Towards a Suburban Spatial Epidemiology: Differentiating Geographical Patterns of Cancer Incidence, Patient Access, and Surgical Treatment in Canada's Urban Fringe

by

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Abstract

Epidemiological studies have traditionally categorised study populations as urban or rural. However, a growing proportion of the global population resides in spaces that are neither dense urban cores nor rural/remote regions. These interstices are distinctly suburban, featuring a low density of services, poor walkability, and spatial isolation relative to their urban counterparts. Contrary to the dominant imaginary of the affluent ‘American Dream’, Canada’s suburbs are increasingly becoming home to socioeconomically deprived populations. Following from the well-established links between socioeconomic status and health geographies, this dissertation presents quantitative geographical evidence that the suburbs differ from their urban and rural counterparts, constituting a third, epidemiologically distinct space. The first substantive chapter provides an introductory tracing of the suburb’s socioeconomic history, laying the contextual foundation for a distinct categorisation. The following three chapters then draw upon this categorisation to differentiate spatial epidemiological patterns of cancer along both urban/suburban/rural and socioeconomic axes. The second chapter uses exploratory temporal mapping to document a recent emergence of oral cancer cases in British Columbia’s suburbs, geographically coincident with immigration from betel quid-chewing regions and an increase in local socioeconomic deprivation. The third chapter then explores head and neck cancer patients’ spatial access to cancer treatment centres across the province, highlighting significantly greater travel times among the most deprived suburban and rural populations. The fourth chapter evaluates whether these spatial and socioeconomic disparities reflect actual treatment rates, focussing on resection surgeries for five cancer types across Canada, excluding Québec. Resection rates were positively associated with socioeconomic deprivation in rural areas and inversely associated in urban areas, while the highest overall rates were observed in middle-SES suburban populations. Drawing upon these three cancer studies, this dissertation proposes a suburban spatial epidemiology, in which suburbs are differentiated from urban and rural spaces. I conclude by asserting that the suburbs’ unique placial contexts merit standalone attention in health research, calling for further examination of suburban spaces in epidemiological research.

Keywords: spatial epidemiology; suburbs; cancer; spatial access; socioeconomic deprivation; geographical information systems

Dedication

This dissertation is dedicated to James Miller and Thomas Walker, whose battles with cancer motivated this work though representing but a fleck on the colourful lives they lead.

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Chapter 1.

Introduction

Human history is often traced along the process of urbanisation; from nomadic hunter-gatherer societies to agrarian villages to city-states and the present-day global metropolis, the densification of population in economic centres continues at an exponential rate [1,2]. This population dynamic has diametrically framed the city against the rural periphery [3], a dichotomisation reflected in contemporary health research. The urban/rural contrast has highlighted important geographical differences in health, however, it fails to capture the one of the greatest population shifts of 20th century North America [1,4]: the mass exodus from urban cores to the suburbs.

In the periphery of nearly every Canadian city and town are the low-density, homogeneously residential neighbourhoods that over 60% of Canadians call home [5]. Few images are more emblematic of the North American middle-class than the suburban home with the white-picket fence. However near it may be, the suburban built environment bears little, if any, similarity to the urban core [6]. Their residents live a different lifestyle than the both the rural dweller and the urbanite [7]. It may therefore be hypothesised that the individuals living in the suburbs will experience different health risks and outcomes. Increased vehicular mortality due to higher traffic volumes, obesity associated with poor neighbourhood walkability, and increased ambulance response times across sprawling subdivisions are a few examples of the small, emergent body of scholarship interrogating the geographical configuration of suburban spaces, and their impacts on human health.

1.1. Overview

This dissertation centres on a differentiation of these interstitial suburban spaces from their urban and rural counterparts. I posit that this third space features unique patterns of health and health care that hold valuable information for enhancing epidemiological research and improving health equity in Canada and abroad. This ‘suburban spatial epidemiology’ is both quantitative and interpretive in nature, predicated on a rich and innately geographical context. Through a tracing of suburban socioeconomic history and three spatial epidemiological studies, I herein present the case for a categorical distinction between urban cores and suburban neighbourhoods.

In this dissertation, I explore the utility of an urban/suburban/rural distinction focussing on its application to six different cancer types. Cancers are a category of approximately 100 diseases characterised by uncontrolled cellular growth and replication and the ability to transit through the body and invade neighbouring tissues [8]. Responsible for over eight million deaths in 2012, cancers are disproportionately prevalent in economically developed regions [9]. In Canada, cancers are the leading cause of potential years of life lost, with an estimated 197 000 new cases and 80 000 deaths in 2015 alone [10].

Advances in cancer diagnosis and treatment have led to significant reductions in mortality in recent decades, with spatial access to cancer care emerging as an important predictor of patient choice and outcome. Regional variations in cancer incidence have been observed across Canada, spurring searches for local risk factors and placing emphasis on the local availability of treatments. In British Columbia (BC), the BC Cancer Agency has instituted a province-wide network of community cancer clinics to bring chemotherapy closer to patients who reside outside the major urban centres, coupled with the construction of five new comprehensive treatment centres across the province. Simultaneously, a process of Canada-wide regionalisation is taking place in which many surgical cancer treatments are being performed only in high-volume centres. These inherently spatial processes present interesting and important avenues for geographical investigation into patient access.

This dissertation focusses on six cancer types: head and neck; lung; liver; pancreatic; ovarian/fallopian, and; oesophageal. These sites were selected due to data availability, but also are known correlates with socioeconomic deprivation, and the latter five have above-average mortality, emphasising the role of cancer care. Importantly, cancer incidence, treatment, and outcome are known to be socioeconomically dependent, such that deprived individuals generally experience higher rates of many cancer types, lower spatial and non-spatial access to treatment, and poorer outcomes. This multifaceted relationship with socioeconomic status intertwines with the Canadian suburbs' rich socioeconomic history, as is described in chapter 2.

1.2. Research Questions

In the context of socioeconomic change in the suburbs, this dissertation's empirical thrust centres on geographies of cancer incidence and treatment. The broader theoretical frame is guided by the following questions:

1. What are the contextual trends and forces that reproduce socioeconomically divergent spaces in suburban Canada ?

2. How does this contextual backdrop reflect geographical trends and patterns in cancer incidence ?

3. In what ways do the socioeconomic disparities experienced in urban, suburban, and rural Canada reflect cancer patients' spatial access to treatment ?

Rather than testing each question as a hypothesis, this dissertation takes an exploratory approach, seeking to develop and contextualise quantitative evidence rather than provide conclusive responses. More specific research objectives are addressed in an empirical manner, as described in the following section.

1.3. Dissertation Objectives

This dissertation comprises a contextualising chapter followed by three studies that assess the spatially- and temporally-dependent interrelationships between selected cancer types, socioeconomic deprivation, and access to treatment. Collectively, this dissertation seeks to provide the empirical basis for a suburban categorisation, responding to the following dissertation objectives:

1. Examine spatio-temporal patterns of head and neck cancer incidence across BC.
2. To dissect trends in spatial access to comprehensive cancer treatment in BC.
3. To dissect trends in spatial access to cancer resection surgery across Canada.

For each of these three objectives I seek to:

1. Identify socioeconomic trends using an index of multiple deprivation.
2. Evaluate whether differences exist for suburban neighbourhoods, relative to their urban and rural counterparts.

By addressing these objectives I seek to address the overarching objective of this dissertation: to evaluate whether there is a geographically and epidemiologically valid basis for analysing suburban neighbourhoods in contrast to urban and rural neighbourhoods.

1.4. Conceptual Framework

This dissertation is based on two distinct approaches that occasionally intersect, but are quite distinct in orientation, methodology, and execution. Conceptually, I position this research as health geography informed by theories and methodologies from medical geography and spatial epidemiology. Briefly introduced here, these approaches are described in greater detail in the literature review section.

Health geography examines the relationships between space, place, and health, emphasising the importance of local contexts in producing and reproducing health, wellbeing, and a person's interface with the health system. A key distinction here is the difference between space, a geometrically or experientially defined location, and place, a socially and subjectively constructed space. For example, chapter one, section seven of this dissertation explores suburbs through a place-making lens, focussing on the production of health through spatial, social, and political contextual factors. Chapters two, three, and four use quantitative geographical and epidemiological methods from medical geography. This dual approach facilitates a more rigourous approach to the research question.

1.5. Dissertation Structure

A review of the literatures in health and medical geographies, spatial epidemiology, spatial access, and cancer epidemiology concludes this introductory chapter. To lay the foundation for the three spatial epidemiological papers constituting this dissertation's empirical evidence, chapter one, section 7 then traces a socioeconomic history of Canada's suburbs. I take an explicitly geographical approach to describe the trends and forces in suburbanisation, emphasising the roles of transportation networks and socioeconomically-defined spaces in economics and policy.

Chapter two then describes a study of trends in oral cavity cancer incidence across British Columbia, highlighting spatial and demographic covariates. Chapter three includes other types of head and neck cancers, in addition to oral cavity cancers, in a study of trends in patients' spatial access to comprehensive cancer treatment centres across the province. The third spatial epidemiological paper appears in chapter four, in which the methodology from chapter four is applied to five different cancer types across the country, instead focussing on how the regionalisation of cancer care in Canada is reflected in socioeconomic and urban/suburban/rural patterns of spatial access. This evaluation of trends and patterns along socioeconomic and urban/suburban/rural axes constitutes a common theme across these three cancer incidence and treatment studies.

1.6. Review of the Literatures

1.6.1. Health and Medical Geographies

Health Geography as a formalised area of study was first distinguished and recognised as such through a series of debate articles in the early 1990s, primarily published through academic venues like *Antipode*, *Progress in Human Geography,* and *Environment and Planning D: Society and Space* [11,12]. At the core of this disciplinary fissure was a series of critiques of medical geography in which authors alleged there was an absence of social, political, and theoretical thought in the subdiscipline with a concomitant need for greater adoption of qualitative methods. While certainly reflective of a much broader paradigm shift in the social sciences, it highlighted within geography important epistemological, methodological, and subdisciplinary differences that continue to both inform and constrain research practice within and beyond geography.

