to be individual, structural, and systemic factors, and highlighted the importance of addressing all three to ensure access. It further noted that when all three factors improve, so does the access to healthcare.[25] Another study highlighted the importance of spatial and aspatial dimensions of healthcare access.[26] Research has shown that unequal access to dental services leads to higher risk for oral diseases.[27,28] Several conceptual frameworks have been introduced to better capture the complexity of access to care. The commonly cited model of healthcare utilization is the Andersen's behavioral model.[29] The Andersen's behavioral model of oral healthcare utilization (Figure 1) conceptualized access as

a combination of predisposing, enabling and need factors that includes individual-level factors (e.g., income, education, insurance) and area-level factors (e.g., service availability, geographic location), reflecting both personal and structural determinants of oral healthcare access or utilization.[30–33]

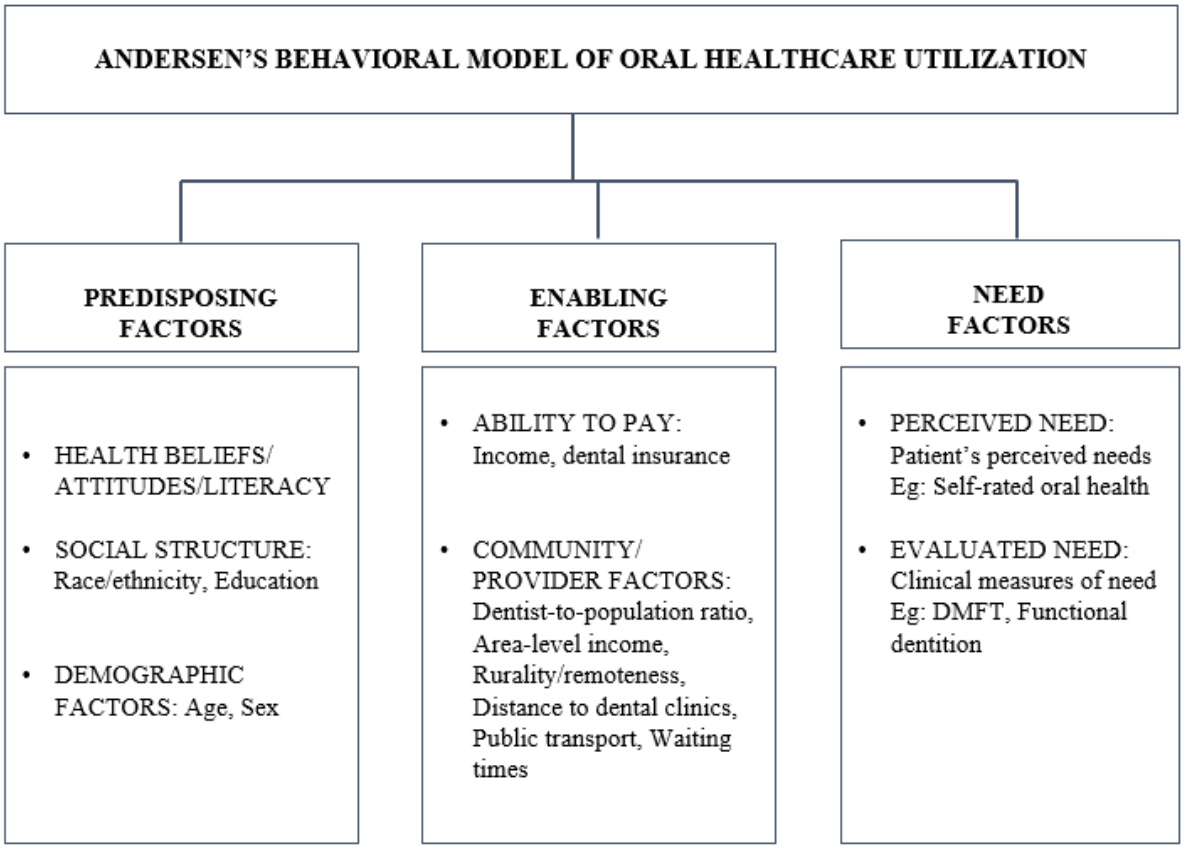

Figure 1: Andersen's Behavioral Model of Oral Healthcare Utilization. Adapted from: Siluvai S, Venkatesan R. Development of a Questionnaire for Dental Utilization Based on the Andersen Model. Published online 2024. doi:10.7759/cureus.671

1.2.1 Determinants of Access to Oral Healthcare: Individual-level Factors

Access to oral healthcare is influenced by individual-level factors that include demographic and socioeconomic characteristics such as age, sex, education, occupation, employment status, income, and dental insurance status, as well as health-related factors like disability, chronic diseases, health awareness, and oral health literacy. These factors influence an individual's ability to perceive the need for care, afford and obtain services.[25]

Among these factors, dental insurance coverage plays a crucial role. While dental insurance coverage is strongly linked to the use of dental services, an individual's income and employment type have historically played a critical role in determining access to such coverage.[34–36] In Canada, prior to the implementation of the Canadian Dental Care Plan (CDCP), the cost of oral healthcare was primarily covered through employment-related benefits, private plans, or out-of-pocket payments.[36] However, for many older adults particularly those who were retired, maintaining dental insurance coverage has been challenging.[36]

According to CCHS 2022, 58.2% of seniors aged 65 and older lacked dental insurance.[28] Additionally, analyses of data from the Canadian Longitudinal Study on Aging (CLSA) indicated that approximately 42% of middle-aged and older Canadians did not have dental insurance.[37] Research has shown that among this population group, the likelihood of having dental insurance decrease with age and lower household income, and that coverage is more common among men. [28,34,37] Nationally, 83% of insured seniors visited a dental professional in the past year with lower rates among those without dental insurance.[28] Cost remains a widely reported barrier to access to oral healthcare among middle-aged and older adults in Canada, particularly in Ontario, where dental insurance coverage for older adults is notably lower than in provinces such as Alberta and British Columbia.[28,34,37]

Education and health literacy are other important determinants of oral healthcare access. Individuals with higher education levels have been consistently shown to have better oral health literacy, make informed health decisions, to be more likely to value preventive oral healthcare, and to be better equipped to navigate the healthcare system.[2,25,38] Disability and chronic health conditions can also pose significant barriers to accessing oral healthcare. In Ontario, the most commonly reported disabilities are related to mobility, pain, and agility.[39] Age-related conditions such as dementia, incontinence, and dyskinesia further contribute to logistical challenges, including difficulties with transportation in terms of availability and cost, and the need for specialized accommodations within oral healthcare settings.[2,40,41] Lastly, health beliefs and awareness play a critical role in shaping oral healthcare access. Individuals who view oral healthcare as necessary only in response to pain, functional limitation or appearance are more likely to delay or forgo preventive visits.[34] Among older adults, there is a common perception that oral health naturally declines with age, mirroring general health deterioration.[40,42] This belief may reduce motivation to seek regular oral healthcare.

1.2.2 Determinants of Access to Oral Healthcare: Area-level Factors

Area-level factors of oral healthcare access include but are not limited to availability or density of dental professionals and their distribution, proximity to dental clinics, rurality or remoteness, neighborhood-level socioeconomic status and availability of public transit.[21,31,43–45] These factors influence whether individuals are able to receive oral healthcare when they need it; they are often interconnected and mutually reinforcing.

A key area-level determinant of access to oral healthcare is the geographic density and distribution of dentists. In 2020, WHO reported a dentist-to-population ratio of 6.53 (per 10,000) in Canada.[46] Statistics Canada further noted that this ratio is higher in densely populated urban areas, particularly in southern Ontario, British Columbia, and coastal regions.[47] Far fewer regions have more than 60 dentists per 100,000 population compared to the number of regions exceeding the same threshold for dental hygienists.[47] Dental professionals are disproportionately concentrated in urban areas compared to rural and remote communities.[48] For example, in Toronto, high-income neighborhoods have a significantly greater dentist density than lower-income areas.[43] In Quebec, cities such as Montreal, Quebec City, and Sherbrooke exhibit substantially higher availability of dental professionals than less urbanized and populated regions.[49] In Saskatchewan, dental services cluster in urban centers and along major commercial corridors.[50] In Ontario, dentists are more commonly located in larger urban areas, particularly within Census Metropolitan Areas (CMAs) in the south-central part of the province, whereas northern district experience notably lower provider availability.[51] Area-level income and remoteness as factors of access to oral healthcare are especially relevant for the growing older population in rural Canada. Between 2016 and 2021, the proportion of residents aged 65 and older increased by 3.1% in rural areas, compared to 1.9% in urban centres.[52] Seniors account for 24% of the rural population in Ontario, and many live on fixed or low incomes.[53] From a provider's perspective, these area-level disadvantages affect where dental professionals choose to practice. Dentists are more likely to establish clinics in higher-income, urban areas because residents have greater ability to pay.[43,51,54,55] In Canada, this could be due to residents being more likely to afford care either through private dental insurance linked to stable employment or out-of-pocket.[56] Additionally, limited public transportation, financial instability of rural practices, and infrastructural gaps further compound these challenges. [54,55] As a result, it becomes difficult to attract and retain dental professionals in such

regions, contributing to ongoing shortages and reinforcing geographic and socioeconomic inequalities in access to oral healthcare.

The maldistribution of dentists and other healthcare resources has often been quantified using measures such as the Lorenz curve and the Gini coefficient. Although initially developed to measure income inequality, they have been widely adapted to assess inequalities in the distribution of healthcare providers, including physicians and dentists.[57–61] A Gini value closer to 0 indicates a more equitable distribution of providers across geographic areas, whereas values approaching 1 reflect concentration in specific regions and shortages elsewhere. [57–61]

1.2.3 Oral Health Policy by the Federal and Provincial Government for Middle-aged and Older Canadians

Canada is often cited as an example of the inverse care law in the context of oral healthcare, wherein those with the greatest need for services experience the least access.[40,62,63] While literature consistently shows that both individual and area-level factors influence access to oral healthcare, a major systemic barrier remains: the lack of universal dental insurance. Canada has historically maintained a medical-dental divide, where dental services are excluded from universal healthcare coverage.[64,65]

The federal government once considered including oral healthcare under Medicare prior to World War II, but later this was dropped in favor of prioritizing physician and hospital services.[66] One justification at the time was the decline in dental caries following the introduction of community water fluoridation in the 1950s, which gave the false impression that professional oral healthcare was less essential, overlooking other significant oral health issues beyond cavities.[66] By 1964, the Royal Commission on Health Services recommended that public oral healthcare be limited to select groups such as children, pregnant women, and those receiving welfare emphasizing that oral healthcare for the broader population should remain a personal responsibility.[62,66] Consequently, dental coverage in Canada evolved into a system reliant on employer-based insurance and out-of-pocket payments.[66,67] The public spending on oral healthcare also reduced over the years.[66] Only about 5-6% of national dental spending is publicly funded, among the lowest in the Organization for Economic Co-operation and Development (OECD); with Ontario allocating just 1.5% to public dental spending. [62,64,66,68]

Healthcare delivery are primarily provincial responsibilities, and as such, public dental programs in Canada varies across provinces. [64,67,69] In Ontario, early efforts focused mainly on children and individuals receiving social assistance or disability support, while adults particularly low-income, elderly, ethnic and immigrant populations were largely left out.[64] Programs like the Ontario Disability Support Program (ODSP) and Ontario Works (OW) offered some coverage for adults, but the services were limited.[70,71] ODSP provided a broader range of benefits, while OW offered emergency-only services that were discretionary, budget-dependent, and inconsistent across municipalities.[70,71] The Ontario Seniors Dental Care Program (OSDCP) was introduced to offer government-funded oral healthcare to low-income seniors, but the program had notable limitations.[64] Service availability was unclear, and early users reported long wait times which led some people to pay out-of-pocket for faster care. Participation from dental providers was voluntary, and not all dentists accepted patients under the program.[64] Additionally, the criteria for income eligibility were ambiguous and appeared to be set at a level that was too low, particularly in high-cost urban areas, excluding seniors who were financially vulnerable.[64]

In December 2023, the Canadian Dental Care Plan (CDCP) was launched by the federal government, marking a significant policy milestone.[72] The program was introduced to provide dental coverage for uninsured Canadians with an adjusted family net income below $90,000, with no co-payments required for those earning under $70,000.[68,72] The rollout followed a phased approach, beginning with seniors aged 70 and older, followed by those aged 65–69, adults with disabilities, and eventually expanding to all eligible adults.[68,72] Additionally, a federal commitment of $250 million for three years was made through the Oral Health Access Fund to support efforts aimed at mitigating oral health inequities and expanding access for underserved populations.[68]

1.3 Study Rationale

Oral health access is determined by a combination of individual-level and area-level factors. Even if an individual has the resources and motivation to seek dental services, barriers at the area-level can still prevent timely and appropriate care. Focusing on the aging population is crucial, as older adults face unique oral health challenges that are linked to broader health issues that can affect nutrition, pain, and quality of life. While several previous studies have explored

the individual and area-level factors of access to oral healthcare at various geographical levels, there is a notable lack of recent studies that analyze oral healthcare access in Ontario. By evaluating both individual and area-level factors of oral healthcare access and their association with oral health outcomes among middle aged and older adults, this study fills an important gap in the literature. The findings will provide insights for policymakers to improve access to oral healthcare and potentially reduce oral health inequalities for Ontario's aging population.

1.3.1 Overall Goal and Specific Objectives

In this thesis, Forward Sortation Areas (FSAs) in Ontario were selected as the primary geographic unit of analysis. FSAs represent the first three characters of Canadian postal codes (e.g., K1A) and are defined by Canada Post to facilitate mail delivery. The first character denotes the province or territory, the second differentiates between urban and rural areas, and the third identifies a smaller geographic segment within the FSA. Given that FSAs capture meaningful geographic variation in service availability, they are widely used in health services research to examine area-level differences in access to care. [43,73,74]

The overall goal of this thesis is to explore the role of individual- and area-level factors of access to oral healthcare in the oral health outcomes of middle-aged and older Ontarians.

The specific objectives are:

1. To assess the geographic distribution of dentists in Ontario across Forward Sortation Areas (FSAs).
2. To evaluate geographic variation of oral health outcomes across FSAs.
3. To evaluate the extent of the association between individual-level factors of access to oral healthcare and oral health outcomes in middle-aged and older adults in Ontario.
4. To evaluate the extent of the association between area-level factors of access to oral healthcare and oral health outcomes in middle-aged and older adults in Ontario.

Chapter 2

2. Geographic and Socioeconomic Inequalities in Dentist Distribution in Ontario

2.1 Abstract

Background: Oral health is a vital component of overall health, yet access to oral healthcare remains uneven across Ontario, shaped by socioeconomic and geographic inequalities. Despite the growing importance of dentist-to-population ratios in understanding service distribution, evidence shows persistent inequalities, with urban and high-income areas better served than rural and low-income regions. To date, few studies have examined dentist distribution across Ontario at a fine geographic scale like Forward Sortation Area (FSA), leaving critical gaps in identifying underserved areas. ***Aim:*** To assess the geographic distribution of dentists in Ontario across FSAs and to further assess whether there are inequalities in this distribution by FSA-level income and geographic remoteness. ***Methods:*** Data on dental practice locations in each FSA were obtained from the Royal College of Dental Surgeons of Ontario (RCDSO) registry. Dentist-to-population ratios (DPR) were calculated by dividing the number of dentists per FSA by the 2021 Census population. FSA-level median household income data were also sourced from the 2021 Census. Choropleth maps were created in ArcGIS Pro to visualize the geographic distribution of dentists and compared with income and remoteness maps. Inequalities in dentist distribution were further quantified using Lorenz Curves and Gini coefficients, with analyses stratified by FSA-level income and geographic remoteness. ***Results:*** The RCDSO dataset included 10,543 registered dentists, of which 10,295 were successfully matched to 516 Ontario FSAs based on 2021 Census data. Twenty-six FSAs had no registered dentists, and the number of dentists per FSA ranged from 0 to 155 (mean 19.9; median 15.0), indicating a skewed distribution with concentration in a few FSAs. FSA populations ranged from 490 to 115,850 (mean 27,565; median 23,519), contributing to wide variation in DPR, which spanned from 0 to 248.1 (mean 8.4; median 5.9). Mapping revealed clear geographic patterns: high DPRs clustered in Metropolitan Toronto, which also coincided with higher-income FSAs, while rural and lower-income areas, particularly in Northern Ontario, had lower DPRs. Urban FSAs generally exhibited higher DPRs than rural FSAs. Lorenz Curve analysis indicated noticeable overall inequality in dentist distribution (Gini coefficient 0.25). Inequalities were more pronounced in lower-income FSAs (Gini 0.36) compared to higher-income FSAs (Gini 0.17)

and were greater in urban FSAs (Gini 0.23) than rural FSAs (Gini 0.14), highlighting the influence of socioeconomic and geographic context on oral healthcare access. ***Conclusion:*** Inequalities in dentist distribution across Ontario FSAs were evident, with FSA-level income and geographic remoteness being associated with access. Policy interventions should account for these inequalities to improve allocation of dental services in underserved areas.