Fundamentally, the health/medical geography dichotomy is defined by a methodological divide along a positivist-constructivist epistemological axis. Curtis and Jones contrast extensive and intensive approaches by way of health inequalities research [13]. Extensive methodologies inform primarily quantitative methods to analyse large samples as multi-point patterns, tending to focus on measurable or classifiable attributes. The term 'extensive' in this case implies a large scope with little depth. An example of this is a statistical analysis of oropharyngeal cancer incidence by patient sex and neighbourhood socioeconomic deprivation score [14]. Conversely, intensive methodologies focus on fewer data points, attempting to interrogate with relatively greater depth both the condition under study and the contextual factors around it. Correspondingly, 'intensive' implies a smaller scope with more depth, and a way for the researcher to gain 'insider knowledge' [13,15]. Hutchinson, for example, conducted in-depth interviews with several young, unintentionally pregnant women in Mozambique about their strategies for coping with adverse life events [16]. The use of terms 'quantitative' and 'qualitative' to delineate these methodological approaches does not account for the use of quantitative methods in social, placial, experiential geographies, nor the use of qualitative methods to contextualise and frame extensive studies [17–23]. Crucially, differences in approaches to knowledge production about a health-related phenomenon is what underscores the divide between health and medical orientations in geography, not the methods of inquiry themselves [13,24].

The methodological divide described above is reflected in the contrasting data and methods used by medical and health geographers, summarised in the literature as compositional and contextual effects on health [13,25–27]. Compositional effects are variables or attributes of a population that convey a measurement or category such as age, sex, ethnicity, socioeconomic status, and may comprise individual (e.g., medical record) or aggregate (e.g., census dissemination area) data. Studies focussing on compositional effects are based on the underlying assumption that individual characteristics are the primary determinants of health, for example, in studies of socioeconomic status and disease prevalence [28–38]. Methods using compositional data (the ‘medical’ geographical approach) include tabulations [39–41], regression [42–45], and multilevel modelling [25,27,46–51].

While compositional effects are individual-level characteristics that collectively define a population, contextual effects encompass the broader social, political, economic, natural, built, and ecological environments [13]. The role of contextual factors had been well-established in health geography by the mid-2000s, as qualitative, subjective-interpretive research informed by social theory gained momentum, pluralist science gained more acceptance [52], and the inability of contextual factors to comprehensively explain spatial variations in health became clear [12,13,53–57].

Accordingly, health geography researchers responded by interrogating socio-contextual aspects of health and disease using qualitative methods through a primarily intensive methodology. Resulting studies examined the effects and experiential aspects of gender and race/ethnicity [58–71], physical ability [72–74], health inequality [75–78], and the potential for geographical information systems to examine contextual effects [79–84], among other socio-contextual studies [85–88].

While these approaches, data, and methods were sharply juxtaposed and hotly contested in the literature, one point was widely agreed upon: that contextual and compositional effects are not mutually exclusive, and are often difficult to disentangle [12,13,42,43,45,47,50,51,89–91]. For example, is the health effect of ethnic concentration due primarily to the spatial concentration of an ethnicity with a higher genetic risk (i.e., the spatial clustering of individuals, each with a high health risk), or is it due to the socio-cultural-political environment (i.e., the augmentation of health risk due to elevated socio-cultural influences in an ethnically homogeneous neighbourhood, coined the ‘group effect’ [92,93])? Multi-level modelling has been used to interrogate these effects quantitatively [25,27,46–51], though the importance of intensive methodologies to better understand these processes is underscored across the literature [13,71,94,95].

Some authors argue that methods examining compositional and contextual effects on health are, in fact, complimentary [15,17–20,54,96]. For example, geographical heterogeneity (non-stationarities) in the relationship between socioeconomic status and health was found between northern and southern Britain, which authors examined through various socio-contextual lenses [39,40,44,45,47,97,98]. Implicit in these studies was a contrastive view of space and place.

The positivist-constructivist axis, along which health and medical geography are dichotomised, frames geographers' contested conceptualisations of the role of space versus place, and their respective importance in examining health. Briefly, 'space' is a geometrically delineated region or area [13], while 'place' is a space, either physical or conceptual, where social meanings, constructions, and relations are ascribed and constituted [99,100]. Space is measured, while place is described, experienced, and/or felt.

Criticisms of medical geography accused the discipline of a narrow, purely spatial conceptualisation of space in the analysis of health events [53,54], as described by Entrikin: 'the richness of place as context [is reduced] to the more limited sense of place as location' [96], albeit conceding that the most useful perception of space is one that rests between the two, a sentiment echoed by Gesler [24].

By the late 1990s, the place-health relationship was still considered by some to be undertheorised, in light of recent geographical inquiry into space and place [13]. Jones and Curtis [101] draw three key theoretical perspectives on the place-health relationship: spatial patterns and diffusion (e.g., environmental pollutants, transmission of viruses), space and place in social relations (e.g., structure and agency in the production and reproduction of 'healthy landscapes' [102]), and landscapes and sense of place (individual and group meanings ascribed to spaces and their constitution of a holistic, culturally-informed view of spaces, e.g, therapeutic and healing landscapes [13,24]. While spatial patterns and diffusion were clearly regarded as members of the medical geography camp, socio-political theories of space and the construction of landscape were central to the definition of health geography [13,54,67,71,85,103].

Criticisms of medical geography targeted a 'positivist' 'biomedical' approach [104]. In contrast to this traditional view of disease as a progressive series of symptoms in an otherwise uninhabited body, health geographers have long insisted that the lived experience of *place* (i.e., space with ascribed human meaning, [99,100,104]), insofar as how an individual's social, economic, political, and environmental contexts affect and are affected by both their sense and state of health, should be at the core of health inquiry [11,12,53,54]. While cartography is certainly not at the core of contemporary geographies, maps have always played a crucial role in forming our understandings of health and disease, serving as a space where discrete cases are transformed into both testable hypotheses and lived experiences through their juxtaposition with political, social, economic, and environmental features [105].

The process of cartography was (and still is) highly subjective, based on the mapmaker's theories and preferences [106–109]. Different features of the built, social, political (etc.) environments are selected for inclusion alongside the geographical phenomenon of choice (e.g., oral cancer incidence). Franco Moretti states characteristically: maps are 'cognitive instruments' that are not the 'conclusion of geographical work… [but] the beginning' [110]. Exploratory interpretation of the mapped data results in the formation of theories of disease [111–114], as summarised by Koch: 'In a real sense, we do not map data, instead, we map theories using data to represent them in place' [105]. While those theories may be tested using quantitative methods like hypothesis tests or spatial modelling, their formation (i.e., the selection of variables/features to include) is highly subjective, based upon the researcher's own experiences, interpretations of the literature, and tastes. Accordingly, any notion of objectivity or positivism in medical geography is questionable. However, as alluded to by Mayer and Meade [95], David Bennett [115], and Anthony Gatrell [116] in their responses to Robin Kearns's [54] criticisms, medical geography has a strong tradition of subjective (but not intuitionist [115]) interpretation of disease and health in the local socio-economic and placial contexts.

1.6.1. Spatial Epidemiology

Rooted in geographical traditions of cartography [105,117,118] and exploratory spatial data analysis (albeit predating the term)[112,119–122], spatial epidemiology emphasises geographical relationships, contingent to Waldo Tobler's First Law: 'all things are related, but near things are more similar than distant things'[123].

The roots of modern aspatial epidemiology are claimed by occupational toxicology, often being said to begin with Percivall Pott, an 18th century English surgeon whose attention was drawn to an unusually high incidence of scrotal cancers among young boys in inner-city London [124,125]. Dr. Pott collected case files and, upon their examination, found that all the affected were from low-income families and had one thing in common: each and every patient worked as a chimney sweep. This job was typically carried out by young boys who would climb down the chimneys naked, in doing so exposing themselves to carcinogenic chemical compounds in the soot, which would collect in sweat, accumulating on the scrotum. The collection and examination of individual-level data such as age, sex, income, and occupation facilitated the discovery of carcinogenicity in chimney soot and subsequent regulation.

Similarly, spatial epidemiology is said to have been born in inner-city London, albeit a century later, during a cholera epidemic in Soho (although these claims are contested [126]). Dr. John Snow and Reverend Henry Whitehead, among others, investigated the outbreak by collecting case notes, visiting affected households, and examining patients [127]. While Rev. Whitehead took a decidedly more ethnographic approach, partly serving in his capacity as a priest, Dr. Snow set about mapping each case at the address level [127,128]. A distinctly distance-decay pattern was observed, which, in conjunction with theoretical evidence of waterborne transmission of cholera, lead Dr. Snow to suspect a local water pump. Once the pump handle was locked, incidence rapidly decreased in the area. This was both the first example of point-level disease mapping and the empirical evidence needed to contest a miasma theory of disease transmission. As such, spatial epidemiology made theoretical contributions to medicine from day one. In these two foundational examples, an analysis of data facilitated a hypothesis that was tested had direct public health implications. Their distinguishing feature is the presence of spatially-referenced data in the latter.

Briefly, spatial epidemiology is distinguished from traditional epidemiology by its ability to make use of spatially-referenced data, beyond simple categorical classification (e.g., binning cases by neighbourhood, as opposed to spatial modelling of their interaction) [120]. The data and functions of GIS for public health and spatial epidemiology are categorised by Pfeiffer and colleagues' conceptual framework, wherein attribute data (tabular or objects, e.g., number of head and neck cancer cases in an area) and feature data (geometries delineating the area corresponding to that in the attribute data) are joined in a database [122]. What sets database representation in spatial epidemiology apart from the traditional variety is the presence of that spatial geometry, whether present as a linked feature class, raster parameters, or coordinate pair. The storage and management of spatially-referenced data, and interoperability of these geographical database management systems with other proprietary packages (e.g., IDRISI GIS and Microsoft Access, or ArcGIS and MySQL) are, debatably, geographic information systems' most fundamental capabilities [129].

The representation of spatially-referenced data in a database format (e.g., reducing the medical complexities and lived experiences of H5N1 patients to case counts) can be construed as a geographical deterministic model, even prior to cartographic representation (for more discussion around the challenges of quantitative and qualitative data reduction, see [129]). The 'fuzziness' (referring to both statistical and socio-cultural models/constructions of uncertainty) inherent in these data are eschewed in favour of a singular, authoritative figure or label. For example, Yiannakoulias and colleagues [130] discuss how case ascertainment bias (i.e., misdiagnosis, misclassification, or erroneous transcription of diagnostic data) is not represented or considered in many analyses of health data. (Interestingly, they found spatial variations in patterns of case ascertainment bias, such that First Nations communities in British Columbia experienced a significantly higher amount of this bias.) Similarly, Koch [105] discusses how lack of fuzziness in categorical data or the classification of cases results in the assertion of commonality among cases, that is, that they share the same symptoms, and potentially, prognosis. Problematically, the uncritical deterministic representation of complex medical, health, and geographical phenomena is granted unique validity once in its database form, but significantly moreso once cartographically represented, as the map asserts authoritative certainty, as do statistical results from both spatial and aspatial methods [105].

The formation of theoretical hypotheses based on the observation and interpretation of data, which then is formulated as a testable hypothesis to be examined via experimentation is a scientific approach attributed to philosopher of science Karl Popper. While traditional epidemiology follows this model closely, spatial epidemiology varies in that many studies do not strictly formulate null hypotheses to test against statistical conditions [122].

While early epidemiological studies, such as that of Percivall Pott, were scarcely quantitative, the ability to evaluate epidemiological data using statistical models has created a common language for studies of different conditions, improved their sensitivity and specificity, and enabled the inference and prediction of disease [131]. The ability to make use of geographically-referenced data sets spatial epidemiology apart from traditional epidemiology. Several approaches and methods for analysing data within a spatial epidemiological framework are outlined as follows.

Given the differentiation provided by the presence of spatially-referenced data, and spatial epidemiology's distinctly cartographic pedigree [105], the mapping of conditions, covariates, and social and contextual factors is a fundamental standalone method, Examples of its use include data exploration for cancer control [132–134], infectious disease [135–137], chronic disease [111,138–143], and injury [144–146].

The inclusion and exclusion of geographical features in cartographic composition is of significant import; different features of the built, social, political, etc. environments are selected for the map, based on the cartographer's theories. As such, the map becomes a testing ground for hypotheses about disease [105]. This ability to present health phenomena on the map enables the user or recipient of the map to subjectively detect and describe spatial or geographical patterns. Static data visualisation still serves as the most commonly used functionality of GIS in public health decision-making [113,132–134]. This functionality appears to fulfill public health practitioners' expectations of GIS, precluding the utilisation of more powerful spatial-analytic or inferential geospatial toolsets [113,132,147–149]. As such, effort is required on the part of medical geographers to illuminate the value of mapping and spatial epidemiology more broadly.

Elliot and Wartenberg classify methods in spatial epidemiology by mapping, clustering, and geographical correlation themes [117]. While mapping merits standalone attention (as above), the latter two methodological themes both represent types of spatial modelling. According to Pfeiffer and colleagues' [122] framework for spatial epidemiological analysis, the second-order analytical ability the GIS and spatial epidemiology hierarchy is data exploration through the analysis of spatial patterns. These capabilities exist primarily within the realm of deterministic methods. Examples include spatial buffers (e.g., for identifying potential neighbourhood features that correlate with body mass index [150]), network distance (e.g., in constructing spatial accessibility models based on travel times from palliative care centres [151]), and some gravity models (e.g., Schuurman and colleagues [152] use a modified gravity model to compute scores for population access to primary health care physicians in Nova Scotia).

Density estimation (hotspot) maps can be conceptualised as deterministic areal representations of point phenomena, for example, in modelling traffic noise [153] or graffiti [154]. Conversely, when Kernel Density is used as a spatial model of exposure to a risk factor (e.g., alcohol outlets as a risk factor for interpersonal violence [155–161]) or to infer point locations from areal data (Shi 2009, Shi et al. 2013)), it is stochastic in nature. Kernel Density Estimation's wide applicability and ubiquity in GIS software packages has resulted in its common use across numerous disciplines and applications [143,144,162–165].

While considered by many to be in its infancy [12,166,167], many spatial-temporal analyses and models are deterministic in nature. One example is found in Mei-Po Kwan's [21] three-dimensional representation of individuals' spatial-temporal trajectories, in which each person's movements through the day are represented as 'pipes' through a cube structure. Another example uses density estimates at different times of day to characterise spatial-temporal variations in violent injury [168]. These highly visual methods of examining patterns in space and time are unique to spatial epidemiology, although they may suffer in terms of statistical rigour.

Stochastic spatial models allow for the statistical inference of a phenomenon based on the assumption of an underlying statistical distribution, and allow for predictive uncertainty to be quantified and non-discrete (fuzzy) boundaries to be constructed for spatial phenomena [122]. By way of example, a contrast can be drawn between spatial epidemiological and traditional epidemiological uses of binary linear regression, wherein the aspatial method, ordinary least squares regression, constructs a line of best fit for a two-dimensional data array (scatterplot), geographically-weighted regression constructs spatial weights for each feature in the data array, based on its relative proximity to each other point, and uses these to produce a line of best fit. However, when the residuals of an ordinary least squares regression (aspatial) are mapped, they can convey geographical information about non-stationarities (spatial heterogeneity of a relationship), in what is certainly a spatial epidemiological approach [122]. The Spatial Scan Statistic [169,170] provides a spatial method for identifying spatial clusters by computing and comparing relative risks within and outside of a spatio-temporally ‘moving window’, and has been used in a variety of spatial epidemiological studies [136,171–176].

1.6.2. Spatial Access

The concept of spatial access is a major theme in spatial epidemiology [117,122,177] with an increasingly independent literature in which geographical information systems play a leading role [178,179]. Khan and Bhardwaj [180] elegantly define access as a ‘degree of fit’ between an individual and the health system. Debates on the definition of access in health services research have resulted in a binary classification of access as two distinct concepts [179]. Aspatial access refers to the socio-contextual effects on one’s ability to connect with health services (e.g., language barriers) [179–186]. Spatial access, conversely, is a geometric and calculable representation of one’s ability to tangibly reach a health service, or vice-versa [187]. Another distinction in access exists between potential and realised access, that is, the difference between an individual’s ability to reach a health service and their actual use of that service [180,182,184,187].

The ability to model access using geographic information systems affords the opportunity to evaluate service provision, identify optimal locations for new services, and analyse the relationships between access to health services and disease outcome. These valuable capabilities have been applied in a variety of domains, and GIS-based methods of calculating access continue to grow in sophistication and accuracy.

Conceptualisations of space used in GIS-based access to health services research can be classified as either Euclidean (straight-line/rhumb line), network (e.g., drive-time), or hyper-space (e.g., airline routes, telehealth) models. The Euclidean method calculates distance as the length of the hypotenuse of a triangle whose vertices are defined by the absolute value of the differences between northings and eastings of an origin-destination coordinate pair. This method has been used in early models of spatial access, as well as a comparative metric for more recent network-based models [188–193].

Network distance calculates the travel distance via road, public transit, or other land-based transportation networks from an origin to a destination, taking the shortest available route (although traffic models are changing this, e.g., Google Maps Directions) via the defined network. Considered the gold standard for accuracy [189,194] (but see [188], who found a covariance of over 99% between network and Euclidean metrics), this method of distance calculation has been used extensively to model individuals' potential access to health services (e.g., [35,179,194,195]).

Hyperspace conceptualisations of distance are uncommon in the health services literatures, but have been used in modelling vector-based transmission of infectious disease, such as H5N1 and West Nile Virus, via airline and marine transportation networks [13,105,123,196–202]. In regions where road connectivity is limited, for example, in the Canadian North, hyperspace distance may be an appropriate method for modelling spatial access to health services.

Geographical information systems provide a tool for calculating access to health services; however, there has been disagreement in the literature over the methods of calculation. This subsection briefly outlines four methodological approaches to spatial access calculation: drive-time catchments; gravity models; two-step floating catchment areas; and density estimation/map algebra.

Drive-time catchment calculation is a network-based geometric cousin of the Voronoi polygon, wherein a service area is calculated from a single point of origin (e.g., a hospital), such that the boundaries of the service area are defined by a series of interconnected points corresponding to the locations at which a person driving by car (usually) would arrive if they were to drive away from the point of origin for a given time. For example, Cinnamon and others [151] calculate one-hour drive time catchments from palliative care centres, resulting in polygons that delineate the region within a one hour's drive from each centre. The population within these polygons is inferred to be serviced exclusively by the facility at its respective origin. Similarly, calculations of drive-times from individuals to a health service are becoming more prevalent in health services literatures, for example, [194,203,204]. This method has the advantage of improved accuracy over Euclidean distance calculations, but suffers from assumptions such as car ownership, no traffic/road construction, consistent driving at the speed limit, and non-preference of individual health service locations [187,205].

The two-step floating catchment area method [182] and its more sophisticated variants [186] calculate catchments, then compute health care provider-to-population ratios based on the number of, for example, doctors at a given health care centre divided by the census-derived population of the areas within that catchment. This method has the advantage of providing intuitive metrics of health service provision, such as the doctor-to-population ratio, but suffers from the problems inherent in the drive-time catchment method, plus the modifiable areal unit problem and edge effects [164,184,186,206].

Gravity models are able to create fuzzy parameters for health service demand (e.g., a larger, more distant health care centre may be preferred over a smaller local one)[164], and account for potential tradeoffs between health service capacity (e.g., number of doctors) and an individual's distance to a provider [182]. However, these models are computationally intense and the results are unintuitive to public health practitioners [186,187].

Considered by some to be the most reliable spatial access to health services metric [187] and by others to be inferior [147], density models (e.g., kernel density estimation) are computationally simple raster-based methods of calculating the spatial density of weighted health service locations [164]. These can then be compared to numerous other areal variables (e.g., population density, median income, median age) using algebraically simple and easily interpretable raster calculations (e.g., provider-to-population ratios)[187]. Further, because these methods result in spatial data that are amenable to raster overlay, they are easier than vector-based accessibility models to implement in spatial decision support systems or combined spatial/aspatial models of access to health services.

There has been little scholarship in GIS-based modelling of aspatial access, although some notable exceptions include Comber and colleagues [179], who mapped perceived access to hospitals and general practitioners against spatial access in the UK, then used geographically-weighted regression to evaluate the spatial heterogeneity of their relationship. Another study by McGrail and Humphreys [185] combined census-derived indicators of aspatial access with spatial access to produce an index of rural accessibility to health services. Further work is needed in this field to produce more comprehensive models of accessibility.