2.2 Introduction

Oral health is widely recognized as a key element of general health.[75,76] However, access to oral healthcare remains inconsistent across Ontario, the most populous Canadian province characterized by considerable geographic, socioeconomic, and cultural diversity.[56,77,78] Generally, the factors influencing access to oral healthcare are complex and multifaceted. A number of theoretical frameworks have been developed to better understand these dynamics. Among the most widely cited is the Andersen Behavioral Model of Healthcare Utilization, which organizes determinants of healthcare use into three primary categories: predisposing factors, enabling factors and need factors.[79] Over time, this model has been refined to incorporate both individual and contextual influences, acknowledging the interplay between personal circumstances and broader community or policy environments.[29,80,81] Complementing Andersen's approach, the Penchansky and Thomas model conceptualizes access through five measurable dimensions: availability, accessibility, affordability, acceptability and accommodation collectively known as the '5 A's.' This framework provides a nuanced understanding of the specific barriers individuals may face when seeking oral healthcare at both individual and contextual levels.[26] The Levesque model further expands on these ideas by framing access as a dynamic interaction between health-system factors (such as the organization and delivery of services) and demand-side factors (such as individuals' abilities to identify, access, and utilize available services) highlighting that barriers may stem from either side.[82]

Together, these frameworks highlight that access to healthcare is shaped by a combination of contextual and individual-level factors, each playing a vital role in determining whether individuals are able to obtain the care they need. In the context of oral healthcare, the presence of a sufficient number of oral healthcare providers in a given area consistently emerges as a significant determinant of access across all models.[24,32,43,83] However, the mere availability of dentists does not guarantee adequate access. It is also crucial to consider whether the number of dentists is appropriate relative to the population, and how well these providers are distributed geographically.[84]

The dentist-to-population ratio (DPR) is commonly used as an indicator for assessing the geographic density and distribution of dentists.[43,61,85] By quantifying the ratio of dentists to

residents in a specific area, DPR provides a useful metric for evaluating the sufficiency of oral healthcare provision relative to population size.

Income-based and urban–rural inequalities in the distribution of dentists are well-documented both globally and within Canada.[43,51,61,76] A scoping review identified a range of determinants influencing where dentists choose to practice, including economic, organizational, professional, personal, and cultural factors. For instance, dentists are more commonly found practicing in regions characterized by higher socioeconomic status, greater economic opportunities, and better professional support, while rural and lower-income regions often face persistent shortages due to factors such as limited infrastructure, fewer career advancement opportunities, and reduced quality of life.[55] Another recent review assessing geographic inequalities in dentist distribution found notable income-based and urban–rural inequalities. These inequalities were largely attributed to factors such as unfavorable working conditions, inadequate facilities, and a lack of financial incentives for dentists to practice in underserved areas.[54] Several studies also measured inequality in distribution of healthcare personnels including dentists using Lorenz curve and Gini coefficient.[57–61] In the Canadian context, these inequalities are equally pronounced. A study based on 2021 census data show that the number of dentists in urbanized communities is nearly twice that in rural or remote areas, and within cities like Toronto, dentist density is significantly higher in high-income neighborhoods compared to low-income areas.[43,48] In Quebec, statistically significant inequalities were noted between urban and rural areas in the distribution of the dental workforce, with urban centers such as Montreal, Sherbrooke and Quebec City exhibiting higher concentrations of dental professionals.[49]

Analyzing DPR is essential for identifying regions with potential shortages or surpluses of dental professionals. Furthermore, mapping the spatial distribution of DPR across geographic areas is critical, as evidence from previous Canadian studies indicates that there is often an oversupply of dental professionals in urban centers and a relative scarcity in rural or underserved communities. [43,48,49,51]

While several studies have examined healthcare resource distribution and related inequalities at the Forward Sortation Area (FSA) level in Canada, there remains a gap in province-wide,

FSA-level analyses specifically focused on the distribution of dentists in Ontario. Previous research has often either combined dentists with other health professionals or limited analyses to specific regions, rather than providing a comprehensive, dentist-specific overview across the entire province.[43,49,50,86] Notably, a study assessing the spatial distribution of dentists across Ontario's census subdivisions (CSDs) was based on data from 2012, and, to date, only one study has examined the distribution of dental hygienists across the entire province at the FSA level.[51,73] This study addresses these gaps by mapping and quantifying FSA-level inequalities in the distribution of dentists across Ontario using recent data. By combining spatial mapping with measures of socioeconomic and geographic inequality, this research not only identifies underserved areas but also explores their connections to broader social and geographic patterns. This dual approach provides insights for targeted workforce planning, resource allocation, and policy interventions to support ongoing efforts toward oral health equity in Ontario.

2.3 Overall Aim

This study aims to assess the geographic distribution of dentists in Ontario across FSAs and to further assess whether there are inequalities in this distribution by FSA-level income and geographic remoteness.

2.4 Methods

2.4.1 Study Setting and Geographic Unit of Analysis

FSA was selected as the geographic unit for this study. It comprises the first three characters of Canadian postal codes used by Canada Post for mail delivery. While FSAs are not originally designed for administrative or health planning purposes, they serve as a practical unit for this study as the dentist location data from the RCDSO uses only FSAs as geographic identifiers and using FSAs also provides the ability to link these data with census data.

Each FSA is defined by the first three characters of postal codes (e.g., K1A). The first character indicates the province or territory, the second distinguishes between urban and rural areas, and the third specifies a more localized region within the FSA. This study focused on FSAs located in Ontario. Figure 2 represents specific regions in Ontario according to the FSAs. [87]

As of the 2021 Census, there were 521 FSAs in Ontario. FSA-level boundaries used for mapping were obtained from the most recent publicly available shapefiles provided by Statistics Canada. FSAs have been used in several previous studies analyzing the geographic distribution of healthcare resources. [43,73,74] According to Canada Post data from February 2025, there were 532 FSAs in Ontario. However, the 2021 Census provided population data for 521 FSAs and one FSA lacked a corresponding boundary shapefile. In addition, five FSAs (L4V, M7A, L5T, L5S, P0Y) had missing income data with populations under 100. These five FSAs were excluded from the analysis, resulting in a final dataset comprising 516 FSAs with complete population and boundary information.

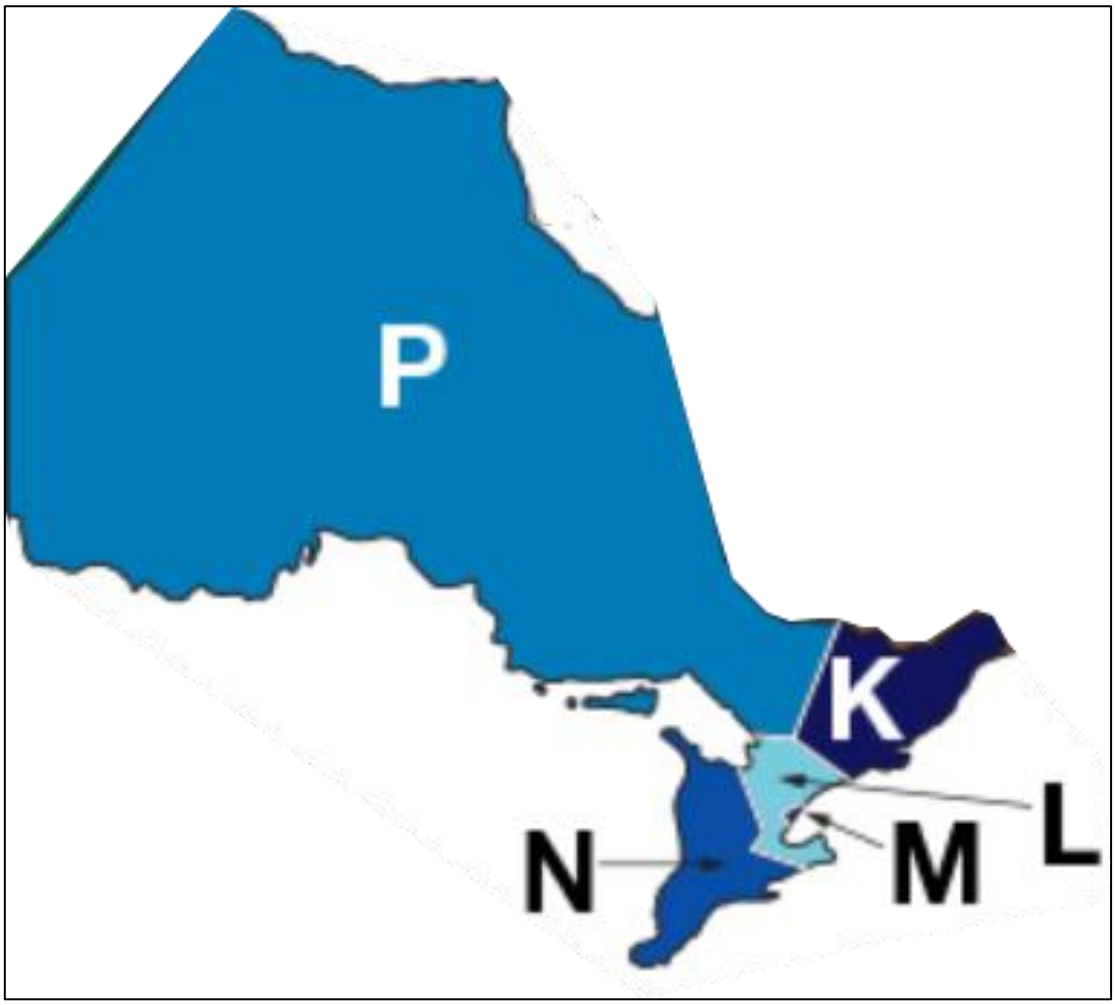

Figure 2: Ontario FSAs: Eastern Ontario (K), Central Ontario (L), Metropolitan Toronto (M), Southwestern Ontario (N), and Northern Ontario (P) Source: Government of Canada

2.4.2 Data sources

2.4.2.1 Dentist-to-Population Ratio (DPR)

Data on FSA codes of dental practice locations in Ontario for the year 2022 were obtained through a formal request to the Royal College of Dental Surgeons of Ontario (RCDSO) registry for research purposes. These data are self-reported by dentists, who are required to update their practice addresses within one month of any change, and the RCDSO maintains this information as part of its public registry.[88] Data from 2022 were used as they align closely with the 2021 Census of population timeframe. Dentists practicing at multiple locations were counted in each FSA where they provided services. In addition to FSA identifiers, the dataset included information on whether dentists accepted patients covered by government dental benefit programs such as the Ontario Disability Support Program (ODSP), Ontario Works, the Ontario Seniors Dental Care Program (OSDCP) and Non-Insured Health Benefits (NIHB).

Population counts for each FSA were sourced from the 2021 Canadian Census, released in February 2022. To calculate the dentist-to-population ratio, the number of dentists in each FSA was divided by that area's total population to account for varying population sizes across FSAs. The ratio was standardized as the number of dentists per 10,000 residents.

2.4.2.2 FSA-level Income

FSA-level income data were obtained from the 2021 Census Community Profile published by Statistics Canada. This dataset includes information on total income, after-tax income, income distribution, sources of income, and various household income measures. For this study, median total household income of FSA was used as it best reflects the overall economic status of households while minimizing the influence of outliers. This approach is consistent with other studies examining FSA-level socioeconomic inequalities. [74,89] Although individual tax return data also provide income information at the FSA level, they were not used due to inconsistencies in population coverage. In addition, using census data for both population counts and FSA-level income ensured consistency in the denominator across FSAs. To assess income-related inequalities, FSAs were grouped into quintiles based on median household income ($): lowest income, second, third, fourth, and highest income quintile.

2.4.2.3 Geographic Remoteness

The geographic remoteness of each FSA was classified as “Urban” or “Rural” according to the second character of the FSA code. According to Statistics Canada, ‘0’ indicates rural and any other character indicates urban area.

2.4.3 Data Mapping

Arc GIS Pro (Version 3.4.0) was used to map the distribution of dentists in Ontario across FSAs.[90] The data table containing the DPR for each FSA was prepared in tabular format and joined to the FSA shapefile using the FSA code as a common attribute. Following the successful join, a choropleth map was created to illustrate the variation in DPR across FSAs. FSAs were categorized into five groups based on DPR. Those with no dentists were mapped separately, while the remaining FSAs were classified using a quartile distribution. To visualize DPR variation, each FSA was assigned a unique color based on predefined DPR categories to ensure clear visual differentiation.

FSA-level median household income data from the 2021 Census was joined to the FSA shapefile using the same geographic identifier. Two separate maps, one showing DPR and the other showing FSA income quintiles were created. Both maps included FSA boundaries, a contextual basemap and geographic labels to support interpretation.

The study also examined how dentists are distributed across geographic remoteness categories: rural and urban. The resulting maps allow for a comprehensive comparison of income-related and remoteness-related inequalities in dentist distribution. This approach is designed to explore whether rural FSAs and those with lower income quintiles are underserved.

2.4.4 Quantifying Inequality in Dentist Distribution

The Lorenz Curve and Gini coefficient, commonly used to evaluate inequalities in resource, service, or income distribution, were applied to quantify the dentist distribution in Ontario. The Lorenz Curve graphically represents inequality by plotting the cumulative population proportion on the x-axis against the cumulative dentist proportion on the y-axis, with FSAs ranked in ascending order based on dentist count. The 45-degree line represents perfect equality, where every proportion of the population would have equal access to dentists. The extent to which the Lorenz Curve falls below the line of equality indicates the level of

inequality in the distribution, the larger the deviation, the greater the inequality. This inequality is quantified by the Gini coefficient, which ranges from 0 (indicating perfect equality) to 1 (indicating perfect inequality). The Gini coefficient was calculated using the Brown's formula:[59,60,91–93]

Gini coefficient = 1-2B= $1 - 2\sum_{1}^{516} \frac{(Xk - Xk-1)(Yk + Yk-1)}{2}$

Where:

X_k = Cumulative proportion of the population

Y_k = Cumulative proportion of dentists

A = Area between the Lorenz Curve and the line of equality

B = Total area under the line of equality

2.5 Results

2.5.1 FSA-level Descriptives of Dentists and Population

The RCDSO dataset initially included 10,543 registered dentists. Of these, 10,295 were successfully matched to Ontario using FSA codes based on the 2021 Census. A total of 26 FSAs had no registered dentists. Table 1 shows the number of dentists per FSA, ranging from 0 to 155, and a mean and median of 19.9 and 15.0, respectively, indicating a skewed distribution with dentists concentrated in a few FSAs.

Table 1: FSA-level descriptives of dentists and population

Statistic	Number of dentists	Population
Number of FSAs	516	516
Minimum	0	490
Maximum	155	115850
Mean	19.9	27565.5
Median	15.0	23518.5

According to Statistics Canada, the total population of Ontario in 2021 was 14,223,942. Among the 516 FSAs included in this study, the combined population was 14,223,789. Population per FSA ranged from 490 to 115850, with a mean and median of 27,565.5 and 23,518.5 respectively. These figures indicate a wide variation in population distribution across FSAs, with a positive skew.

The DPR exhibited a wide range of values, with the lowest at zero to the highest at 248.1. This broad variation likely results from outliers, including large rural FSAs with no registered dentists and small urban or commercial FSAs with a high density of dentists relative to the resident population. The mean DPR was 8.4, while the median was 5.9, indicating that half of the FSAs had a DPR below the median value. The 95th and 99th percentiles were 20.9 and 48.5, respectively. These findings demonstrate a pronounced right-skew in the DPR distribution, with a few FSAs exhibiting extremely high ratios potentially due to small population sizes and others with very low ratios, suggesting possible shortages in dentist supply.

Figure 3 Illustrates the distribution of dentists across FSAs in Ontario, highlighting both the FSA boundaries and the number of dentists per 10000 population. As outlined in the methods, FSAs with no registered dentists were mapped separately, while the remaining FSAs were divided into quartiles: 0.000001–3.81, 3.81–6.17, 6.17–9.27, and 9.27–248.06. A clear geographic clustering of dentists is observed in and around the Metropolitan Toronto region, where the majority of FSAs with a DPR greater than 9.27 are concentrated.

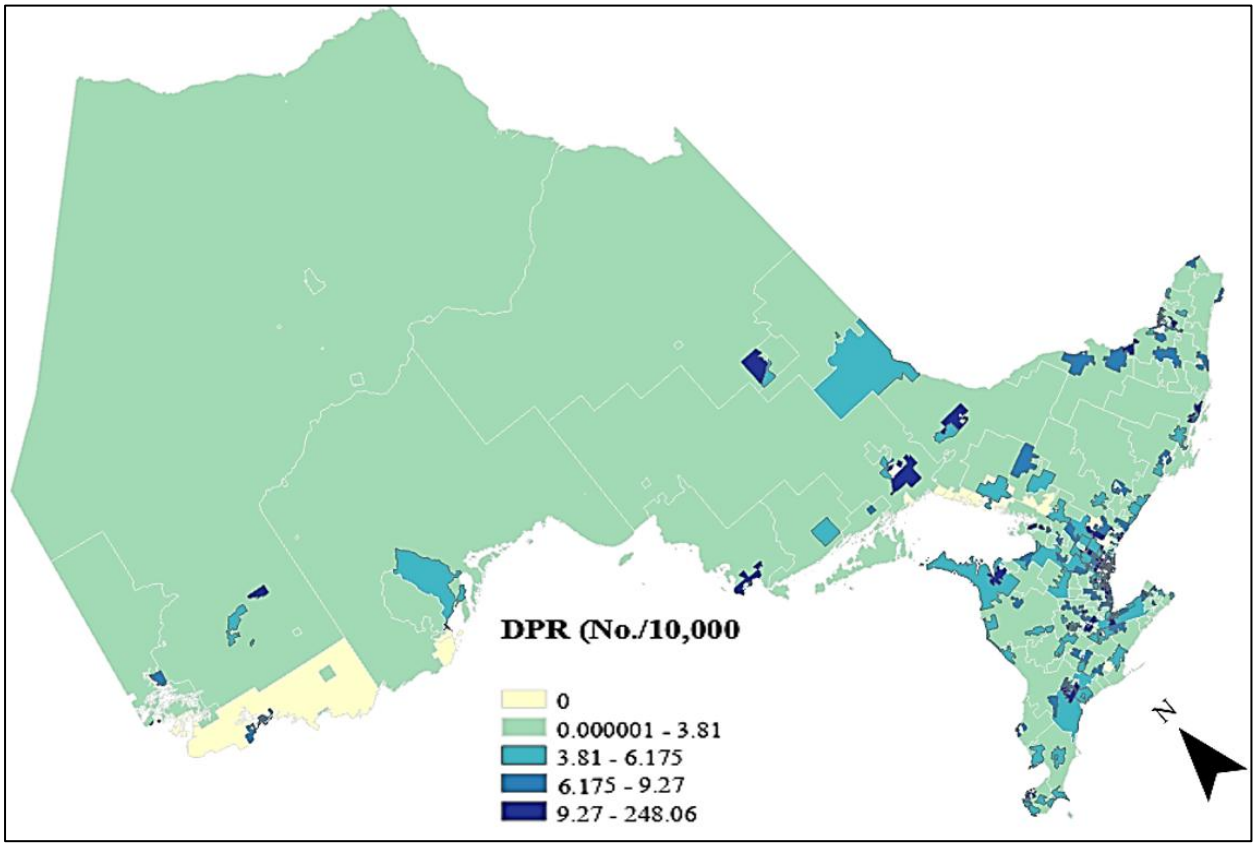

Figure 3: Distribution of dentists (no. per 10,000 population) by FSA in Ontario

Figure 4 Illustrates the geographic distribution of FSA-level income grouped into quintiles: lowest ($ 45,200 to $ 74,000), second ($ 74,500 to $ 83,000), third ($ 84,000 to $ 97,000), fourth ($ 98,000 to $ 115,000), and highest ($ 116,000 to $ 198,000). FSAs in the highest income quintile are primarily concentrated in the Metropolitan Toronto region, surrounded by FSAs in the fourth and third quintiles. In contrast, FSAs located in Northern Ontario predominantly fall within the lowest two income quintiles. This pattern indicates a tendency for both high- and low-income areas to form geographic clusters.

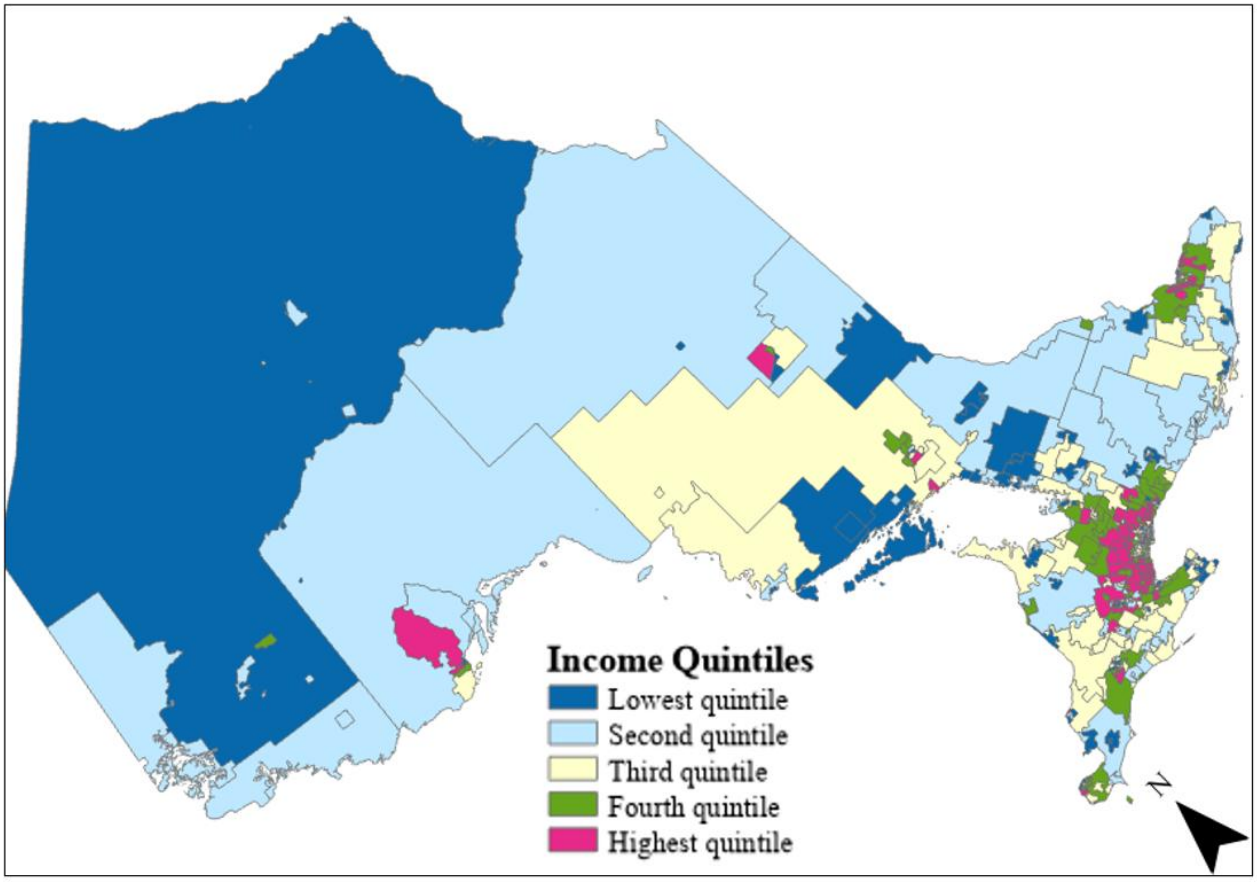

Figure 4: Distribution of income quintiles (median total household income in $) by FSA in Ontario

Figure 5 depicts the urban–rural classification of FSAs based on Statistics Canada's definitions. Urban FSAs are primarily concentrated in the Metropolitan Toronto and Central Ontario regions, while the majority of Northern FSAs are rural. A few urban FSAs appear as isolated pockets within rural zones.

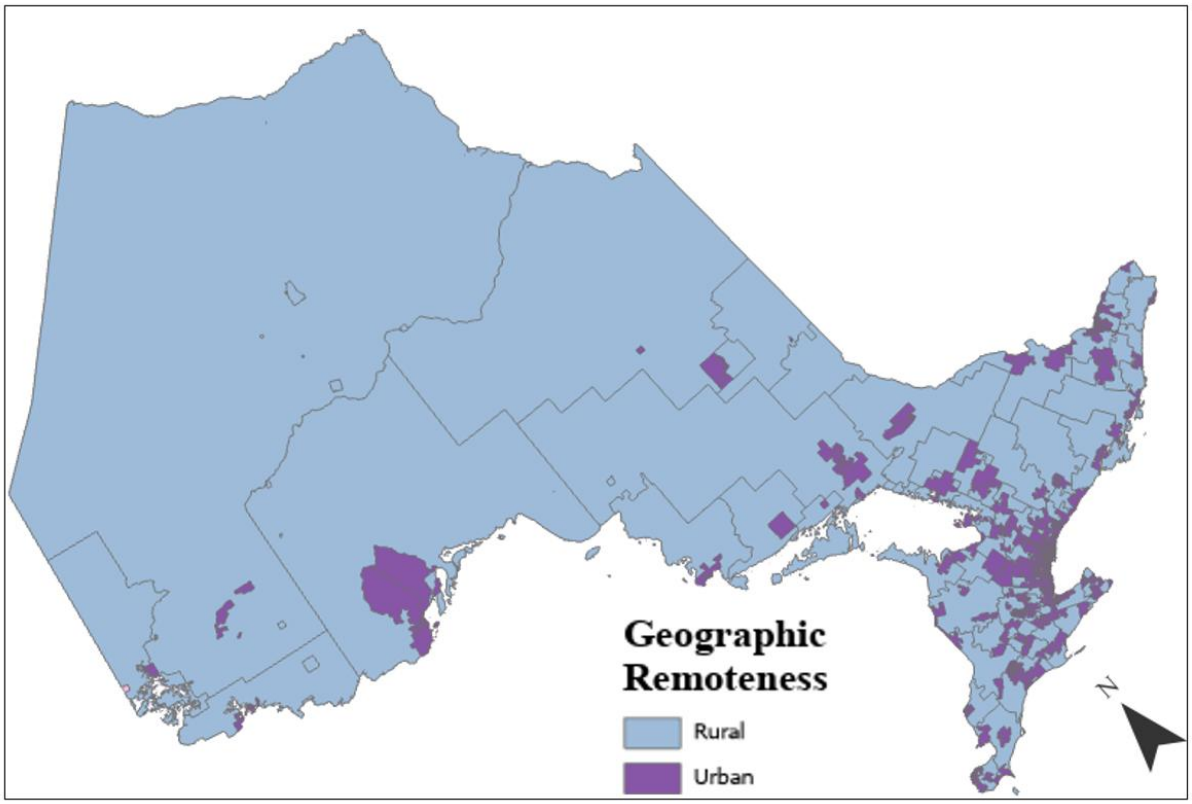

Figure 5: Distribution of geographic remoteness groups (Urban/Rural) by FSA in Ontario

Figure 3 and Figure 4 provide a visual comparison of dentist density and income across FSAs in Ontario. FSAs within the highest income quintile generally exhibit higher dentist-to-population ratios. In contrast, FSAs in the lowest income quintile are more commonly located in regions with lower dentist density. These patterns suggest a potential association between area-level income and dentist density, with a greater concentration of dentists observed in higher-income FSAs.

Similarly, **Figure 3 and Figure 5** reveal that urban FSAs have higher DPRs compared to rural FSAs, with many rural FSAs, especially in Northern Ontario, falling into the lower DPR categories. The isolated urban pockets within rural regions also exhibit higher income levels and greater dentist density. This suggests that both geographic remoteness and socioeconomic conditions may influence the distribution of oral healthcare resources across Ontario.

2.5.2 Lorenz Curve and Gini Coefficient

The first Lorenz Curve illustrates the inequalities in dentist distribution relative to the population across FSAs in Ontario **(Figure 6).** While perfect equality would produce a Lorenz curve along the 45-degree line, the observed curve shows slight deviation with a Gini Coefficient of 0.25, indicating some degree of inequality in dentist distribution.

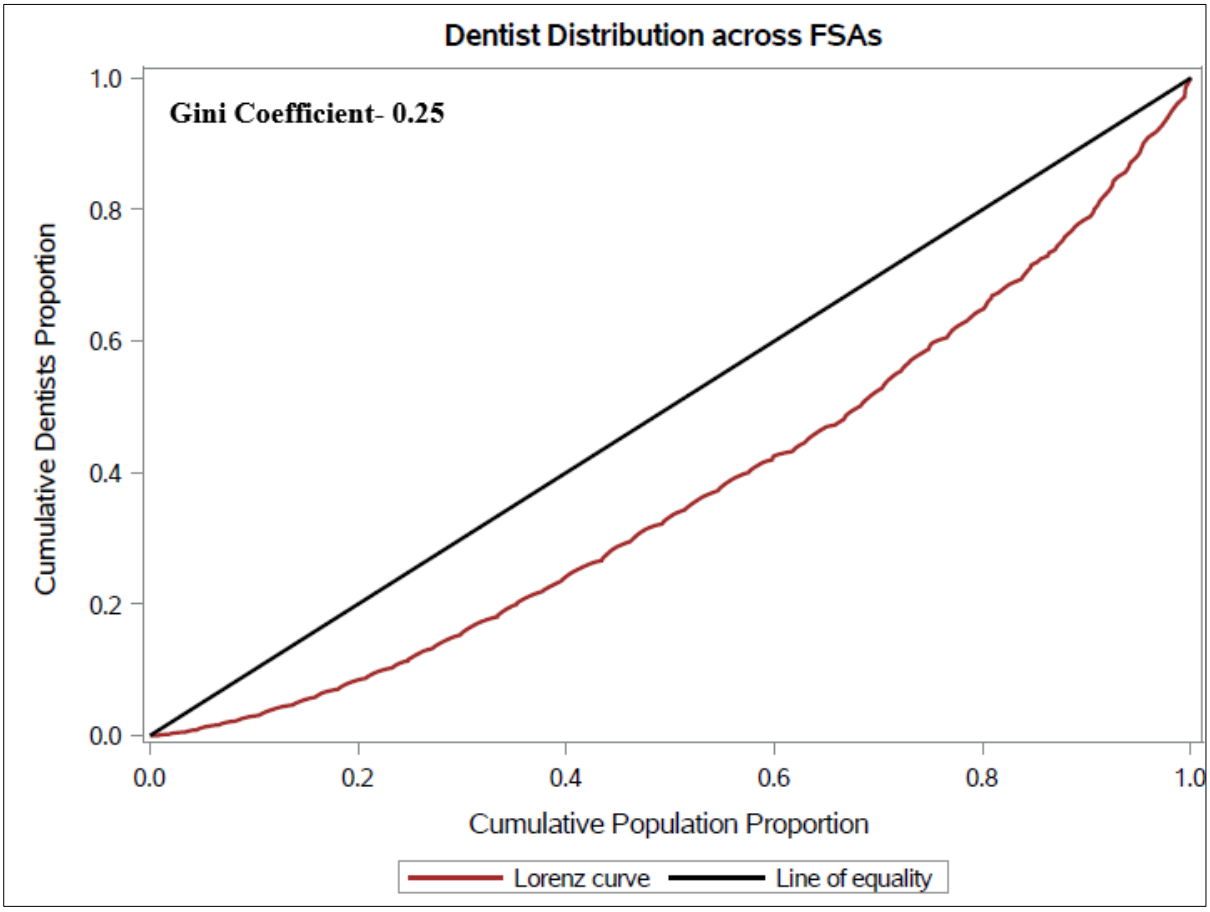

Figure 6: Lorenz Curve for dentist distribution across FSAs in Ontario

When FSAs were stratified by median total household income quintiles and separate Lorenz curves were plotted for each group, the analysis revealed more pronounced inequalities in dentist distribution within lower-income areas (**Figure 7**). Specifically, the Gini coefficient increased as income quintile decreased reaching a peak of 0.36 in the lowest income quintile, which is higher than the overall Gini coefficient and, when compared to 0.17 in the highest income quintile. This trend of increasing inequality with decreasing income suggests the influence of socioeconomic context on dentist distribution.