The literature is replete with GIS-based studies of access to health services in a variety of domains. Several studies evaluating health service provision have included a focus on socioeconomic inequalities in access [35,179,207–209]. Others have evaluated access to palliative care [151], primary care [152,164,179,182,183,185,189,206], hospitals [179,184], vaccination centres [194], paediatric services [187,192,210], mental health services [211], and pharmacies [212]. In addition to evaluations of service provision and access to services, GIS-based models of accessibility can be used to identify the optimal locations for new health services, for example, palliative care centres [213].

Researchers have also examined the role of spatial access in patient outcome in a wide range of fields, including mental health [211], alcohol treatment [214], discretionary medical conditions [215], and choice of treatment for breast cancers [190,203,204,216–220] and prostate cancers [221]. However, to retain policy relevance, Higgs [205] argues that more work is needed in the access-outcome field. GIS-based health services research suffers from a lack of interpretability by public health practitioners [180]. Luo and Wang [182] argue that it is up to health service researchers and spatial epidemiologists to strike a balance such that models must be simple enough to interpret and use for policymaking, yet sophisticated enough to be geographically-accurate, a challenge that extends across all spatial epidemiology.

1.6.3. Cancer Epidemiology

Epidemiology, as defined by David Hunter [222], is ‘a discipline that seeks to explain the extent to which factors people are exposed to (environmental or genetic) influence their risk of disease, by means of population-based investigations’. In accordance with the scope of this dissertation, I focus on environmental and social factors, forgoing discussion of genetic risk.

'Environment' has contrasting definitions; in geographical terms, our conceptualisation of environment in cancer research can be defined by the 'scale of seeing' [105]. At the global, national, and regional scales, the environment encompasses physical and social landscapes, at the neighbourhood level, built features, and at the individual level, organs and tissues. At the cellular level, 'environment' approaches a genetic definition, similar to that used in cancer epidemiology, where it refers to the space external to the body or an origin not rooted in human gene expression [223–226].

As highlighted in Hunter's [222] definition, cancer epidemiology is concerned with population patterns. Because epidemiologists cannot manipulate experimental conditions, observational methods must be used to identify and characterise associations [227]. For example, the observation of high rates of lung cancer in the late 1950s/early 1960s among tobacco smokers suggested a causal link. However, the establishment and confirmation of a cause has strict criteria within epidemiology. A causative factor must exhibit a dose-response relationship, a lack of temporal ambiguity, biological plausibility, and a coherence of all the evidence [227]. These criteria ensure a level of rigour in epidemiological studies, but also post challenges in the confirmation of environmental risks.

Early study designs focussed on lifestyle factors, occupational exposures, and relied heavily on between-country comparisons and migrant studies [227]. Between-country comparisons look for statistically significant differences in controlled epidemiological data (e.g., cancer rates adjusted for age and sex distributions) between two regions in an attempt to isolate environmental risk factors, for example, attributing higher rates of stomach cancers in Eastern Europe than Western Europe to highly salted and cured foods. Migrant studies examine cohorts of individuals who have moved from one country to another to identify deviations from their country of origin's type-specific cancer rates. For example, studies have analysed immigrants from Japan (high rates of stomach cancer) to the United States (high rates of colorectal cancer). These studies have demonstrated that immigrants tend to acquire the cancer rates of their new country, evidence that environmental risk is dominant in digestive tract cancers [227]. Conversely, while high rates of oral cancers (particularly on the base of the tongue and floor of the mouth) among South Asian immigrants to North America might suggest a genetic component, these sustained rates are attributed by Warnakulasuriya [228] to continuing consumption of betel quid in their destination country.

Tightly intertwined with occupational toxicology, environmental cancer epidemiology studies non-genetic risk factors [224]. Most known environmental risk factors have been identified in epidemiological studies, then confirmed biologically under laboratory conditions [224]. Environmental risk factors can be differentiated into voluntary and involuntary categories. Voluntary exposures encompass environmental risk factors to which an individual is deliberately exposed though action [224]. The most widely known example is tobacco, the second greatest cause of cancers [227,229–231]. Considerable epidemiological and biological research has led to an exceptional level of certainty that smoking and oral consumption of tobacco cause cancers. The 1964 US Surgeon General’s Report on Smoking and Health was based on seven prospective cohort studies and later supported by over twenty retrospective cohort studies, all of which showed a statistically significant increase in lung cancer risk among smokers [227]. This serves as an exemplar of how epidemiological cancer research identified a risk factor, which was then translated into policies like packaging labels and no-smoking zones; unfortunately, there are still over three million deaths annually due to smoking, a figure that is on the rise, globally [227].

While often considered a confounder for health-related behaviours (i.e., there no biologically plausible basis to infer that being poor causes cancer), the strength of socioeconomic status as a predictor of cancer risk merits standalone attention [29,232–235]. A considerable body of epidemiological literature is building around the association between socioeconomic status (and its constituent variables: income, education, employment, etc.) and cancer incidence, mortality, and survival [29,31,37,38,171,223,233,236–242]. Conway and colleagues [243], in a pooled study of 27 countries (approximately 63 000 participants) found that socioeconomic status is a strong predictor of head and neck cancers, even after controlling for behavioural factors such as smoking and alcohol consumption and compositional factors like age, sex, and ethnicity. This suggests that there is an additional, yet unknown factor that epidemiological studies are currently seeking to identify (including the 31 studies in the INHANCE consortium). Crucially, the emphasis on socioeconomic status underscores the need for cancer control policies that are tailored to local socioeconomic contexts, such as the World Health Organization's 2005 Crete Declaration for oral cancer prevention [229].

1.7. Socioeconomic Geography of the Canadian Suburb

In recent decades a series of trends and forces have catalysed the migration of socioeconomically deprived populations from the urban cores, rural hinterlands, and across national borders into suburban neighbourhoods across Canada. Not only do they experience the health risks contingent to social and financial disadvantage, but those risks are compounded by risk factors endemic to the suburbs. The history of the North American suburb provides a contextually rich, implicitly geographical basis for framing suburban health. In order to establish the basis for a distinctly suburban spatial epidemiology, this chapter traces a cursory history of suburban socioeconomics and health.

1.7.1. Defining the Canadian Suburb

The suburbs constitute one feature of urban sprawl, which refers both to the processes and the sites of low-density peripheral growth of cities [7]. Suburbs specifically are defined in a variety of terms centring on low-density residential neighbourhoods, typically featuring somewhat homogeneous architecture, predominantly single-family or fully-detached houses, and the personal motor vehicle as the dominant mode of transportation [244]. Throughout both academic and popular literatures, suburbs are commonly defined in contrast to urban cores, while 'the suburbs' is often used to invoke a type of ethnically homogeneous, middle-class placelessness and commuter lifestyle [4].

Quantitatively, the simplest functional definitions are based on population density, where administrative areas with 150 to 400 residents per square kilometre are classified as suburban, used by the Organization of Economic Communities and Development and Statistics Canada, for example [245,246]. While somewhat simplistic, such single-variable definitions are more broadly applicable, particularly in areas where more detailed population or built environment data may not be available.

More sophisticated definitions tend to use various combinations of metrics describing the vibrancy of activity centres, the accessibility of road networks, residential unit density, and land use mix [247]. And while precise definitions vary widely, there is broad agreement across the academic literature that land use, density, and transportation are central defining features of suburbs [7].

While there is a substantial literature describing suburbanisation in the United States, the Canadian literature is relatively thin [248], with some studies appearing in the last ten years. While their histories are somewhat similar in character [249,250], the physical and social changes associated with post-WWII suburbanisation moved at a slower pace in Canada [248,251,252]. It is important to note that while much of the recent Canadian literature focusses on immigration, race and ethnicity played a much more significant role in suburbanisation in the US than in Canada, where economic class appears to have been a key discriminant [249,252].

1.7.2. The Road to Suburbia

The desire to flee the unhealthy and unpleasant urban cores had existed for generations prior, but was inhibited by two key factors: capital and mobility. The financial resources needed to flee the city were concentrated among the landed and entrepreneurial classes. In Edinburgh's New Town, residents would travel by private horse-drawn carriage to conduct business [253], but the technology required to support commuting did not exist in any practical form until the early 19th century.

The geographer Peter O. Muller defines the stages of North American urban development by the dominant mode of local transportation. If the 19th and early 20th centuries were a time of horse-drawn trams, electric streetcars, and the early autocar, then the post-WWII era is the age of the freeway [254]. Publicly-funded highways and arterial roads radiated from the urban cores, creating the infrastructure for automobile-centred suburbs [255], effectively rescaling the city from walking distances to automotive expanses. Anybody who could afford a family car and a suburban home moved out to these new developments.

By enforcing a strict spatial organisation and the separation of land uses into large, homogenous areas, zoning laws encourage urban sprawl and prevent socioeconomically diverse neighbourhoods from forming [6,256]. Increasingly being zoned out of the urban cores and inner suburbs, industrial operations were required to relocate to the outer peripheries [257]. The concentration of jobs in large industrial parks on the periphery coupled with poor public transit provision ensured that workers required an automobile to reach the workplace [3]. The effects were particularly harsh for low-income unskilled and semi-skilled workers, many of whom resided in socioeconomically deprived urban cores, far from the industrial parks of the outer periphery [7].

The rise of the automobile and its publicly-funded infrastructure, financial policies and loaning practices, and modern zoning are all geographical processes that ensured the emergence of the modern Canadian suburb as a heterogeneously white, middle-class space. By selectively syphoning off population, economic capital, and political capital from the urban cores, post-war suburbanisation left many cities in North America impoverished and neglected [3].

1.7.3. The Second Flight

While the second half of the 20th century can be characterised by a socioeconomic disaggregation between the suburbs and the urban cores, the present day situation looks rather different. Contrary to the suburbs' persistent popular imaginary as independent, wealthy, and white, there is a growing recognition of a recent socioeconomic transition. Wealthy suburbanites are moving farther out, into newer exurban developments like Hammonds Plains, Nova Scotia, Aurora, Ontario, Cochrane, Alberta, and South Langley, British Columbia. Others are returning to the rapidly gentrifying urban cores, displacing Canada's socioeconomically deprived inner-city populations. With nowhere else to go, low-income families and recent immigrants are moving into aging houses in the once-affluent post-war suburbs [2,250,258]. This shuffle is changing the socioeconomic configuration of Canada's cities, where the urban cores were in the hands of the gentrifying classes and the paint began to chip from white picket fences across the country.

Beginning in the early 2000s, low interest rates and declining property values made the suburbs an attractive settlement option for low-income families [259,260]. Low-income, largely immigrant populations began concentrating in Canada's 'ethnoburbs', many of whom would share space and resources among multiple families to secure a rental or a mortgage [260–264]. A low market supply of housing in suburban ethnic enclaves, the relaxation of rent controls, and tight competition meant that many new immigrant families paid over half of their pre-tax income on rent in Toronto [260]. So while newcomers had suburban housing, their situation hardly resembled the American Dream. In recent decades, immigrant incomes have been declining relative to those of Canada-born populations [265]. These economic conditions have disproportionately stifled immigrant populations' socioeconomic mobility, effectively entrenching the socioeconomically deprived suburban enclave [266,267].

The dispersion of socioeconomically deprived populations into Canada's suburbs presents a new urban geography of poverty: low-income, largely immigrant communities that were once highly visible in the inner-cities are now hidden away in the peripheries, distanced from amenities, workplaces, and services.

1.7.4. An Emergent Suburban Health

The modern suburb was largely a product of a desire to flee unhealthy conditions in the inner-city while remaining within commuting distance. Transportation technologies, economic policy, and zoning regulations put the suburban lifestyle within reach for all but the most deprived members of society. But while the early suburbs of Edinburgh and Brooklyn represented clean air, quiet streets, and a sanitary environment free from pestilence, the contemporary reality of a suburban life for millions presented a new set of latent health risks. These environmental, behavioural, and social risk factors constitute a new suburban health paradigm, one that is innately social and spatial.

Suburban areas feature an expansive, homogeneously residential built environment, and while retail centres are often found clustered along major arterial roads, overall land use mix is generally low. This lack of diversity in the neighbourhood landscape has been linked to reduced overall health and wellbeing [7,268]. While access to food retailers is generally high in Canadian suburbs [269], spatial segregation of grocers from residential neighbourhoods decreases accessibility for those with limited or no access to a private vehicle, such as the elderly and otherwise socioeconomically disadvantaged populations [270–274].

Automobile use directly correlates with dwelling density [275], such that the private vehicle is central to nearly every aspect of social and economic life [6,276,277]. This commuter lifestyle [4] comes with a significant psychological cost to the detriment of drivers' mental health [278,279]. Several early studies have linked driving stress to cardiovascular disease risk [280–282], though an early mortality study identified lower cardiovascular disease mortality risk among middle-class suburban populations in the US [283]. A poor non-automotive transportation infrastructure discourages the use of active transportation modes, which in combination with a low density of recreational facilities, contributes to a sedentary lifestyle [7]. Excessive time spent commuting, particularly for populations who rely on suburban public transit, also reduces the amount of time a person could otherwise engage in healthy physical and social activity, including food preparation. As a result, fast food availability and consumption tends to be higher in suburbanised areas [284–286].

In addition to the built environment effects on health, there is some evidence that suburbanisation may contribute to other environmental risks, such as poor water quality, an increased urban heat island effect, and increased population exposure to radon [7]. Air pollutants emitted from automobiles have been implicated in a greater incidence of asthma symptoms and hospitalisation [287,288], impaired lung growth and function [289], low birth weight [290], and infant mortality [291]. Importantly, the increased emissions from both suburban home construction and motor vehicle use is a significant contributor to anthropogenic climate change, which has already been implicated in human health risks, particularly among socioeconomically deprived populations [292–294].

As described in the previous chapter, spatial access to health services is a known predictor of health care choices and outcomes. Several US studies have demonstrated that, overall, suburban neighbourhoods experience lower mortality rates than urban cores and rural peripheries [295,296], although urban sprawl has been linked to a higher incidence of chronic disease [297]. It is important to note that suburban health risks not equally distributed: they tend to be more concentrated in the most socioeconomically deprived populations [7]. As Howard Frumkin and colleagues put it: “it seems to take a ‘village’ not only to raise a child, but also to support an adult, and to look after the elderly. In sprawling regions… we may forfeit critical opportunities to promote health across the life span.” [7](p. 185).

1.7.5. Spatial Epidemiology as a Lens

Suburban health is the product of explicitly geographical processes; as such, spatial epidemiology presents a powerful toolset for interrogating patterns of socioeconomic deprivation and health in suburban settings. The diffusion and concentration of socioeconomically diverse and divergent populations is both spatial and temporal, as are patterns of spatial access, the built environment, and health service locations. Within a geographical information science paradigm, questions of scale, zone, spatial contexts, and place emerge throughout the literatures on suburbanisation and health. While this dissertation does not attempt to directly answer such questions, they constitute important decision points in the following three spatial epidemiological studies.

Chapter 2.

The Suburbanisation of Oral Cavity Cancers

Adapted from Walker BB, Schuurman N, Auluck A, Lear SA, Rosin M. Suburbanisation of oral cavity cancers: evidence from a geographically-explicit observational study of incidence trends in British Columbia, Canada, 1981-2010. BMC Public Health. 2015;15:758.

2.1. Abstract

2.1.1. Background

Recent studies have demonstrated an elevated risk of oral cavity cancers (OCC) among socioeconomically deprived populations, whose increasing presence in suburban neighbourhoods poses unique challenges for equitable health service delivery. The majority of studies to date have utilised aspatial methods to identify OCC. In this study, we use high-resolution geographical analyses to identify spatio-temporal trends in OCC incidence, emphasising the value of geospatial methods for public health research.

2.1.2. Methods

Using province-wide population incidence data from the British Columbia Cancer Registry (1981-2009, N=5473), we classify OCC cases by census-derived neighbourhood types to differentiate between urban, suburban, and rural residents at the time of diagnosis. We map geographical concentrations by decade and contrast trends in age-adjusted incidence rates, comparing the results to an index of socioeconomic deprivation.

2.1.3. Results

Suburban cases were found to comprise a growing proportion of OCC incidence. In effect, OCC concentrations have dispersed from dense urban cores to suburban

neighbourhoods in recent decades. Significantly higher age-adjusted oral cancer incidence rates are observed in suburban neighbourhoods from 2006-2009, accompanied by rising socioeconomic deprivation in those areas. New suburban concentrations of incidence were found in neighbourhoods with a high proportion of persons aged 65+ and/or born in India, China, or Taiwan.

2.1.4. Conclusions

While the aging of suburban populations provides some explanation of these trends, we highlight the role of the suburbanisation of socioeconomically deprived and Asia-born populations, known to have higher rates of risk behaviours such as tobacco, alcohol, and betel/areca consumption. Specifically, betel/areca consumption among Asia-born populations is suspected to be a primary driver of the observed geographical shift in incidence from urban cores to suburban neighbourhoods. We suggest that such geographically-informed findings are complementary to potential and existing *place-specific* cancer control policy and targeting prevention efforts for high-risk sub-populations, and call for the supplementation of epidemiological studies with high-resolution mapping and geospatial analysis.

2.2. Introduction

Globally, oral cavity cancers (OCC) are the 10th most common cancers among males and 18th among females, accounting for an estimated 299 051 new cases in 2012 [9]. Significant inequalities in OCC incidence have been observed [32,298], reflecting variations in known risk factors, specifically age, ethnicity, and tobacco, alcohol, and betel/areca nut consumption [37,299–302]. Recent studies have confirmed significantly higher incidence [32,37,303,304], prevalence [304], mortality [305], and lower survival [34,306] among socioeconomically deprived populations. Socioeconomic deprivation can be defined as a state of disadvantage resulting from a combination of social, economic, and situational influences on an individual, neighbourhood, or community. While the literature on socioeconomic deprivation and OCC incidence continues to mature, no studies to date have contrasted patterns of cancer incidence between urban, suburban, and rural neighbourhoods [307]. This geographical differentiation may reveal unique risk profiles useful for informing cancer control policy. Accordingly, this study utilises geospatial methods to analyse and map spatio-temporal trends in OCC, characterising findings using unique local geographies of suburbanisation, deprivation, and demography. In this way, we provide a template for geospatially-informed epidemiological analysis of cancer registry data.

In the post-World War II period in North America, a move to the suburbs signified a rise in social class as people left the deprived inner-cities for more affluent neighbourhoods [308,309]. However, the last two decades have witnessed the suburbanisation of socioeconomically disadvantaged populations in North America and Western Europe [259,277,307,310,311]. The health risks of suburban life are well documented, with researchers demonstrating links between adverse health outcomes, reduced access to health care resources relative to urban cores [310], more sedentary lifestyles [312], and lower community cohesion [313] among suburban residents. Residential population density has also been linked to poor health [150,314], with a substantial literature from the 1990s exploring the hypothesis that dense urban areas somehow contributed to higher cancer incidence [315,316] and mortality [317], although these studies are typically conducted for large areal units (e.g., at the city scale, rather than the neighbourhood), and none to date have focussed on OCC.

The objective of this analysis was to identify geographical trends in OCC incidence in British Columbia from 1981 to 2009, with a focus on suburban growth and socioeconomic deprivation. Accordingly, we sought to (1) map concentrations of OCC cases over space and time, (2) compute and contrast age-adjusted incidence rates between urban, suburban, and rural residents over time, and (3) characterise these trends by the local socioeconomic, demographic, and cultural characteristics of areas with high a concentration of cases.

2.3. Methods

2.3.1. Ethics Statement

Ethics approval for this study was obtained from the University of British Columbia/British Columbia Cancer Agency Research Ethics Board (H08-00839) and the Simon Fraser University Research Ethics Board (2013s0753).

2.3.2. Data

Census population data (years 1981, 1986, 1991, 1996, 2001, and 2006) within British Columbia for the smallest-area geographical units (approximately 85 residents per unit) were obtained from Statistics Canada. Male and female populations for each geographical unit and each census year were mapped using geographical information systems and the population density for each census geographical unit was calculated. The proportion of residents aged 65 years and over was also calculated for every census geographical unit. Results were manually cross-checked against Statistics Canada records for verification. Each geographical unit was then classified as urban, suburban, or rural, based on its population density, using Statistics Canada's definition of suburban neighbourhood as a Census area with an average population density between 150 and 400 persons per square kilometre [245]. This metric was selected for consistency with official Statistics Canada and Organisation of Economic Co-operation and Development data and literature.