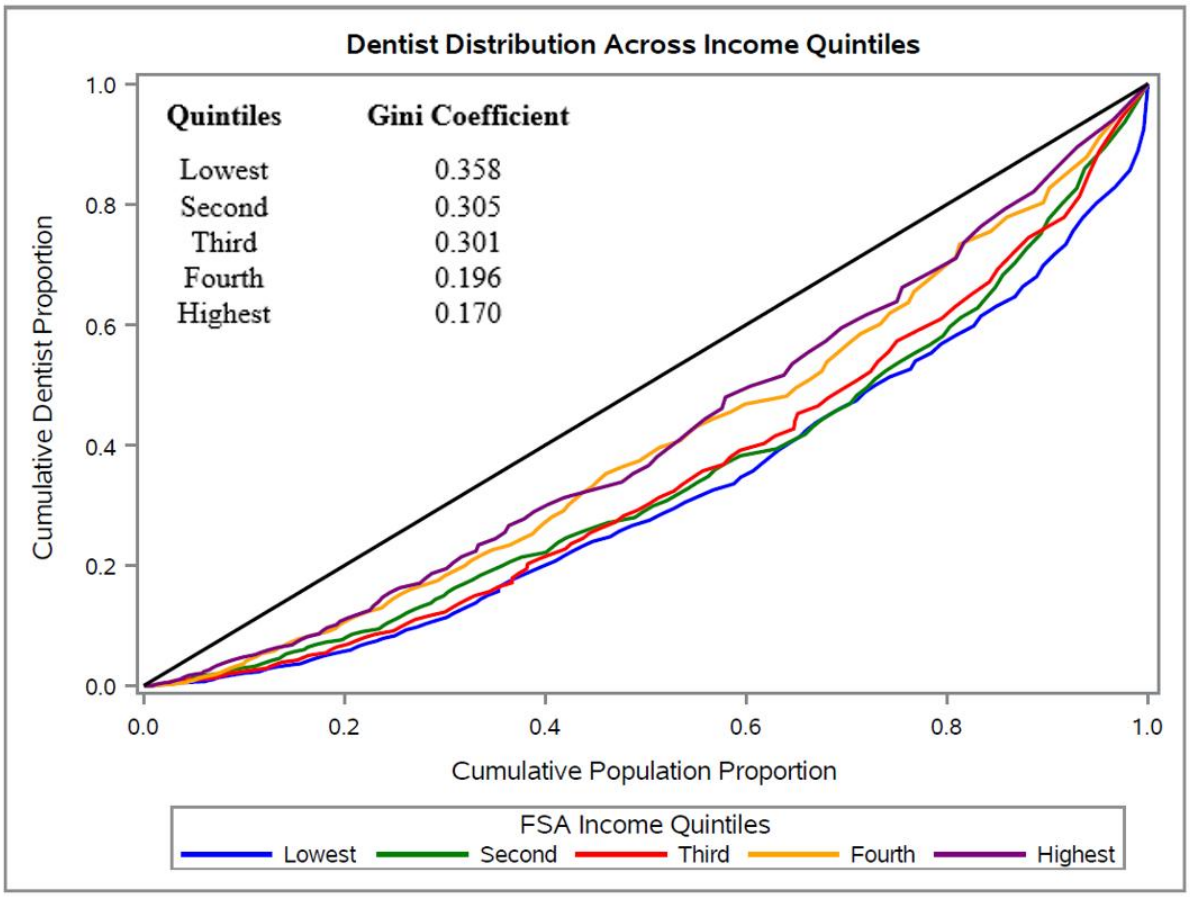

Figure 7: Lorenz Curve and Gini coefficient for dentist distribution across FSA income quintiles

Figure 8 presents Lorenz Curve for the distribution of dentists across rural and urban FSAs. The curve for urban FSAs deviates more noticeably from the line of equality compared to the rural curve, reflecting greater inequality. The Gini Coefficient was 0.14 for rural FSAs and 0.23 for urban FSAs. This indicates that, urban FSAs had more unequal dentist distribution in Ontario when compared to rural FSAs.

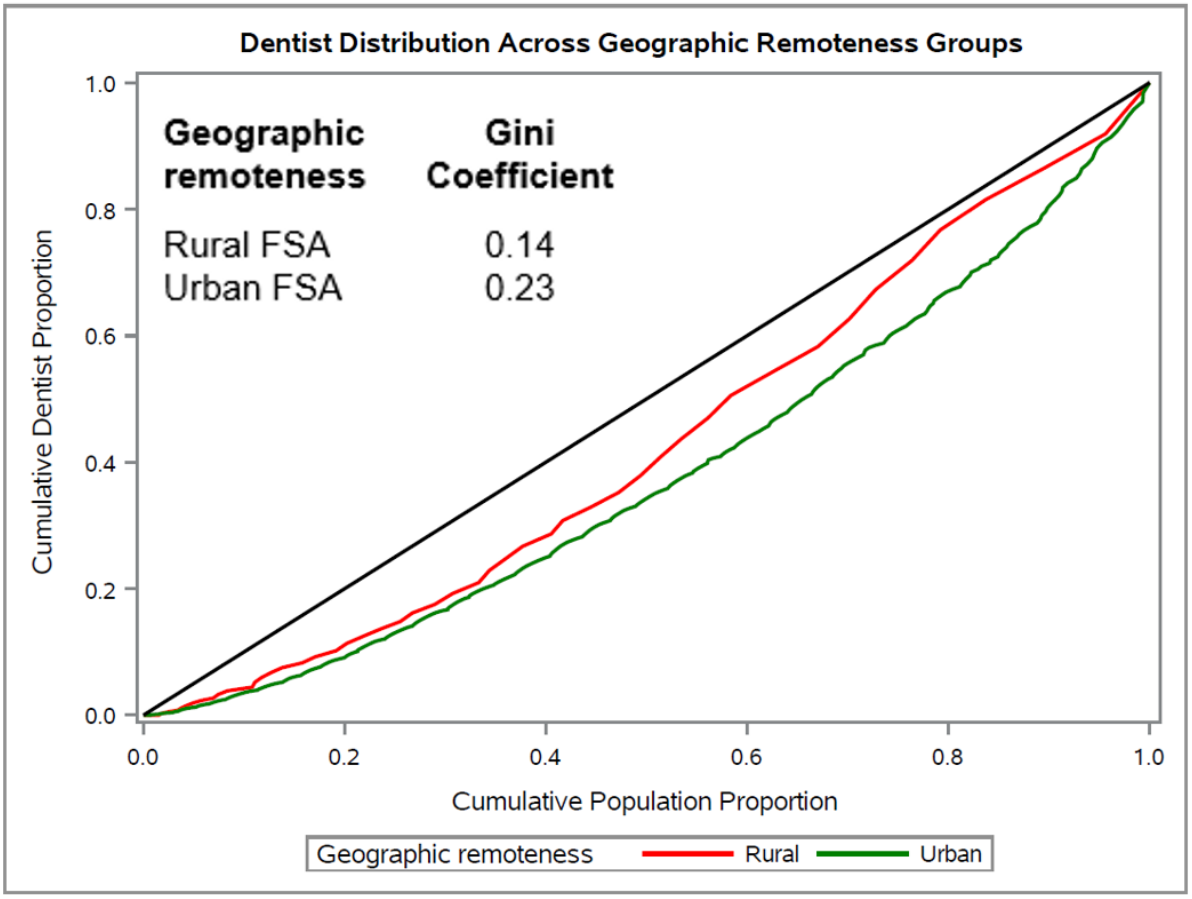

Figure 8: Lorenz Curve and Gini coefficient for dentist distribution across geographic remoteness groups

2.6 Discussion

This study investigated the geographic distribution of dentists across FSAs in Ontario, with a focus on how DPR varies according to FSA-level income and geographic remoteness. By combining spatial mapping with quantitative measures of inequality, we provided an assessment of inequalities in access to oral healthcare in Ontario.

The descriptive analysis revealed substantial variation in the supply of dentists across Ontario's FSAs, as evidenced by a wide range of DPR values and the concentration of extreme values in some FSAs which means there was under-servicing and over-servicing in some areas. Our findings highlighted spatial imbalances in DPR across Ontario's FSAs and these patterns appeared to be closely tied to FSA-level income and geographic remoteness. Choropleth maps showed that high-income FSAs generally have higher DPR than low-income FSAs. Distinct income-based geographic clusters were also observed in the FSA-level income map, with concentrations of both high-income and low-income areas. Additionally, most of the urban FSAs tended to have higher DPR than rural counterparts, highlighting inequalities in oral healthcare access. Beyond spatial visualization, Lorenz Curves and Gini coefficients offered quantitative insights into inequality in dentist distribution. Our analysis showed notable within-group inequalities: the lowest income quintile exhibited the most unequal distribution of dentists, while the highest income quintile had the most equal distribution across FSAs. When stratified by remoteness, urban FSAs displayed slightly higher Gini coefficients than rural FSAs, indicating that even within similar FSA-level income or geographic remoteness categories, access to oral healthcare remained uneven. This indicated that not only was there inequality in overall dentist distribution, but also not all communities within the same income bracket or remoteness group had equal access to oral healthcare.

Similar findings have been reported in previous studies conducted in Canada and globally. In 2012, a study that focused on dentist distribution in metropolitan Toronto FSAs revealed income-related inequalities in dentist distribution, where higher DPRs were clustered in affluent neighborhoods. [43] Another study in Saskatoon revealed significant inequalities in dental services within urban areas.[50] This is consistent with our findings, where FSAs in Metropolitan Toronto and Central Ontario regions that predominantly fall within the top two

income quintiles exhibited higher DPR values. Additional research using 2012 InfoCanada data analyzed dentist distribution across Ontario at the CSD level.[51] This study found strong clustering of dental offices within larger urban regions such as Census Metropolitan Areas (CMAs), particularly in the South-Central Ontario, including Toronto and its surrounding municipalities. [51] In contrast, dental offices were more dispersed in the Southeast, Southwest, and Northern regions of Ontario, where many CSDs fall outside these urban classifications. [51] Although our study used FSAs and a different metric (DPR), the distribution patterns observed in our study align with those from the InfoCanada study, underscoring persistent geographic inequalities in oral healthcare access across Ontario.[51]

A study on dental hygienist distribution throughout Ontario FSAs reported uneven provider distribution at the FSA level.[73] These inequalities were partly due to outliers, such as large rural FSAs with very few hygienists and small urban FSAs, often in downtown cores with low residential populations but high concentrations of practicing hygienists. However, when data were aggregated to broader geographic levels such as FSA-1 or FSA-2 (based on the first character and the first two characters of the FSA, respectively), these inconsistencies were reduced.[73] This emphasizes the value of using FSAs as the appropriate unit of analysis, as they can reveal localized inequalities in provider distribution that can be masked at more aggregated levels. Such granularity enables better identification of underserved areas and supports more targeted planning and resource allocation for oral health services.

Studies from non-Canadian contexts also further underscore how dentist distribution is influenced by economic development and urban-rural divides. In the US, a nation-wide analysis of Health Professional Shortage Area (HPSA) found that rural regions had the highest proportion of the population underserved in oral healthcare.[94] A study in Ohio reported about 70% of dentists were practicing in metropolitan counties.[95] A study examining global patterns of dentist distribution reported the Gini coefficient varied across Human Development Index (HDI) groups and highest Gini coefficient value was seen among low HDI countries.[61] In Japan, municipal level unequal distribution of dentists with a Gini coefficient of 0.25 was reported and also noted that there was a tendency for dentists to open their clinics in higher income and urban areas.[96] Additionally, research from Iran reported a Gini coefficient of 0.39 nationwide for dentist distribution, with notable associations between DPR, HDI, and urbanization.[97]

Our study's findings indicate that dentist distribution varied across FSAs, shaped by an interplay of socioeconomic and geographic factors. One key explanation for the observed spatial patterns is the economic accessibility of oral healthcare. Individuals with lower incomes who are less likely to have dental coverage encounter greater financial barriers when accessing oral healthcare.[28] Dentists are more likely to establish practices in higher income areas where residents can more readily afford dental services, either through private insurance, employer-sponsored benefits (typically associated with full-time employment), or out-of-pocket payments.[43,54–56] This purchasing power of the populations was coded as an economic determinant of geographic distribution of dentists.[55] Urban FSAs, which make up the majority in Ontario, are likely to have a higher concentration of dentists. This could partly be because urban centers offer greater job opportunities, attracting both patients and practitioners. Dentists are inclined to set up clinics in areas with high market demand, which are often urban and higher income settings. Rural areas, however, continue to face ongoing challenges such as a shortage of providers, limited specialized services, and longer travel distances, which can discourage care-seeking and negatively impact oral health.[51] As the market in urban cores becomes saturated, some dentists expand into suburban or peri-urban areas to access new patient populations. This diffusion process described by the “spill-over” hypothesis or location theory might increase Gini values within urban FSA groups, as observed in studies on physicians and dentists in Japan.[98] However, such redistribution is often slow and uneven, leaving some rural regions with ongoing provider shortages due to lower population density and limited economic incentives. This trend is evident in Canada, where the populations of rural and small towns grew in 10 out of 13 provinces and territories between 2021 and 2024, with the highest net migration reported in Ontario and Quebec.[99] While existing literature consistently shows that urban and higher-income areas have better dentist coverage, this study using Lorenz Curve and Gini coefficient highlighted the within-group hidden inequalities. These intra-group inequalities highlight that tailored strategies are needed to address the distinct needs of both underserved rural and urban communities.

Strengths and limitations: As with most research, this study presents both strengths and limitations. A key strength is the use of the RCDSO data, which provides the most comprehensive and up-to-date list of licensed dentists practicing in Ontario. Unlike studies that rely on census data or commercial sources (e.g., InfoCanada), this study used practice address data directly reported by dentists to the provincial regulatory body.[48,51] This approach improves

the accuracy and relevance of spatial distribution measures and helps avoid limitations related to office-level or outdated listings. [48,51]

However, the use of RCDSO data comes with certain limitations. While the data are self-reported, dentists are mandated to update their practice and contact information within 30 days of any changes.[88] This requirement may help reduce the risk of outdated or incorrect geographic information (e.g., outdated FSA), but some inconsistencies may still occur due to reporting delays. Dentists who are registered but not actively practicing are not easily identifiable; in such cases, their home or mailing address may be listed as their primary address, which could lead to misclassification. Additionally, some entries corresponded to FSAs not yet assigned by Statistics Canada, which may represent non-residential, institution-based, or newly created postal areas; these were excluded from analysis. A small number of FSAs were outside Ontario, but it is unknown whether these dentists also maintained practice locations within the province. Despite these limitations, the RCDSO remains the only mandated source for dentists' FSA code data in Ontario. Using data from the RCDSO, previous studies reported 8,300 registered dentists in 2013 and 8,467 in 2016, indicating modest growth during that period.[51,100] In contrast, our dataset includes 10,295 dentists in Ontario as of 2022, suggesting a more substantial increase in the dental workforce in recent years.

Another advantage of this study is the selection of the Gini coefficient as the main metric to assess inequality. While alternative relative indices such as the Theil index, Atkinson index, and coefficient of variation exist, each has important limitations such as overestimating inequality (Theil), limited reflection of positional inequality (Atkinson), and inability to capture within-group variation (coefficient of variation).[57] The Gini coefficient was selected for its clarity, transparency, and widespread application in healthcare resource distribution.[57–59,92] However, it has some limitations. The Gini coefficient cannot distinguish between different patterns of inequality, meaning that different distributions can yield similar Gini values with intersecting Lorenz curves, making comparisons tricky.[101] It is also most sensitive to inequalities in the middle of the distribution and may underrepresent extremes, such as areas with very low or very high dentist availability.[101] In the literature, various formulas for calculating the Gini coefficient are used, with inconsistent approaches to interpreting their values. [57,61,102–104] To the best of our knowledge, many researchers have refrained from applying strict cut-offs for Gini coefficients using Brown's formula in healthcare workforce distribution, reflecting the broader uncertainty about what constitutes an "acceptable" level of

inequality.[58–60,91,92,96,105] Therefore, this study avoids fixed numeric thresholds and instead provides contextual interpretation of the Gini coefficients alongside Lorenz Curves by clearly stating the formula.

The study's focus on within-group inequalities (e.g., among FSAs within the same income or geographic category) using Lorenz Curves and Gini coefficients allowed us to uncover inequalities that might be masked in aggregate-level analysis. This approach strengthens the policy relevance of our findings at the FSA level in finding solutions to improve oral healthcare access in underserved communities. Finally, an additional strength of this study is its timeliness. While a similar study was conducted over a decade ago, the distribution of dentists, population demographics, patterns of urban development, and health system dynamics have changed substantially since then. This study provides a more current and relevant assessment of dentist distribution, making its findings more applicable to present-day planning and policy decisions. Future research should assess whether the Canadian Dental Care Plan (CDCP) leads to changes in DPR across different regions particularly in rural or underserved areas as the program may influence demand and incentives for dental services. Future work should also explore potential inequities that may emerge over time, providing policymakers with the evidence needed to identify gaps, measure progress, and make informed decisions to improve equitable access to oral healthcare across Ontario.

Chapter 3

3 Individual and Area-level Access to Oral Healthcare and Oral Health Outcomes Among Middle-Aged and Older Adults in Ontario: A Data Linkage Analysis of the Canadian Longitudinal Study on Aging (CLSA)

3.1 Abstract

Background: Oral health is a critical component of healthy aging, yet older adults frequently experience high rates of oral disease, tooth loss, and limited oral healthcare utilization. In Ontario, access to dental services is uneven, influenced by both individual factors such as income, education and insurance coverage, and area-level determinants, including dentist availability, socioeconomic conditions, and remoteness. Despite programs aimed at improving access, inequalities persist, particularly among lower-income and rural populations. Understanding how these factors jointly affect oral health outcomes is essential for informing targeted interventions and policy planning. ***Aim:*** To assess the geographical variation in oral health outcomes across Forward Sortation Areas (FSAs) in Ontario and to assess the association between individual- and FSA-level factors of oral healthcare access and oral health outcomes among middle-aged and older adults in Ontario. ***Methods:*** We retrieved data of 8821 middle-aged and older Ontarians from the Canadian Longitudinal Study on Aging (CLSA) follow-up 2 data. The outcome variables included Self-Reported Oral Health (SROH), Functional Dentition (FD), and Last Dental Visit (LDV). The individual-level predictor variables were age, sex, race, post-secondary education, total household income and type of dental insurance; FSA-level predictors were Dentist-to-Population Ratio (DPR), FSA-level income and geographic remoteness. Multilevel random-intercept binary logistic regression models were constructed for each outcome. Odds Ratio (OR) and Confidence Intervals (CI) were used to interpret fixed effects. Random effects were evaluated using Intra-Class Correlation Coefficient (ICC) and Median Odds Ratio (MOR). ***Results:*** The study participants were aged 50 and above, with roughly half over 65 years. Most were White, had post-secondary education, and were married or in common-law relationships. They were distributed across 453 FSAs. The mean DPR was 75.8 (median 67.5). Regarding oral health, 10.1% reported poor

SROH, 17.9% had no FD, and 14.1% had no dental visit in the past year, while 36.4% lacked dental insurance and only 7% were covered by government insurance. The ICCs (MORs) were 10.9% (1.83) for SROH, 9.4% (1.74) for FD, and 13.4% (2.0) for LDV, suggesting that a considerable portion of the variation in each outcome can be attributed to differences between FSAs. Multilevel analysis revealed that individual-level access factors, including age, sex, total household income, post-secondary education, and dental insurance type, were significantly related to oral health outcomes, whereas FSA-level variables showed no significant associations, except for a modest effect of FSA-level income. ***Conclusion:*** Individual-level factors were associated with oral health outcomes across FSAs. The minimal influence of FSA-level variables in the association suggests that geographic variation observed may be better explained by including additional individual and/or FSA-level factors.

3.2 Introduction

In 2016, the World Dental Federation redefined oral health as a multidimensional concept that includes the ability to communicate, eat, and express emotions confidently, without pain or disease affecting the craniofacial region.[106] Maintaining good oral health is gaining momentum as a key aspect of healthy aging, defined as "the process of developing and maintaining the functional ability that enables well-being in older age".[7,106–109] Aging is frequently accompanied by a range of health and functional challenges, including chronic diseases, frailty, polypharmacy, and limited daily activities.[106,110] Oral health issues are one of the most commonly reported concerns in older adults globally, and with the global population aging, preserving oral health in later life has become an increasingly important public health priority.[5,106,111] In Canada, the growing proportion of older adults highlights the need to address their specific oral health needs.[2] Oral health problems are highly prevalent among older adults, often linked to systemic health issues, and can contribute to malnutrition, social isolation, and diminished cognitive function.[4,5,106,109,110]

Retention of natural teeth is essential for maintaining functional chewing, clearer speech, and facial aesthetics, yet dentures, while partially restorative, cannot fully replicate the capabilities of natural dentition.[109,110] Their use in older adults may also be complicated by factors such as xerostomia, diminished motor coordination, inadequate adaptation, and associated discomfort, which can hinder mastication and contribute to nutritional deficiencies and cognitive decline.[8,110] Key outcomes of oral health status and oral healthcare utilization in older adults include self-reported oral health (SROH), functional dentition (FD), and Last dental visit (LDV), with SROH reflecting perceived oral health and predicting tooth loss, FD (≥20 natural teeth) supporting mastication, speech, and appearance, and regular dental visits being critical for preventing and managing oral diseases.[42,78,110,112–115]

Previous national surveys have highlighted the burden of these outcomes among Canadian adults and seniors. The Canadian Health Measures Survey (CHMS) Cycle 1(2007-2009) reported that 6.4% of adults aged 20 to 79 were completely edentulous, with the highest prevalence seen among those aged 60 to 79.[12] According to the Canadian Longitudinal Study on Aging (CLSA), 8% of individuals between the ages of 45 and 85 had no natural teeth, with edentulism rates increasing with age and many reporting problems with dentures.[7] More recently, the 2024 Canadian Oral Health Survey (COHS) showed that approximately 11% of

adults aged 60 and older were edentulous.[13] Across Canada, almost two-thirds of adults reported going without a dental visit in the previous year, with approximately 60% of older adults reporting no recent dental visit.[15] In Ontario, only 67.2% of individuals aged 12 and older had a dental visit in the previous year.[15] Trends in SROH have also shown a decline with age; analysis across three Canadian Community Health Survey (CCHS) cycles (2003–2014) revealed a consistent increase in the proportion of lower-income older adults reporting suboptimal oral health.[14] Specifically, 2018 CCHS data showed that among Ontarians aged 55 and older, 8.5% reported fair oral health and 4.2% reported poor oral health.[42]

Access to oral healthcare is a crucial factor influencing oral health outcomes among older adults, particularly as aging increases vulnerability to oral diseases. While biological changes associated with aging, such as enamel wear, tooth attrition and reduced salivary flow, contribute to oral health decline, the most prevalent dental conditions, such as caries and periodontal disease, can be prevented with regular and timely oral healthcare.[5,109,111] Individual factors like age, sex, education, race, income, and dental insurance status influence access to oral healthcare. Among middle-aged and older Canadians, those with lower income and limited education commonly report poorer oral health. [16] In Ontario, low-income older adults have consistently experienced disproportionately poorer oral health for over a decade, with those of Chinese origin reporting worse outcomes than their White and Black counterparts. [14,18] Dental insurance coverage also varies across demographic groups, with the likelihood of having coverage declining with age and increasing with income, though coverage remains more common among men.[28,34,37] Financial cost remains a major barrier to oral healthcare, particularly in Ontario, where older adults have lower insurance coverage than in Alberta and British Columbia. [28,37,78]

Beyond individual factors, area-level factors may also contribute to oral health inequalities among older adults. Factors such as the supply of dental professionals, area-level socioeconomic conditions, and whether an area is rural or urban can either support or hinder access to dental services. In Canada, dental professionals are unevenly distributed, with higher concentrations in major urban centers like Toronto, Montreal, and Quebec City, while rural, remote, and lower-income areas such as northern Ontario, often experience limited provider availability and reduced access to care.[21,43,50,51,116] This uneven distribution is particularly

concerning given the rising migration of older adults to rural locations. In Canada, the senior population in rural regions increased more rapidly than in urban centers between 2016 and 2021, with older adults in Ontario now making up 24% of the rural population. [53] Many of these individuals face financial constraints and limited insurance coverage, as they often live on fixed or low incomes post-retirement and lack access to employer-sponsored or affordable private dental plans.[53,117]

Ontario, Canada's most populous province, is characterized by significant socioeconomic, ethnic, and regional diversity alongside notable oral health inequalities. Although initiatives like the Ontario Seniors Dental Care Program (OSDCP) exist, challenges in oral healthcare access persist among many older adults; these challenges are expected to be mitigated with the implementation of the new national program, Canadian Dental Care Plan (CDCP). While most previous studies in aging have focused solely on older adults, this study leverages CLSA data to include middle-aged adults as well, allowing for the early identification of oral healthcare access related barriers and oral health risks before individuals transition into older age. Although the influence of both individual and area-level factors is increasingly acknowledged, no previous study has assessed their multilevel association with oral health outcomes among middle-aged and older adults in Ontario using Forward Sortation Areas (FSAs) as geographic units. Therefore, this study fills an important gap by examining how individual and area-level factors of oral healthcare access relate to individual's SROH, FD and LDV.

3.3 Research Objectives and Hypotheses

1. To assess the geographical variation of oral health outcomes across FSAs in Ontario.
   Hypothesis: There will be a significant variation of oral health outcomes across FSAs

2. To assess the association between individual-level factors of oral healthcare access and oral health outcomes in middle-aged and older adults in Ontario.
   Hypothesis: There will be an association between individual-level factors of oral healthcare access (i.e., age, sex, education, race, total household income and type of dental insurance) and oral health outcomes. There will be a protective association for lower age, higher education, higher income and presence of dental insurance.

3. To evaluate the association between FSA-level access to oral healthcare factors and oral health outcomes in middle aged and older adults in Ontario, after adjusting for individual-level access factors.

   Hypothesis: There will be an association between FSA-level factors of oral healthcare access and oral health outcomes. There will be a protective association for higher DPR, higher FSA-level income and urban FSAs.

3.4 Methods

3.4.1 Data Source and Study Population

This study conducted a cross-sectional analysis using secondary data from the follow-up 2 wave of the Canadian Longitudinal Study on Aging (CLSA). [118] The CLSA is a large, population-based cohort that originally recruited over 50,000 Canadians between the ages 45 and 85 years. [118] Participants residing on First Nations reserves or settlements, in the three northern territories, or in long-term care facilities (excluding independent or transitional housing) were excluded. [118] Full-time members of Canada's armed forces and non-permanent residents, and individuals deemed cognitively impaired during recruitment, and non-English and non-French speaking people were also excluded.[118] The participant selection method is summarized in Figure 9. The baseline wave included 51,338 participants, while follow-up wave 2 (2018–2021) comprised 40,349 participants (14,848 in the Tracking cohort and 25,501 in the Comprehensive cohort). Participants were recruited through the Canadian Community Health Survey on Healthy Aging, provincial health registries, and random-digit dialing. [118] Data collection for the Tracking cohort was completed via telephone interviews, whereas the Comprehensive cohort underwent in-person interviews and assessments at designated Data Collection Sites.[118] The detailed sampling strategy is explained elsewhere.[118,119]

For this study, we focused on CLSA participants residing in Ontario. FSAs with fewer than two participants were excluded to ensure reliable variance estimation for multilevel modelling. After applying these criteria, the final sample included 8,821 participants (5,476 in the Comprehensive cohort and 3,345 in the Tracking cohort). FSA-level data on the number and location of dental practices in Ontario were obtained from the Royal College of Dental

Surgeons of Ontario (RCDSO) for the year 2022. Because dentist address data were only available for 2022, the follow-up Wave 2 CLSA data were selected to align with this timeframe FSA-level income, specifically median total household income ($), were sourced from the 2021 Census Community Profiles provided by Statistics Canada.

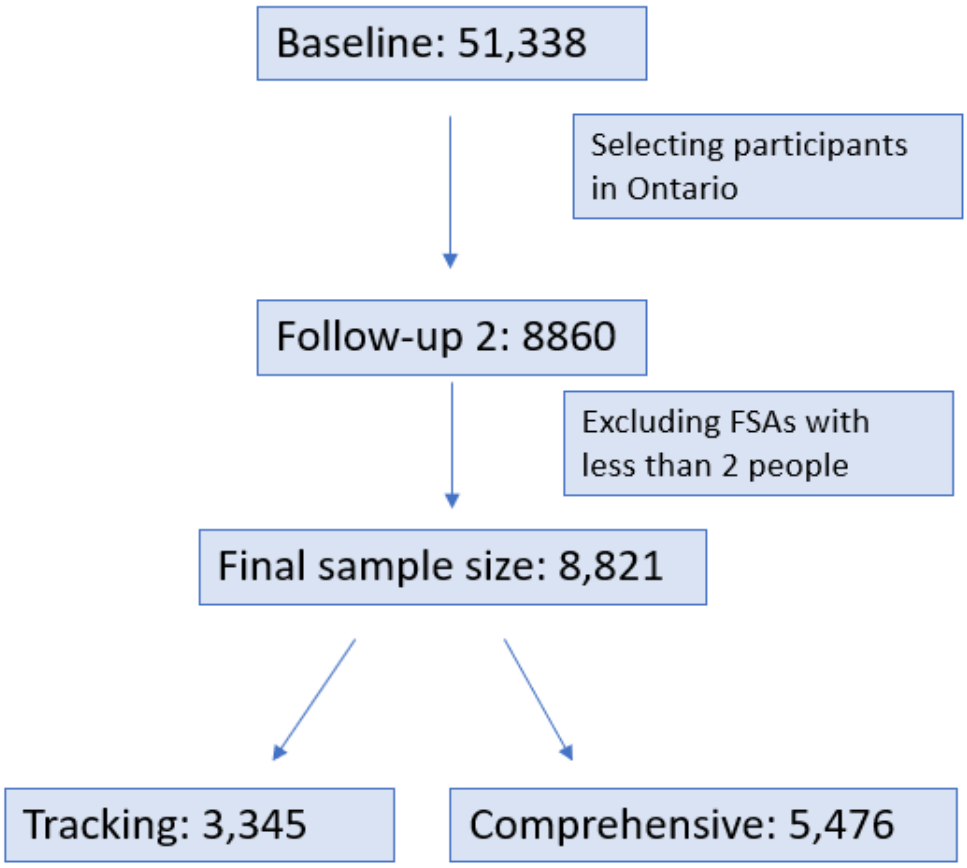

Figure 9: Participant selection and final sample size from the CLSA data

The FSA code served as the geographic link to merge individual-level CLSA data (sociodemographic characteristics and oral health outcomes) with FSA-level data (DPR, FSA-level income, and Geographic remoteness). FSAs, the geographic units in this study, are the first three characters of the postal code created by Canada Post based on population density and geography to sort and deliver mails in Canada. They are commonly used as neighborhood or community boundaries in various Canadian health studies.[89,120–122] In total, there were 521 FSAs in Ontario according to Census 2021 Statistics Canada. Income data were not available for five FSAs, and the CLSA dataset included 492 FSAs within Ontario. An additional 39 FSAs with fewer than two participants were excluded from the analysis. After merging the FSA-level variables with the CLSA dataset, the final number of FSAs included in the analysis was reduced to 453.

3.4.2 Measurements

3.4.2.1 Dependent Variables

The primary outcomes were self-reported oral health (SROH), functional dentition (FD), and last dental visit (LDV).