Oral cavity cancer incidence data were acquired from the British Columbia Cancer Registry, a comprehensive population-based provincial registry. Data included all cases from 1981-2009 (inclusive) with International Classification of Diseases in Oncology (version 3) site codes C003-5 (mucosa of upper and lower lips), C020-23 (dorsal surface, ventral surface, border and anterior 2/3rd of tongue), C028-29 (overlapping lesions of tongue and tongue), C030-31, 039 (upper and lower gum), C040, 041, 048,049 (anterior, lateral floor of mouth, overlapping lesions of floor of mouth, floor of mouth), C050-52,058, 059 (soft palate, hard palate and uvula, overlapping lesions of palate, palate), and C060-62, 068,069 (cheek, vestibule of mouth, retromolar area, mouth, and unspecified parts of the mouth) [318]. Data fields comprised patient age at the time of diagnosis, patient sex, patient residential postal code at the time of diagnosis, and year of diagnosis (aggregated to 5-year periods corresponding to the aforementioned census years).

2.3.3. Spatial and Statistical Analyses

Using geographical information systems, each case was mapped by patient residential postal code at the time of diagnosis. To visualise the geographical distribution of incidence, case locations were spatially interpolated using the kernel density estimation method [162]. This method constructs a spatial density function around each point on the map and produces a visual hotspot, such that areas with many cases are brighter than areas with few or no cases.

Each case was placed on the neighbourhood type map of its respective census year, corresponding to the year of diagnosis. In this way, we derived the neighbourhood type (urban, suburban, or rural) of each case at the time of diagnosis.

Pearson's Chi-square test for association was used to determine whether neighbourhood type (rural, suburban, or urban) is associated with 5-year period and patient sex. Trends in the proportion of cases in each neighbourhood type were evaluated using the Cochrane-Armitage Chi-square test. The mean case population density was calculated for each neighbourhood type in each 5-year period. To examine the geographical relationships between incidence, age, and ethnicity, the percentage of population aged 65 and over and the percentage of population born in India, China, or Taiwan (regions with high betel quid/areca nut consumption) were mapped for each census geographical unit.

Age-adjusted incidence rates (AAIRs) with 95% CI were calculated for each neighbourhood type and 5-year period, using the 1996 British Columbia standard population (selected because it was the midpoint of the study period). Patients under age 40 years were excluded (n=41, 0.7%) to minimise estimate error induced by low case counts in younger populations. Due to data incompleteness for the year 2010 we projected case counts for that year, assuming an equal distribution of the annual number of cases from 2005-2009 (i.e., the average AAIR per year from 2005-2009 was added to the four-year rate to simulate the year 2010).

To investigate the temporal trends in neighbourhood types, 5-year periods, sex, and socioeconomic deprivation, we used the Vancouver Area Neighbourhood Deprivation Index (VANDIX). The VANDIX score was calculated for each patient postal code using data from the 2006 census, as described in our previous work [14,319]. Median VANDIX scores for each neighbourhood type were calculated to examine trends in patient neighbourhood deprivation.

2.4. Results

OCC cases were mapped and classified by 5-year period and neighbourhood type (N=5473). The resulting case counts are shown in Table 1. A greater overall proportion of male cases (64%) is observed throughout, a finding consistent with the literature [305]. However, this disparity is decreasing as female patients comprise a growing proportion of OCC incidence. The proportion of female cases in suburban areas has doubled since the first 5-year period (from 2.3% of total incidence in 1981-85 to 5.3% in 2005-09); conversely, the proportion of male suburban cases appears to be in decline (from 6.6% of total incidence in 1981-85 to 5.5% in 2005-09).

Table 2.1 Number of Cases by Year, Sex, and Neighbourhood type.

	1981-85		1986-90		1991-95		1996-00		2001-05		2006-09		
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**Total**
Urban	355	113	482	242	508	312	459	328	466	300	317	261	**4143**
Suburban	42	15	55	22	63	35	43	29	53	35	44	43	**479**
Rural	85	28	107	39	121	47	83	40	97	62	97	45	**851**
Total by sex	**482**	**156**	**644**	**303**	**692**	**394**	**585**	**397**	**616**	**397**	**458**	**349**	**5473**
Total by period	638		947		1086		982		1013		807		

Significant increases in the proportion of suburban cases (Cochrane-Armitage x^2=418.144, df=1, p<0.0005) and rural cases (Cochrane-Armitage x^2=9.458, df=1, p<0.002) were detected, as shown in Figure 1; the proportion of urban cases declined over the years, which was also found to be highly significant (Cochrane-Armitage x^2=123.064, df=1, p<0.0005).

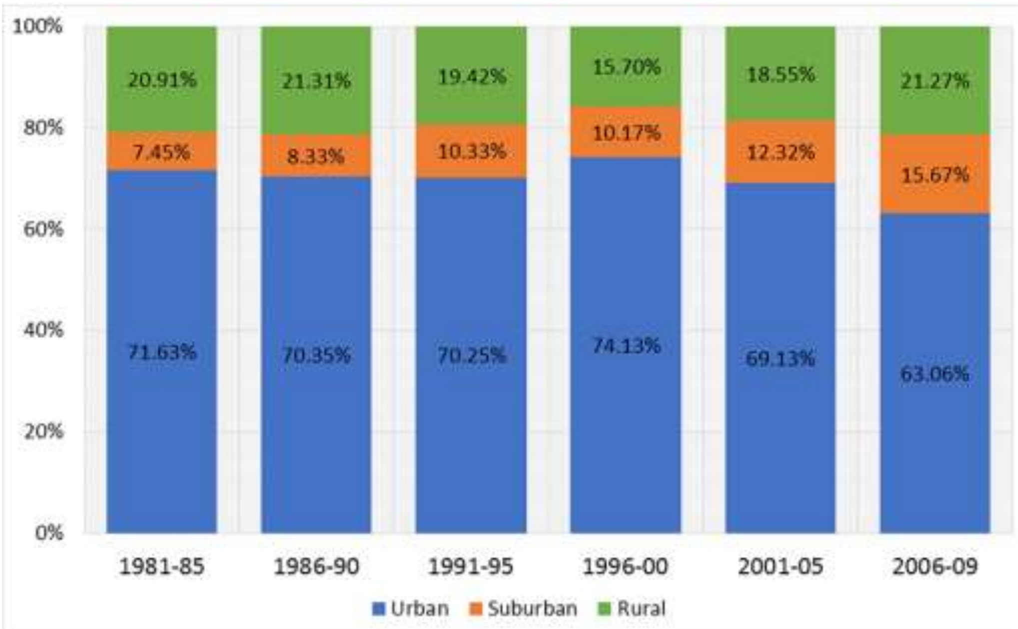

Figure 2.1 Proportion of cases by neighbourhood type
Urban cases decline and rural cases remain relatively stable while the proportion of suburban cases doubles from 1981 to 2009. These trends are statistically significant for all three neighbourhood types (p<0.01).

When mapped, temporal trends in case concentrations are visible from 1981 to 2009, as shown for the Metro Vancouver area in Figure 2. White pixels represent a concentration of cases within 1500 metres. In the first decade 1981-1990, cases were concentrated in urban areas, dispersing throughout the 1990s and 2000s into the suburban fringe. While only Metro Vancouver is shown in this figure, similar patterns are found in all other cities in British Columbia. These maps are not published to protect patient confidentiality.

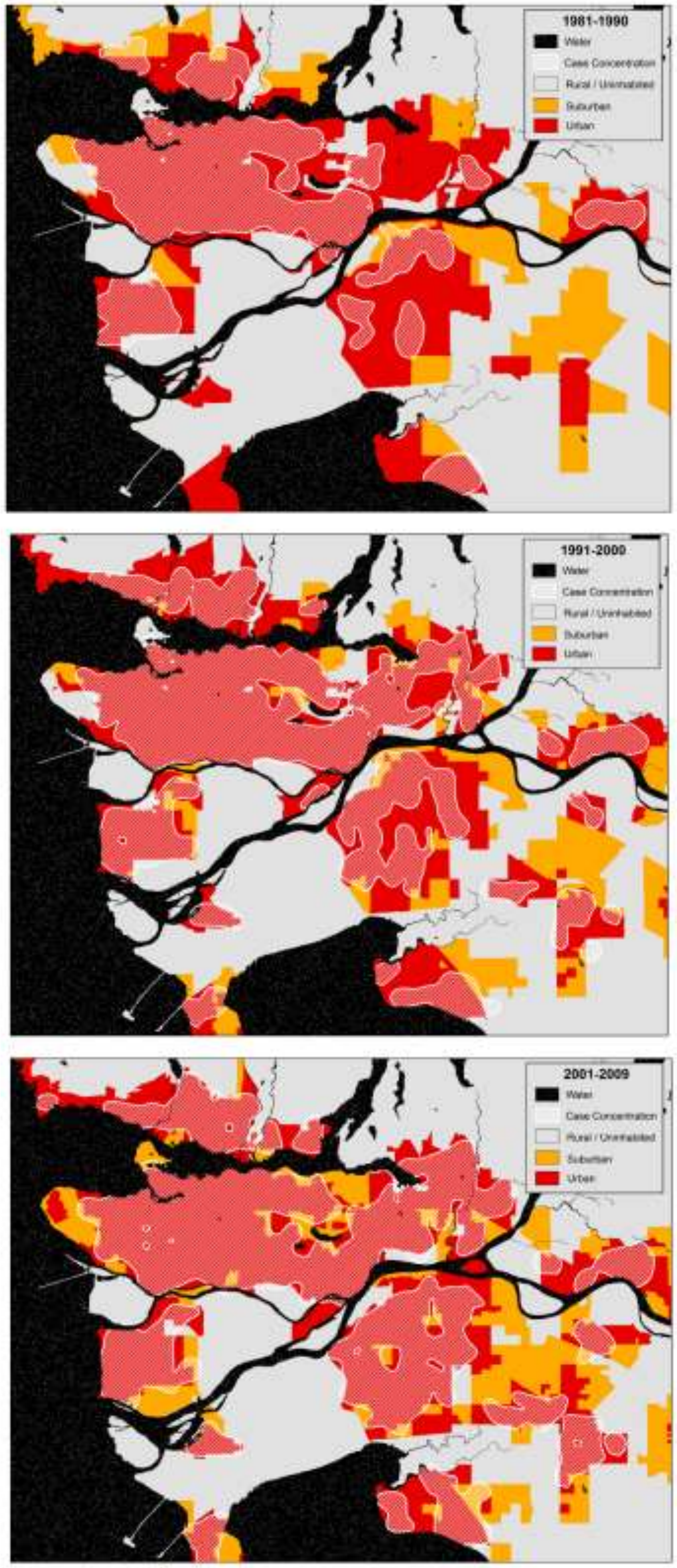

Figure 2.2 Oral cavity cancer case concentrations for Vancouver, by decade

Case concentrations (approximated by white hashed areas) are found to disperse from the urban cores in the 1980s to the surrounding areas in the 1990s and 2000s, including into lower-density suburban areas. This pattern is consistent throughout cities in British Columbia.