1. SROH was measured using the question: "In general, would you say the health of your mouth is excellent, very good, good, fair or poor?" with answers of excellent, very good, good, fair and poor. Consistent with previous research, the responses were dichotomized as: good SROH (excellent, very good, good) versus poor SROH (fair or poor) for analysis.[16,37]
2. FD was measured by the item: "Do you have 20 or more natural teeth?", with responses coded as absence of FD versus presence of FD for analysis.
3. Last dental visit was assessed using the question: "When did you last visit a Dental Professional?" with response categories in the last 12 months, in the last 5 years, in the last 10 years, more than 10 years ago and never visited a dentist. For the purpose of analysis, responses were dichotomized as last dental visit in less than 12 months versus last dental visit more than 12 months.

3.4.2.2 Independent Variables

3.4.2.2.1 Individual-level Variables

The individual-level variables include:

1. Age (years) – recorded as continuous variable and categorized as: middle-aged adults: <65 years, young-old: 65 to 74 years, middle-old: 75 to 84 years, oldest-old: 85 years and above for analysis based on previous research.[123,124] Older adults were defined as those aged 65 years and above, consistent with the eligibility age for the Old Age Pension in Canada.[125]
2. Sex – assessed and categorized as male and female
3. Post-secondary education – assessed as: No post-secondary degree, certificate, or diploma/trade certificate or diploma from a vocational school or apprenticeship training/ non-university certificate or diploma from a community college, CEGEP, school of nursing etc/ University certificate below bachelor's level/ Bachelor's degree/University degree or certificate above bachelor's degree. For analysis, these were further grouped into post-secondary education completed (if at least earned a trade

certificate or diploma from a vocational school or apprenticeship training) versus post-secondary education not completed

4. Race – coded as white (for white only) and non-white (for all other racial groups)
5. Total household income ($)– based on the question: “What is your best estimate of the total household income received by all household members, from all sources, before taxes and deductions, in the past 12 months?” Responses were grouped as: <$20,000; $20,000–49,999; $50,000–99,999; $100,000–149,999; and ≥$150,000
6. Type of dental insurance – based on the question: “What type of dental insurance do you have?” with response options: no insurance, private insurance, or government insurance.

3.4.2.2.2 FSA-level Variables

The FSA-level variables include:

1. Dentist-to-population ratio (DPR) at the FSA level, calculated by dividing the number of dentists in each FSA by its population.
2. FSA-level income is based on median total household income, derived from the 2021 Census community profile at the FSA level.
3. Geographic remoteness, coded as urban or rural based on the second character of the FSA code, where ‘0’ indicates rural and any other character indicates urban.

3.4.3 Conceptual Model

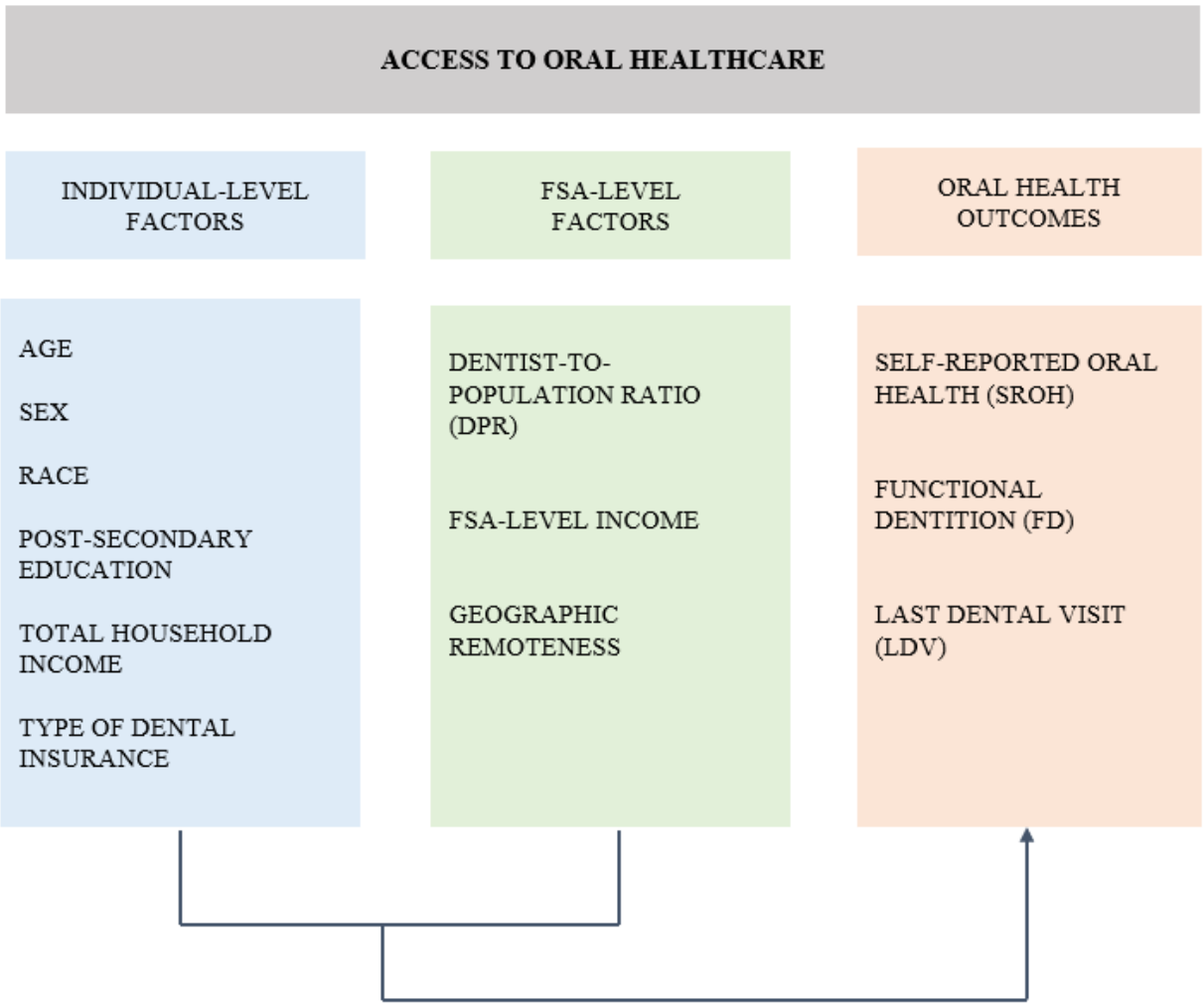

Figure 10: Conceptual model showing association between individual-level and FSA-level factors of oral healthcare access and oral health outcomes

3.4.4 Statistical Analysis

Frequency distributions for categorical variables and descriptive statistics for continuous variables were applied to assess the sociodemographic characteristics and oral health outcomes of the study sample and FSA level variables. Sampling weights were applied as described by the CLSA. Inflation weights were used to generate population-representative descriptive estimates, while analytic weights were applied for inferential analyses. [126]

Multilevel binary logistic regression (Random Intercept Model) was performed to evaluate the association between individual and FSA-level variables and individual's oral health outcomes across FSAs. For objective 1 (Model 1), a series of null models (models with no predictors or covariates) were first estimated for each outcome (SROH, FD, LDV). A null model (also known as an empty model or intercept-only model) is the foundational step in multilevel modelling. It included no predictor variables, only a random intercept for the higher-level unit in our study, the FSA. This helps us to partition the total variance in each outcome into between FSA variance and within FSA variance. This helps determine whether there is sufficient variation in the outcome across FSAs to justify multilevel modelling. For objective 2 (Model 2), individual-level variables were added to the null model. These included: Age (<65 years, 65 to 74 years, 75 to 84 years, 85 years and above), Sex (Male/Female), Post-secondary education (post-secondary education completed / not completed), Race (White/Non-White), Total household income (<$20,000; $20,000–49,999; $50,000–99,999; $100,000–149,999; ≥$150,000), Type of dental insurance (No insurance / Private / Government). For objective 3 (Model 3), FSA-level variables like DPR, FSA-level income, and geographic remoteness were introduced to assess its association with oral health outcomes.

Association between predictors and outcomes (fixed effects) were interpreted using odds ratios (ORs) and their corresponding 95% confidence intervals (CIs), providing measures of both magnitude and direction. Random effects were evaluated using two measures: the Intra-Class Correlation Coefficient (ICC) and the Median Odds Ratio (MOR). The ICC estimated the proportion of total variance attributable to differences across FSAs and was calculated using the formula:

$ICC = \tau^2/(\tau^2+\pi^2/3)$,

Where: τ^2 is the variance of the random effects and $\pi^2/3$ is the residual variance of the standard logistic distribution.

The MOR was used to quantify FSA-level variance on the odds ratio scale and was calculated using:

MOR = exp (sqrt (2 * V_A) * 0.6745),

Where V_A is the variance of the FSA-level random intercept.

Unlike the ICC, which reflects the proportion of total variance due to clustering, the MOR translates this variance into an interpretable OR scale, showing the median increase in odds when a randomly selected individual moves from an area with lower odds of an outcome to an area with higher odds. Since the MOR depends only on area-level variance and the ICC depends on both area- and individual-level variance, these measures are not equivalent and offer distinct yet complementary perspectives on between-area heterogeneity. Furthermore, the MOR can be interpreted on the same scale as fixed effects odds ratios, allowing for direct comparison. The FSA-level income variable was rescaled by dividing it by 10,000 to facilitate more interpretable odds ratio estimates. All individual- and area-level predictors were grand-mean centered prior to analysis to allow for a meaningful intercept interpretation. For categorical variables, this was done by subtracting the overall sample proportion from each binary value (0 or 1). The method and rationale for centering in multilevel modeling are discussed in the literature.[127] All analyses were conducted using SAS 9.4, with the multilevel models estimated using the PROC GLIMMIX procedure and pooled estimates across imputed datasets obtained using PROC MIANALYZE.

To handle missing data, Multiple Imputation by Chained Equations (MICE) was implemented using the Fully Conditional Specification (FCS) method to iteratively impute missing values under the assumption that a joint distribution exists for the dataset. Logistic regression was employed for imputing categorical variables. The missing data patterns were examined and determined to be arbitrary. The missing data were assumed to be Missing at Random (MAR). All variables used in the final analysis were included in the imputation model to enhance the accuracy of the imputations. A total of 10 imputed datasets were generated. Convergence criteria for all the imputations were satisfied. Following imputation, the frequency distributions of observed and imputed values were compared to assess the plausibility of the results that account for imputation uncertainty and Rubin's rules were used to obtain pooled final parameter estimates and standard errors. The CLSA study used two modes of interview for data

collection [Telephonic (Tracking dataset) and In-person (Comprehensive dataset)] which can introduce response bias that could be misinterpreted as area-level effects. Therefore, the survey design variable 'Mode of interview' was controlled in the null model for all outcomes. This ensures that the variation is not artificially inflated by differences in data collection methods. This step provides a robust foundation for subsequent models that explore individual and FSA-level influences on oral health outcomes.

Ethical Considerations:

Ethical approval for this study was obtained from the Health Sciences Research Ethics Board (HSREB) at Western University in London, Ontario, Canada.

3.5 Results

3.5.1 Characteristics of CLSA Participants

The sample was composed of 8821 participants aged 50 and above who participated in the second follow-up wave of the CLSA, representing 4152381 Ontarians (Table 2). Approximately 50% of the participants were above 65 years and female; and a majority were white, had completed post-secondary education and were either married or in a common-law relationship. A total of 8,821 participants were distributed across 453 FSAs. The mean DPR across FSAs was 75.8, with a median of 67.5. About 10.1% reported poor SROH, 17.9% had no FD, and 14.1% reported no dental visits in the previous year. 36.4% lacked dental insurance; only around 7% of them had government coverage.

3.5.2 Geographic Variation in Oral Health Outcomes

The null models (Model 1) revealed statistically significant between-FSA variance for all oral health outcomes: SROH (0.402), FD (0.340), and LDV (0.509). The corresponding ICCs were 10.9% for SROH, 9.4% for FD, and 13.4% for LDV, suggesting that 10.9%, 9.4% and 13.4% of the total variation in these outcomes can be attributed to differences between FSAs. This highlights the relevance of a multilevel modelling approach. The MOR values were 1.83, 1.74 and 2.00 for SROH, FD and LDV respectively. This means, for example, that if an individual moved from an FSA with lower odds of poor SROH to a FSA with higher odds, their likelihood of reporting poor SROH would increase 1.83 times or by 83%, reflecting significant geographic variation. Such variation can be attributable to differences in individual-level characteristics, FSA-level factors, or both.

Table 2: Characteristics of study participants, CLSA follow-up wave 2, 2018-2021 (n=8821); weighted percentage

Variable	Category	Prevalence (%)
Survey design		
Mode of interview	Telephonic	87.05
	In-person	12.95
Socio-demographic characteristics		
Age	<65 years (Middle aged)	49.44
	65-74 years (Young old)	29.86
	75-84 years (Middle old)	15.76
	>=85 years (Oldest old)	4.94
Sex	Female	52.76
	Male	47.24
Marital status	Single, never married or never lived with a partner	6.22
	Married/living with a partner in a common-law relationship	73.88
	Separated	3.91
	Divorced	5.95
	Widowed	10.04
Race	White	93.73
	Non-white	6.27
Post-education	Post-secondary education completed	70.38
	Post-secondary education not completed	29.62
Total household income	Less than $20,000	3.28
	$20,000 or more, but less than $50,000	18.58
	$50,000 or more, but less than $100,000	29.97
	$100,000 or more, but less than $150,000	18.34
	$150,000 or more	18.13
	Missing	11.69
Oral health variables		
Self-reported oral health	Poor	10.07
	Good	89.07
	Missing	0.86
Functional dentition	Absent	17.94

	Present	81.07
	Missing	0.99
Last dental visit	Last dental visit in more than 12 months ago	14.11
	Last dental visit in less than 12 months	85.12
	Missing	0.77
Availability of dental insurance	No	36.44
	Yes	62.74
	Missing	0.82
Type of dental insurance	No insurance	36.44
	Government	6.82
	Private	55.92
	Missing	0.82
FSA level variables (No. of FSA= 453)		
Geographic remoteness	Rural FSA	13.81
	Urban FSA	86.19
Dentist-to-population ratio	Mean	75.8
	Median	67.5
	Standard deviation	56.3
	Min-Max	0 - 1425.49
FSA-level income	Mean	98630
	Median	99000
	Standard deviation	22715.6
	Min-Max	45200 - 164000

3.5.3 Individual-level Effects

In Model 2, among the six individual-level variables (age, sex, race, post-secondary education, total household income, and type of dental insurance), age, sex, total household income, and type of dental insurance consistently showed significant associations across all models for all outcomes. Specifically, females had significantly lower odds of experiencing negative oral health outcomes compared to males: poor SROH (OR = 0.69, 95% CI: 0.59–0.80), absence of FD (OR = 0.75, 95% CI: 0.66–0.86), and last dental visit in over 12 months (OR = 0.67, 95% CI: 0.59–0.77).

With respect to age, individuals classified as "middle-old" and "oldest-old" were significantly less likely to report poor SROH than those in the middle-aged group. In contrast, for FD, older age was associated with worse outcomes: all three older age categories showed significantly higher odds of lacking FD compared to their middle-aged counterparts, and the odds increased progressively with age (ORs: 2.50 < 4.37 < 5.91). This pattern suggests that the likelihood of being completely or partially edentulous rises sharply with increasing age. The “middle-old” group had lower odds (OR=0.8, 95% CI: 0.65–0.99) of LDV over 12 months ago compared with the middle-aged group, while the associations for the other age groups were not statistically significant.

Individuals with private dental insurance had lower odds of poor outcomes compared to individuals without a dental insurance [SROH: OR = 0.59 (95% CI: 0.49–0.71); FD: OR = 0.81 (95% CI: 0.69–0.94); LDV: OR = 0.35 (95% CI: 0.30–0.41)]. Having government dental insurance was also associated with lower odds of poor SROH (OR = 0.68, 95% CI: 0.50–0.93) and of LDV over 12 months ago (OR = 0.37, 95% CI: 0.28–0.50), while no significant association was observed for FD. Higher total household income was significantly associated with better oral health for the three outcomes, with odds of negative outcomes decreasing as income increased. Individuals who had completed post-secondary education had reduced odds of lacking FD (OR = 0.56, 95% CI: 0.49–0.64) and LDV (OR = 0.76, 95% CI: 0.65–0.89), compared to those without post-secondary education, whereas it was not significantly associated with poor SROH (p=0.39). Race was not significantly associated with any of the oral health outcomes.