Table 2.2 Age-Adjusted Incidence Rates by Neighbourhood Type, per 500 000 Person-Years, with 95% Confidence Intervals.

	1981-85	1986-90	1991-95	1996-00	2001-05	2006-09
Urban	**0.81** (0.71, 0.90)	**1.11** (1.00, 1.21)	**0.98** (0.89, 1.06)	**0.89** (0.81, 0.97)	**0.78** (0.70, 0.85)	**0.70** (0.64, 0.76)
Suburban	**0.79** (0.49, 1.08)	**1.14** (0.81, 1.46)	**1.76** (1.35, 2.17)	**1.39** (1.06, 1.73)	**1.40** (1.10, 1.70)	**1.98** (1.64, 2.32)
Rural	**0.69** (0.54, 0.84)	**1.07** (0.88, 1.26)	**1.40** (1.16, 1.64)	**0.95** (0.76, 1.14)	**1.14** (0.94, 1.34)	**1.25** (1.06, 1.44)

AAIRs for OCC are shown in Table 2 and Figure 3. A divergence between urban, suburban, and rural incidence rates is observed following the 1986-1990 5-year period. The steady decline in urban rates is contrasted by increases in rural and suburban incidence. The divergent trend in age-adjusted incidence rates confirms the observed trend of fewer case concentrations in dense urban cores accompanied by increasing incidence in rural/suburban areas, supporting our mapped findings.

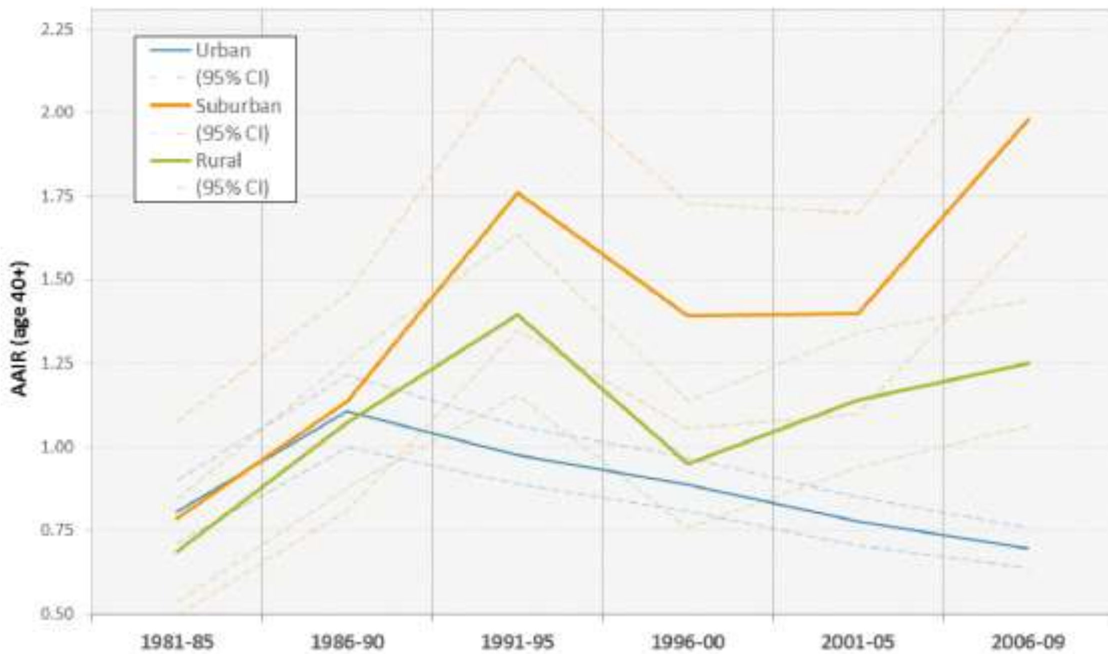

Figure 2.3 Age-adjusted incidence rates
AAIR (per 500 000 person-years, in five-year intervals) by neighbourhood type, illustrating the shift in incidence from urban cores outwards to the suburbs.

The Vancouver Area Neighbourhood Deprivation Index scores for each patient's residential postal code at the time of diagnosis show distinct trends between neighbourhood types, as shown in Figure 4. Higher levels of socioeconomic deprivation within suburban and rural patients' census areas were observed in the 1980s. However, the 2005-09 period is characterised by a sharp increase in suburban patients' median neighbourhood deprivation score, corresponding to declining SES among OCC patients.

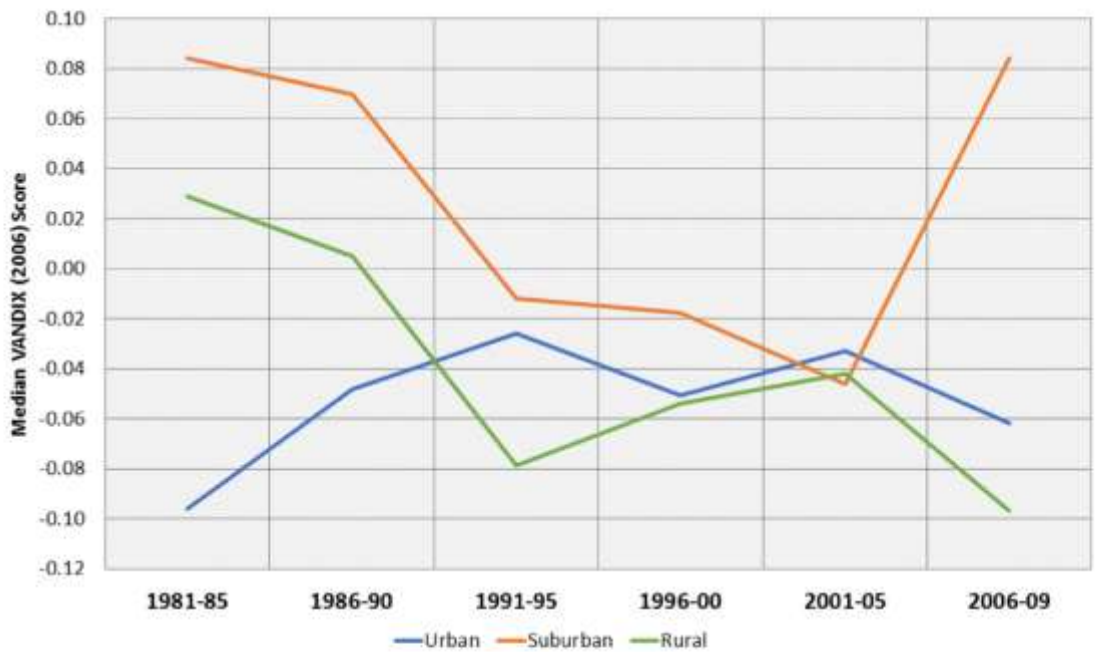

Figure 2.4 Median VANDIX score by neighbourhood type

Note the convergence in recent decades, interrupted by a sharp rise in deprivation among suburban patients from 2006 to 2009. This may reflect the documented increase in suburban deprivation and its known correlation with OCC incidence.

Neighbourhoods with a high proportion of seniors correspond to case concentrations in most cities in the study area, as shown in Figure 5. However, case concentrations not coincident with a high proportion of people ages 65+ years appear to have high proportions of Indian, Chinese, or Taiwanese residents; very few neighbourhoods have both.