Table 3: Random intercept model for 'Poor self-reported oral health' showing the Null Model (Controlled for survey design), Model 2 (survey design & individual variables), Model 3 (survey design, individual and FSA level variables)

	Model 1 (Null Model)				Model 2				Model 3			
Fixed effects	**OR**	**95% CI**		**p value**	**OR**	**95% CI**		**p value**	**OR**	**95% CI**		**p value**
Intercept	0.11	0.10	0.13	<.0001	0.74	0.45	1.21	0.224	0.78	0.44	1.40	0.409
In-person interview	0.75	0.62	0.91	0.004	0.79	0.65	0.96	0.016	0.79	0.64	0.96	0.018
Age 65 to 74 years (Young old)					1.02	0.85	1.23	0.798	1.02	0.85	1.23	0.796
Age 75 to 84 years (Middle old)					0.71	0.56	0.90	0.005	0.71	0.56	0.90	0.005
Age 85 years and above (Oldest old)					0.62	0.42	0.91	0.014	0.62	0.42	0.91	0.015
Female					0.69	0.59	0.80	<.0001	0.68	0.59	0.80	<.0001
Post-secondary education completed					0.92	0.77	1.11	0.390	0.93	0.78	1.11	0.410
White					0.75	0.55	1.01	0.062	0.75	0.55	1.02	0.063
$20,000 or more, but less than $50,000					0.65	0.43	0.98	0.039	0.64	0.43	0.97	0.034
$50,000 or more, but less than $100,000					0.33	0.22	0.49	<.0001	0.32	0.22	0.48	<.0001
$100,000 or more, but less than $150,000					0.25	0.17	0.38	<.0001	0.25	0.17	0.37	<.0001
$150,000 or more					0.14	0.08	0.23	<.0001	0.13	0.08	0.22	<.0001
Dental insurance (Government)					0.68	0.50	0.93	0.015	0.68	0.50	0.93	0.015
Dental insurance (Private)					0.59	0.49	0.71	<.0001	0.59	0.49	0.71	<.0001
DPR									1.00	1.00	1.00	0.608
FSA income									1.02	0.97	1.07	0.511
Urban FSA									0.95	0.68	1.34	0.774
Random effects												
FSA level Variance	0.402	0.245	0.559		0.370	0.210	0.530		0.374	0.211	0.538	
ICC	10.90%				10.10%				10.20%			
MOR	1.83	1.60	2.04		1.79	1.55	2.00		1.79	1.55	2.01	
OR (Odds Ratio); ICC (Intra-class Correlation Coefficient); MOR (Median Odds Ratio)												
Reference category: Middle-aged adults (<=65 years); Male; Not completed post-secondary education; Income less than 20,000, No insurance; Rural FSAs												

Table 4: Random intercept model for 'Absence of functional dentition' showing the Null Model (Controlled for survey design), Model 2 (survey design & individual variables), Model 3 (survey design, individual and FSA level variables)

	Model 1 (Null Model)				Model 2				Model 3			
Fixed effects	**OR**	**95% CI**		**p value**	**OR**	**95% CI**		**p value**	**OR**	**95% CI**		**p value**
Intercept	0.22	0.19	0.24	<.0001	0.53	0.35	0.79	0.002	0.46	0.28	0.75	0.002
In-person interview	0.72	0.61	0.84	<.0001	0.79	0.67	0.94	0.006	0.81	0.68	0.96	0.013
Age 65 to 74 years (Young old)					2.50	2.11	2.96	<.0001	2.51	2.12	2.97	<.0001
Age 75 to 84 years (Middle old)					4.37	3.63	5.26	<.0001	4.40	3.65	5.30	<.0001
Age 85 years and above (Oldest old)					5.91	4.55	7.68	<.0001	5.95	4.57	7.74	<.0001
Female					0.75	0.66	0.86	<.0001	0.76	0.66	0.86	<.0001
Post-secondary education completed					0.56	0.49	0.64	<.0001	0.56	0.49	0.65	<.0001
White					0.92	0.69	1.21	0.544	0.91	0.69	1.20	0.507
$20,000 or more, but less than $50,000					0.65	0.47	0.90	0.009	0.66	0.48	0.91	0.011
$50,000 or more, but less than $100,000					0.37	0.27	0.52	<.0001	0.38	0.27	0.53	<.0001
$100,000 or more, but less than $150,000					0.25	0.18	0.36	<.0001	0.26	0.18	0.37	<.0001
$150,000 or more					0.17	0.12	0.25	<.0001	0.18	0.12	0.26	<.0001
Dental insurance (Government)					1.08	0.84	1.39	0.566	1.08	0.84	1.40	0.536
Dental insurance (Private)					0.81	0.69	0.94	0.005	0.81	0.70	0.94	0.006
DPR									1.00	1.00	1.00	0.352
FSA income									0.97	0.92	1.01	0.121
Urban FSA									1.11	0.82	1.49	0.500
Random effects												
FSA level Variance	0.340	0.220	0.461		0.293	0.169	0.417		0.293	0.168	0.418	
ICC	9.40%				8.20%				8.20%			
MOR	1.74	1.56	1.91		1.68	1.48	1.85		1.68	1.48	1.85	
OR (Odds Ratio); ICC (Intra-class Correlation Coefficient); MOR (Median Odds Ratio)												
Reference category: Middle-aged adults (<=65 years); Male; Not completed post-secondary education; Income less than 20,000, No insurance; Rural FSAs												

Table 5: Random intercept model for 'Last Dental Visit more than 12 months' showing the Null Model (Controlled for survey design), Model 2 (survey design & individual variables), Model 3 (survey design, individual and FSA level variables)

	Model 1 (Null Model)				Model 2				Model 3			
Fixed effects	**OR**	**95% CI**		**p value**	**OR**	**95% CI**		**p value**	**OR**	**95% CI**		**p value**
Intercept	0.15	0.14	0.18	<.0001	1.42	0.93	2.17	0.106	1.65	0.99	2.76	0.055
In-person interview	1.06	0.89	1.27	0.491	1.15	0.97	1.38	0.111	1.21	1.01	1.45	0.041
Age 65 to 74 years (Young old)					0.87	0.73	1.02	0.086	0.87	0.74	1.03	0.100
Age 75 to 84 years (Middle old)					0.80	0.65	0.99	0.036	0.81	0.66	0.99	0.041
Age 85 years and above (Oldest old)					0.95	0.71	1.28	0.750	0.95	0.71	1.28	0.750
Female					0.67	0.59	0.77	<.0001	0.67	0.59	0.77	<.0001
Post-secondary education completed					0.76	0.65	0.89	0.001	0.77	0.66	0.90	0.001
White					0.77	0.59	1.01	0.057	0.76	0.58	0.99	0.044
$20,000 or more, but less than $50,000					0.63	0.43	0.91	0.015	0.64	0.44	0.92	0.018
$50,000 or more, but less than $100,000					0.32	0.22	0.46	<.0001	0.33	0.23	0.48	<.0001
$100,000 or more, but less than $150,000					0.25	0.17	0.38	<.0001	0.26	0.18	0.39	<.0001
$150,000 or more					0.25	0.17	0.38	<.0001	0.26	0.17	0.40	<.0001
Dental insurance (Government)					0.37	0.28	0.50	<.0001	0.38	0.28	0.51	<.0001
Dental insurance (Private)					0.35	0.30	0.41	<.0001	0.35	0.30	0.41	<.0001
DPR									1.00	1.00	1.00	0.214
FSA income									0.95	0.90	1.00	0.034
Urban FSA									0.78	0.57	1.07	0.122
Random effects												
FSA level Variance	0.509	0.341	0.676		0.377	0.224	0.530		0.366	0.212	0.520	
ICC	13.40%				10.30%				10.00%			
MOR	2.00	1.70	2.20		1.80	1.60	2.00		1.80	1.60	2.00	
OR (Odds Ratio); ICC (Intra-class Correlation Coefficient); MOR (Median Odds Ratio)												
Reference category: Middle-aged adults (<=65 years); Male; Not completed post-secondary education; Income less than 20,000, No insurance; Rural FSAs												

3.5.4 Area-level Effects

In model 3, after incorporating FSA-level variables into the model, while controlling for individual-level characteristics, only FSA-level income showed statistically significant association with LDV. However, the odds ratio (OR = 0.95) was very close to 1, suggesting only a weak inverse association. It suggests that for every 10,000 dollars increase in FSA income, the odds of not having a dental visit in the last 12 months (LDV) decreased by 5%. None of the other FSA-level variables showed significant association with any of the three oral health outcomes (SROH, FD, or LDV), indicating a limited contribution of FSA-level factors in explaining oral health outcomes.

3.6 Discussion

This study used CLSA data from the follow-up wave 2 to examine how individual- and area-level oral healthcare access factors are associated with oral health outcomes among Ontario's middle-aged and older adult population. A substantial proportion of participants reported negative oral health outcomes. The presence of significant FSA-level variation in oral health outcomes suggests that individual- and/or FSA-level factors may impact oral health. Although few studies have examined area-level variation in oral health outcomes, some evidence supports its presence. For example, Bower et al. observed significant differences in oral health across postcode sectors in Scotland, while a study in Brazil reported notable variation at both city and neighborhood (Census sector) levels.[128,129]

Findings from our study's multilevel analysis showed that except race, other individual-level access to oral healthcare factors including age, sex, total household income, post-secondary education, and type of dental insurance were significantly associated with oral health outcomes. These findings are comparable to several other studies. A longitudinal study in Canada reported that the likelihood of rating oral health as poor increased with age.[14] Interestingly, in our study, the two oldest age groups reported better SROH despite having significantly higher odds of lacking FD compared to middle-aged adults. This finding is consistent with previous research. For instance, one study found that individuals aged 67 or younger were 225% (OR=3.25) more likely to report poor SROH compared to those older than 67 years. [130] Likewise, a United States study reported that the odds of experiencing tooth loss were greater for all age groups above 55 years compared to those aged 45–54 years, with the odds increasing progressively across older age categories. [131] The findings in our study possibly reflect age-related differences in

how oral health is perceived. Older adults may normalize tooth loss and diminished function as part of aging, and still rate their oral health positively. This may suggest that self-reported outcomes may be influenced by cultural expectations, personal adaptation, and individual health beliefs.[14] Studies in the past have shown that reduced chewing ability is associated with poorer self-rated oral health. [130,132,133] However, edentulous individuals may adapt to their condition and report satisfactory oral health, whereas dentate individuals particularly those experiencing pain, discomfort, or functional problems may be more likely to report oral health issues. [134] These findings emphasize the importance of interpreting subjective indicators within a broader context and, when possible, triangulating them with objective clinical assessments. LDV was not associated with age in our study except for one category. This contradicted with studies in which the utilization rate was found to decrease as age increased. [85,135]

In our study, females reported significantly lower odds of poor oral health outcomes. However, findings on sex differences in oral health perception and outcomes have been mixed. In a study from Thailand, no significant relationship was observed between sex and SROH in older adults, whereas another study found males reported reduced use of dental services. [130,135] However, the findings from our study are consistent with another analysis of CLSA data, which showed that females reported lower prevalence of poor SROH compared to males.[37] Additionally, a study from Brazil found a greater percentage of older women reported their oral health as excellent or good compared to men.[136]

As expected, socioeconomic factors such as educational attainment and income, and dental insurance were protective against poor oral health outcomes. A clear gradient was observed between total household income and all three outcomes, with the odds of negative outcomes decreasing progressively across higher income categories. Individuals with postsecondary education were less likely to report not having a FD and more likely to have had their LDV in the past year. Insurance coverage, both private and public, was also protective compared to non-insured individuals. A similar dose-response association between socioeconomic status and oral health outcomes has been reported in other studies involving older adults, particularly dental service utilization and tooth loss.[44,85,135] Furthermore, some studies have reported that higher levels of education and income are positively linked to greater use of dental services and lower prevalence of tooth loss among the elderly. [85,131,137]

However, in our study, FSA-level variables (DPR, FSA-level income, geographic remoteness) were of less significant association with oral health outcomes after adjusting for individual-level predictors, except for a weak association between FSA-level income and LDV, suggesting oral health inequalities to be more strongly driven by individual-level oral healthcare access-related factors. These findings are consistent with previous multilevel studies that reported similar patterns. For instance, a study in Scotland found that area-level deprivation was not significantly associated with oral health outcomes after adjusting for individual-level factors.[128] Likewise, another study found no association between tooth loss and the DPR.[131] However, our findings contrast with other studies that found significant relationships between area-level socioeconomic status and these oral health outcomes. For example, a U.S. study reported that greater income inequality at the state level, as measured by the Gini coefficient, was linked to increased rates of tooth loss.[131] A study in France found higher dental service use in high-income areas, regardless of density of dental practitioners. [85] In Korea, regional deprivation was linked to poorer oral health outcomes in both adults and seniors; and tooth loss was lower in cities with higher Human Development Index (HDI)-income and HDI-education scores in Brazil. [44,138]

We included last dental visit as an outcome alongside other self-reported measures, as it is commonly acknowledged in the literature as a key measure of oral healthcare access. It is frequently used as a proxy for dental service utilization in population-based studies.[78,114,115] FD was selected in place of edentulism due to its relevance to essential oral functions such as chewing, speaking, and denture use.[109,110] It also serves as an indicator of disease control and overall oral hygiene, making it a meaningful measure of oral health. Likewise, SROH is commonly used in large population-based surveys as a practical and economical means of capturing individuals' perceptions of their oral health, particularly when clinical examinations are not feasible.[42,112] Although all outcomes in this study are self-reported and therefore there is a potential for reporting bias, they remain widely accepted and utilized in large-scale population health research. Additionally, the CLSA study did not include objective oral health measurements. Various measures have been used to assess area-level socioeconomic status in previous studies, including neighborhood income, the Human Development Index, the Gini coefficient, and deprivation indices. [44,85,131,138] In our study, median total household income was used to represent FSA-level income, as it was available from the same Census data as population counts and it is consistent with prior Canadian research on area-level socioeconomic

factors.[74,89,139] Median income is preferred over mean because it is less influenced by extreme values and might reflect the typical economic conditions within an area.

Strengths and limitations: To the best of our knowledge, this is the first study in Ontario to utilize multilevel modelling to examine the association between access-to-oral healthcare factors at both individual- and FSA-level and oral health outcomes. The CLSA includes participants aged 50 years and above, allowing for the examination of midlife factors that influence health trajectories into older age. Including the oldest age group provides insight into the transitions experienced during the later years of life. [118] This is particularly relevant for oral health, as middle-aged adults often begin to experience declines that may worsen over time. Unlike ecological studies that rely on aggregated outcomes and use area-level predictors as proxies for individual-level characteristics, this study used individual-level oral health outcomes within a multilevel framework. This approach reduces the risk of ecological fallacy and enables a more accurate assessment of both individual and area-level influences on oral health. Additionally, incorporating three oral health outcomes (SROH, FD, and LDV) allowed for a comprehensive assessment of oral health among the study population. Collectively, these outcomes offered complementary insights that strengthened the overall interpretation of the results.

While many previous multilevel studies have identified associations between area-level access factors and oral health outcomes, our study did not find any statistically significant relationships despite having significant FSA-level variation in all three oral health outcomes. One potential explanation lies in the use of CLSA data, which was not designed to be representative at small geographic scales such as FSAs. A study from Calgary comparing CLSA and census data at the FSA level reported notable discrepancies, suggesting that local-level estimates may not align with national or provincial trends.[140] However, no similar validation has been conducted in Ontario, and this remains an area that warrants future research. FSAs were used as the geographic unit of analysis because they provide a scale between individual postal codes and Census Subdivisions (CSD) with sufficient CLSA respondents for analysis. [141] Also, FSAs vary in size, especially in rural areas, and may not correspond to socially cohesive neighborhoods. Observed differences may therefore reflect broader geographic factors rather than localized area-level effects, highlighting the influence of the Modifiable Areal Unit Problem (MAUP).[142]

Additionally, the FSAs in CLSA sample are predominantly urban, which enhances its relevance to urban populations but limits generalizability to rural areas. Some FSAs in our sample included as few as two participants, which might have limited the statistical power to detect area-level differences and potentially introducing unstable or biased estimates. To assess the robustness of our findings, a sensitivity analysis was conducted excluding FSAs with fewer than 10 participants, and results remained consistent. This further supports the concern that FSAs may not function as the best geographic units while using the CLSA data. Certain groups including low-income individuals, institutionalized individuals, those living on First Nations reserves, and people who do not speak English or French are excluded or underrepresented in the CLSA, further restricting generalizability to underserved populations or FSAs with distinct demographic profiles. Additionally, our analysis did not account for cross-boundary oral healthcare-seeking behaviors, such as individuals receiving oral healthcare outside their residential FSA. As a result, the DPR used may not reflect actual exposure to dental resources, potentially leading to misclassification and attenuated associations with oral health outcomes.

A significant FSA-level variance suggests meaningful proportion of variation in oral health outcomes remains attributable to differences between individuals and/or FSAs. This indicates that unmeasured individual- and FSA-level factors may still play a role in influencing oral healthcare utilization across FSAs. Finally, this study's cross-sectional design limit causal inference; associations observed reflect correlations at a single point in time. Despite these limitations, the CLSA's methodological rigor, large sample size, and the use of individual- and area-level data in this study provide a valuable basis for advancing oral health equity research in aging populations.

Chapter 4

4 Integrated Discussion

The overarching aim of this thesis was to investigate the distribution of dentists across Ontario's Forward Sortation Areas (FSAs) relative to the population, and to examine how both individual- and FSA-level factors related to access to oral healthcare are associated with oral health outcomes among middle-aged and older Ontarians. The thesis comprised two studies. The first involved a spatial mapping and inequality measures to evaluate the geographic distribution of dentists across FSAs and to assess how this distribution varies by FSA-level factors such as income and geographic remoteness. The second study was a cross-sectional analysis using data from the Canadian Longitudinal Study on Aging (CLSA) linked to Royal College of Dental Surgeons of Ontario (RCDSO) data to explore associations between individual-level access factors and oral health outcomes, as well as the effect of FSA-level access to oral healthcare indicators after adjusting for individual-level characteristics.

While previous studies have identified area-level inequalities in the supply of oral healthcare providers in parts of Ontario, often highlighting better access in urban and affluent areas, these analyses have been limited in scope. Most have focused on specific regions, examined only certain provider types such as dental hygienists, or failed to assess dentist distribution at the FSA level across the entire province.[43,51,73] As a result, there is a lack of comprehensive, province-wide evidence on dentist distribution using small-area geographic units. This study addresses that gap by using FSAs as the unit of analysis to assess dentist distribution and its implications for oral health access in Ontario. The use of FSAs was guided by prior health research in Canada, including regional studies in Ontario and province-wide analyses of dental hygienist supply.[43,73] The inclusion of FSA-level covariates such as income and geographic remoteness is consistent with Canadian and international studies that highlight the influence of socioeconomic context and geographic location on the distribution of oral healthcare providers.[22,43,48,50,61,94,95] Although the impact of individual- and area-level factors on oral health is well established, to our knowledge, no research has explored these relationships within Ontario using small-area units such as FSAs. Understanding dentist distribution at this localized level is critical, as uneven access to providers can lead to significant barriers in

receiving timely and preventive oral healthcare, ultimately affecting oral health outcomes. This study therefore sheds light on localized inequalities in dentist distribution and examines how these area-level structural inequalities, in combination with individual factors, influence self-reported oral health (SROH), functional dentition (FD), and Last dental visit (LDV) among aging Ontarians.

Chapter 2 contributes to the literature by deepening the understanding of structural inequalities in access to oral healthcare through a geographic lens in Ontario. It highlights how the spatial distribution of oral healthcare resources, specifically dentists, reflects broader patterns of social and geographic inequality. By focusing on FSA-level characteristics such as income and remoteness, this chapter highlights the area-based determinants that shape the distribution of dentists. This contribution is particularly important in contexts like Ontario, where oral healthcare is not universally insured, and where provider location can significantly shape access to services.[20,22,28,37] The chapter offers an important structural perspective on equity, demonstrating how geographic context itself can produce or reinforce disadvantage in oral healthcare access.

Chapter 3 focuses on oral health inequalities among middle-aged and older adults in Ontario, examining how both individual- and FSA-level factors influence oral health outcomes such as SROH, FD and LDV. Using a multilevel modeling approach, it explores who is affected and why, emphasizing the influence of key individual socioeconomic and demographic determinants of oral healthcare access such as income, dental insurance, age, and sex. This analysis is particularly timely as Canada is undergoing a significant demographic transition marked by a growing population of older adults, especially from the baby boomer generation.[2] In line with global public health priorities, healthy aging has emerged as a central concern, with oral health recognized as a critical component, not merely the absence of disease, but the ability to maintain function, social connection, and overall well-being.[7,106,109] Conditions like tooth loss, often the outcome of preventable oral diseases, can severely impact nutrition, cognition, communication, and quality of life.[4,106,109,110] This chapter highlights persistent geographic inequalities in oral health status and access within the aging population, a group with unique vulnerabilities and healthcare needs.

4.1 Synthesis of Key Findings

4.1.1 Geographic and Socioeconomic Inequalities in Dentist Distribution in Ontario

We examined the geographic distribution of dentist-to-population ratios (DPR) across Ontario's FSAs, with particular attention to variation by FSA-level income and geographic remoteness. To provide a comprehensive evaluation of inequalities in access to oral healthcare, this study integrated spatial visualization through choropleth maps with quantitative inequality metrics, specifically the Lorenz Curve and Gini coefficient.

Descriptive analysis revealed considerable variation in DPR across FSAs, with clear evidence of both under-servicing and over-servicing in certain areas. These spatial inequalities were closely associated with FSA-level socioeconomic and geographic characteristics. FSAs with higher income and urban classification consistently demonstrated higher DPR values, while lower-income and rural FSAs exhibited lower dentist densities, indicating a patterned inequity in provider distribution.

While choropleth maps allowed us to visually highlight this maldistribution, the Lorenz Curve and Gini coefficient enabled a more precise quantification of inequality across FSA-level income quintiles and remoteness categories. The Lorenz Curves for higher income quintiles were closer to the line of equality, whereas those for lower income quintiles deviated substantially from it. This pattern was also reflected in the Gini coefficient values, which declined with increasing income levels, indicating more equal dentist distribution in wealthier FSAs. Similarly, in terms of geographic remoteness, urban FSAs exhibited Lorenz curves farther from the equality line and had higher Gini values than their rural counterparts. By applying these inequality measures across both income and remoteness groupings, we were able to show not only how the value of inequality varied by group but also to identify which specific groups experienced greater inequalities in dentist distribution. Our findings suggest that the most unequal distribution of dentists occurred in lower-income and urban FSAs, revealing critical intra-group inequalities in access to oral healthcare that may be masked by aggregate-level patterns.

4.1.2 Individual and Area-level Access to Oral Healthcare and Oral Health Outcomes Among Middle-Aged and Older Adults in Ontario: A Data Linkage Analysis of the Canadian Longitudinal Study on Aging (CLSA)

We used cross-sectional data from the second CLSA follow-up to conduct a multilevel analysis examining how access to oral healthcare at both the individual- and FSA-levels relates to oral health outcomes among middle-aged and older Ontarians. Our study participants included respondents aged 50 years and above, and we selected three oral health indicators as outcomes SROH, FD, and LDV based on their established relevance in the literature. Guided by a multilevel framework, we used two-level random intercept models to account for clustering within FSAs, allowing us to distinguish between individual- and FSA-level effects.

Across all three oral health outcomes, the null models demonstrated significant geographic variation, with Intraclass Correlation Coefficients (ICCs) indicating that the variation was attributable to differences between FSAs. The Median Odds Ratio (MOR) values reinforced this finding, showing that the odds of negative oral health outcomes could nearly double when a person moves from an FSA of lower odds of negative outcome to an FSA of higher odds. These results justify the use of multilevel modelling and highlighted the importance of both individual- and FSA-level influences on oral health.

Individual-level access to oral healthcare factors were significantly associated with oral health outcomes. We found that females had lower odds of poor SROH, lacking FD, and not having dental visits in the previous year, a pattern consistent with sex differences observed in other oral health research. Interestingly, while older adults were more likely to lack FD, they reported better SROH compared to their middle-aged counterparts. This finding suggests a possible disconnect between clinical indicators and perceived oral health among older individuals, potentially reflecting a process of adaptation or shifting health expectations with age. Lower total household income and the absence of dental insurance were strongly and consistently linked to poorer outcomes, with income demonstrating a clear dose-response relationship. These findings support previous studies emphasizing the persistent role of socioeconomic inequalities in shaping oral health. Notably, having private dental insurance appeared to be

particularly protective across all three outcomes, reinforcing the importance of dental coverage in facilitating timely and preventive care.

At the area level, only one significant association was observed. FSA-level income showed only a weak association with LDV, and no significant relationships were found between other FSA-level variables and oral health outcomes. This contrasts with findings from other studies that have reported significant area-level influences on oral health. One possible explanation is that FSAs may not adequately capture relevant neighborhood-level social and service-related contexts, and the CLSA's sampling design does not ensure representativeness at this geographic level. As such, our area-level findings should be interpreted with caution. However, the robustness of individual-level findings, particularly those related to age and sex, suggests that these results are generalizable to the provincial population of middle-aged and older adults. Although the FSA-level variables were not statistically significant, this does not diminish the relevance of area-level access factors in oral healthcare. The lack of significance may be attributed to methodological limitations or sampling-related issues.

4.2 Strengths and Limitations:

The first study provides an assessment of dentist distribution across Ontario using the most recent and comprehensive data from the RCDSO. Unlike studies based on census or commercial data, this analysis used self-reported practice addresses from a mandated source, improving spatial accuracy.[51,116] The use of FSAs enabled small-area analysis, and the application of Gini coefficients and Lorenz Curves enhanced transparency in measuring inequality. However, some FSAs were excluded due to invalid or non-residential codes, and reporting delays may introduce minor inaccuracies. While the Gini coefficient offers clarity, it has limitations in capturing distribution extremes and lacks standardized interpretation thresholds.[101]

The second study applies multilevel modeling to examine how both individual- and FSA-level access factors relate to oral health outcomes, using data from the CLSA. The large, diverse sample of adults aged 50 and above enables analysis across midlife and older age groups. However, the CLSA was not designed to be representative at smaller geographic units like FSAs, and the sample is predominantly urban, limiting applicability to rural or underserved areas. Additionally, some groups such as low-income individuals, those in institutions or on

reserves, and non-English/French speakers are underrepresented because of the CLSA's eligibility criteria. Finally, the cross-sectional design limits causal inference. Despite these constraints, this study offers meaningful insights into the access related factors of oral health among middle-aged and older adults in Ontario.

4.3 Policy Implications

These studies reveal critical findings with relevance to dental health policy in Ontario. There are evident inequalities in the geographic distribution of dentists across the province. Not all areas have a sufficient number of dentists relative to their population, and this distribution appears to be influenced by area-level characteristics such as income and geographic remoteness. The associations observed between insurance, income, and oral health outcomes in middle-aged and older Ontarians highlight gaps that the Canadian Dental Care Plan (CDCP) and its expansion are expected to address. This study also provides a valuable baseline against which the impact of the CDCP can be assessed in the future. While the CDCP represents an important step toward improving affordability and expanding coverage to low-income and uninsured individuals across all age groups, coverage alone does not guarantee access.[143]

Even with expanded insurance coverage, access to oral healthcare may remain limited in regions where dental providers are not readily available. In such circumstances, individuals, particularly older adults, those with lower incomes, and those facing mobility challenges, may need to travel considerable distances to receive care. This highlights an important consideration. The full potential of programs like the CDCP can only be realized when adequate service availability accompanies insurance coverage. Ensuring a more equitable geographic distribution of dental professionals is therefore essential to maximizing the impact of the CDCP across all communities.

To address these structural access barriers, policy efforts should go beyond insurance expansion and actively support a more equitable distribution of dental professionals. This could include targeted incentives, such as relocation grants or practice start-up subsidies, for dentists willing to establish practices in underserved FSAs. Encouraging new dental graduates to complete a period of service in underserved communities, possibly through mandatory rotations or residency placements, could also help distribute services more evenly. Additionally, streamlining the credentialing process for internationally trained dentists could help increase

the dental workforce in areas with low dentist-to-population ratios. Together, these strategies can help ensure that all Ontarians, regardless of where they live, can access timely and preventive oral healthcare.

4.4 Future Research Directions

Future research can move beyond dentist-to-population ratios by integrating more dynamic area-level measures of accessibility that reflect how individuals actually reach oral healthcare services. This could include the incorporation of travel time and transportation networks such as road infrastructure, public transit routes, and availability of private transportation options to provide a more accurate representation of geographic access. For example, employing advanced spatial methods like the traditional or Enhanced Two-Step Floating Catchment Area (2SFCA) method allows calculation of an accessibility score for each area by considering both the supply of dentists and the population demand within realistic travel catchments. This approach can better capture the nuances of oral healthcare availability, including service areas overlapping multiple regions and potential cross-boundary utilization of dental providers. Considering cross-boundary care-seeking behavior is also critical, especially in densely populated urban regions where administrative boundaries do not limit patient choice. Understanding these patterns will clarify how geographic and administrative units correspond or fail to correspond to actual oral healthcare utilization. Beyond geographic factors, incorporating additional area-level socioeconomic determinants such as indices of material and social deprivation to capture broader socioeconomic vulnerabilities that may influence access to oral healthcare. Finally, to capture trends and changes over time, future research should leverage longitudinal data, that enables the examination of how individual- and area-level access factors and associated oral health inequalities evolve to establish a causal relationship.

4.5 Overall Conclusion

The first study incorporated in this thesis highlights interrelated inequalities at the FSA level in oral healthcare access-related factors, namely the DPR, FSA-level income, and geographic remoteness across Ontario. The second study further demonstrates how these FSA-level and individual-level factors, such as total household income and insurance status, influence oral health outcomes among middle-aged and older Ontarians. Although the inequalities in dentist distribution observed in the first study were particularly pronounced along income and rural-urban lines, these findings call for targeted policy action. Policymakers in Ontario should

prioritize strategies to improve access in underserved communities while addressing the needs of uninsured and low-income older adults. This work also provides a valuable baseline against which the impact of initiatives such as the CDCP can be assessed in the future. Future research should build on these findings by employing longitudinal designs to track changes in access and oral health over time, examining cross-boundary care-seeking behaviors, and incorporating a broader range of area-level factors and socioeconomic indicators to more accurately reflect the nature of oral healthcare access.

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Appendices

Appendix A: Western Research Ethics Board (REB) Study Approval Letter

Western Research

Date: 3 April 2025

To: Dr Noha Gomaa

Project ID: 120760

Review Reference: 2025-120760-106393

Study Title: Impact of Access to Oral Health Care on Oral Diseases and Multimorbidity: An Analysis of the Canadian Longitudinal Study on Aging

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Date Approval Issued: 03/Apr/2025 13:21

REB Approval Expiry Date: 26/Apr/2026

Dear Dr Noha Gomaa,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Electronically signed by:

Joshua Hatherley, Ethics Coordinator on behalf of Dr. N. Poonai, HSREB Chair 03/Apr/2025 13:21

Reason: I am approving this document

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Curriculum Vitae

Name:	Anusha P Nair
Post-secondary Education and Degrees:	Tagore Dental College & Hospital Chennai, India 2011-2016 B.D.S. SRM Institute of Science & Technology Chennai, India 2017-2019 M.P.H. The University of Western Ontario London, Ontario, Canada 2023-present MSc Epidemiology
Honors and Awards:	Western Graduate Research Scholarship 2023-2025 Graduate fellowship 2024-2025
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Publications:

Mohan N, **Prabakaran A**, Sooria CB, Thavody J, Sujina CM, Chandran P, et al. Caregiver burden for older adults with serious mental illness and factors influencing it: A community-based exploratory survey. Indian J Psychiatry 2025; In press.

Chandran P, Thavody J, Sujina CM, Mohan N, Kumar S, Tharayil HM, **Prabakaran A** et al. Undetected comorbidities in older adults with serious mental illness, and opportunities for screening – A cross-sectional study from Kerala. Indian J Psychiatry 2025; 67:391-8.

Thavody J, Sujina CM, Chandran P, Shibu Kamar TM, Tharayil HM, Mohan N and **Prabakaran A**. The Sociodemographic Profile of Community-Dwelling Older Adults with Serious Mental Illness in Kerala – A Cross-Sectional Study. Indian J Psychol Med. 2023; XX:1–6.

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