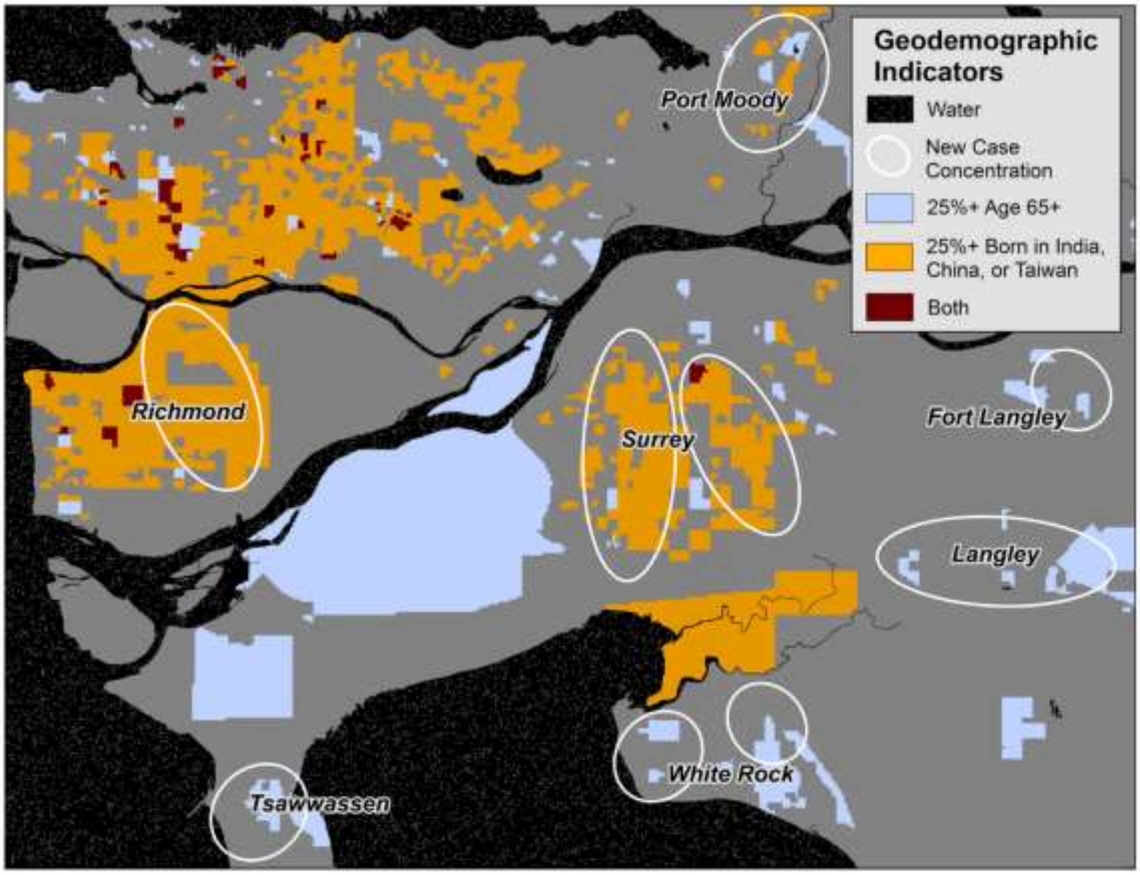

Figure 2.5 New case concentrations in Metro Vancouver

2006 census geographical units where over 25% of residents are ages 65+ and/or born in India, China, or Taiwan. New oral cancer case concentrations since the 1990s are approximated by white ellipses, found exclusively on the urban periphery. The observed increase in age-standardised incidence rates in suburban areas may be explained by the high percentage of immigrant populations from India, China, and Taiwan, where consumption of betel quid/areca nut is high.

2.5. Discussion

Through the use of spatial temporal mapping and geospatial analysis, this study provides novel insight into rising OCC incidence in suburban neighbourhoods. By mapping these data, we identified divergent trends in suburban areas otherwise obscured in epidemiological studies using an urban/rural dichotomy. Through examination of the resulting trends and maps, we hypothesise that this recent increase in both un-adjusted and adjusted incidence in suburban neighbourhoods may be explained by three simultaneous geodemographic transitions in the suburbs including: increases in aging; socioeconomic deprivation; and increases in betel/areca consuming populations.

As established in the literature, risk behaviours such as tobacco and alcohol consumption correlate with socioeconomic deprivation among oral cancer cases [320]; this pattern is particularly strong in our study findings. However, the association between suburban incidence and deprivation may be linked to changes in the age structure and ethnic composition of suburban areas in British Columbia. Previous research has documented increasing deprivation levels among suburban immigrants in Canada, suggesting that foreign-born residents bear a disproportionate burden of socioeconomic disadvantage [259,311].

In 2011, one in every four British Columbians was foreign-born, 72% of whom arrived from Asia (primarily India, China, and Taiwan) [321]. Previous studies have found disproportionately high oral cancer rates among South Asian and Chinese populations [322], including a study conducted in British Columbia [318]. While tobacco use is very prevalent (particularly among males) in China, studies have shown significantly lower use among Chinese and South Asian populations in Canada than other ethnic groups [234,323]. Lower consumption of alcohol among Chinese and South Asian populations in Canada was also observed [234]. However, these ethnic groups have a high prevalence of betel quid and areca nut consumption (with or without tobacco) [323]. A recent meta-analysis of fifty publications implicates betel quid and areca nut in half of all oral cancer incidence in India (49.5%, chewed with tobacco) and Taiwan (53.7%, chewed without tobacco) [324]. In the Southern provinces of China, the prevalence of betel/areca use is as high as 82.7%, although data for most regions are highly limited [325]. While traditionally rare in North America, there is a high prevalence of betel/areca consumption among South Asian, Chinese, and Taiwanese immigrants in Western regions, including in British Columbia [228,300,322].

The observed development of OCC case concentrations in areas of high East- and South-Asian immigration may be due to several combinations of risk factors, including betel/areca consumption (with and without tobacco), socioeconomic deprivation, and aging among immigrant populations. Similar demographic transitions are occurring also in the United States and Western Europe, driving increased betel/areca-related oral cancer incidence [324]. The use of map-based and spatial-analytical studies in these regions may yield additional evidence to inform this hypothesis and inform place-specific public health interventions.

While the majority of cases occur in urban areas throughout the study period, the proportion of cases in suburban areas has more than doubled since 1981. This emergence of suburban incidence is observed in cities throughout the province and may be due to a growing senior population in these previously rural areas. While in 1991 the average proportion of residents ages 65 years and over in suburban neighbourhoods throughout British Columbia was 13.1%, it has steadily risen to 15.5% in 2006. Conversely, the urban average in 1991 was 17.7%, falling to 14.7% in 2006 and rural figures have remained around 12% throughout. This transition suggests an increased overall burden of oral cancer risk in suburban areas and may partially explain the observed geographical pattern shown in Figure 2.

The recess in age-adjusted incidence rates observed in the 5-year period 1996-2000 may be attributable to the redrawing of official census area boundaries in 1996. However, by 2006-2009, a clear divergence is apparent between neighbourhood types. That this pattern persists after age-adjustment suggests that the growing senior population in suburban neighbourhoods does not entirely account for the observed increase in suburban oral cancer rates.

A distinct convergence of socioeconomic deprivation in the 1990s and early 2000s may be explained by increasing suburban and rural affluence as baby boomers relocated from urban centres to surrounding areas. However, we hypothesise that the subsequent increase in median suburban deprivation in the most recent decade is linked to suburbanisation of deprivation and is a contributing factor to the increase in suburban incidence in recent decades. That high deprivation is geographically coincident with immigrant neighbourhoods underscores their unique barriers in access to screening and treatment. The challenges imposed by language, mobility, and cultural norms are amplified by suburban deprivation, isolation, and increased travel distance to health care resources [310,326]. Accordingly, we emphasise the need for improved education and awareness of OCC risk factors such as betel quid/areca nut consumption, and underscore the importance of accessible, culturally-sensitive screening programs in North America, Western Europe, and other high-immigration regions undergoing suburbanisation.

2.5.1. Study strengths and limitations

The use of geospatial methods enabled us to categorise and map finer-resolution geographical patterns that would have been obscured using traditional epidemiological methods. Additionally, this approach enabled a more nuanced classification to include suburban cases beyond the common urban/rural dichotomy. Through the examination of map-based data, supplemented with our local knowledge of the study area, we hypothesised that immigration and aging patterns may be geographical correlates to increasing suburban OCC incidence. The use of a map-based data analysis platform (geographical information systems) facilitated the investigation of these hypotheses both visually and using statistical methods.

Crucially, population data from the BC Cancer Registry include over 90% of all known cases, enabling us to infer with a high degree of confidence that the observed trends reflect the true patterns at the population level. Census data for every census year in the study enabled temporally accurate neighbourhood classification, while the Vancouver Area Neighbourhood Deprivation Index provided insight into the socioeconomic context of suburban cancer incidence. However, the use of 2006 census data to model deprivation limits its accuracy for earlier time periods. Additionally, our method for constructing AAIRs for 2010 assumes a rate consistent with the preceding four-year period (2005-2009), and low female incidence prevented the calculation of reliable sex-specific AAIR estimates.

While the suburbanisation of OCC case concentrations was observed for all cities in British Columbia, low numbers of Asia-born immigrants outside the Metro Vancouver area limits our ability to address the betel/areca hypothesis in smaller urban areas. Future map-based analyses may yield more insight into this pattern in the context of other large North American and Western European cities.

2.6. Conclusion

This study has identified a shift in oral cavity cancer incidence from urban cores to the suburbs through recent decades in British Columbia, Canada. This spatial shift is coincident with changes in socioeconomic deprivation associated with urban, rural, and suburban neighbourhoods. Crucially, the higher observed incidence in suburban areas may be explained by an increasing number of senior residents, socioeconomically deprived populations, and patterns of immigrant settlement and associated betel/areca consumption among Asia-born populations. Future research is required in other study areas to identify the extent and magnitude of the patterns observed herein. The findings of this study are directly applicable to public health policy implementation including identification of areas where increased culturally-sensitive screening for OCC may be appropriate.

The growing ubiquity of maps in mobile and web-based applications underscores their potential to communicate spatial knowledge. Geospatial methods, such as those used in this study, enable the spatio-temporal analysis and mapping of cancer registry data to provide researchers with cartographic tools for developing epidemiological hypotheses, identifying opportunities for location-specific policy, and targeting high-risk sub-populations. As such, we advocate for greater use of geospatial methods to supplement traditional epidemiological studies and communicate results to policymakers.

Chapter 3.

Socioeconomic Disparities in Head and Neck Cancer Patients' Access to Cancer Treatment Centres

In this chapter, we move beyond the identification of patterns in oral cancer incidence to explore how these relate to patient patterns of spatial and socioeconomic access to treatment.

3.1. Abstract

3.1.1. Purpose

Both and socioeconomic status and travel time to cancer treatment have been associated with treatment choice and patient outcomes. An improved understanding of the relationship between these two dimensions of access may enable cancer control experts to better target patients with poor access, particularly in isolated suburban and rural communities.

3.1.2. Methods

Using geographical information systems, we mapped head and neck cancer patients across British Columbia, Canada from 1981 to 2009, and modelled their travel time to the nearest treatment centre at their time of diagnosis. We analysed patients' travel times by urban, suburban, and rural neighbourhood types and used an index of multiple socioeconomic deprivation to assess the role of SES in patients' spatial access.

3.1.3. Results

Significant trends in socioeconomic deprivation and spatial access to treatment were identified, with the most deprived quintiles of patients experiencing the greatest travel

burden, particularly in suburban and rural communities. However, the establishment of new treatment centres has decreased overall travel times for patients in recent decades.

3.1.4. Conclusions

Socioeconomic deprivation is strongly associated with head and neck cancer patients' spatial access to cancer treatment centres. The most socioeconomically deprived patients consistently have longer travel times in urban, suburban, and rural communities. Further research is needed to assess how these combined measures of access affect patient outcome.

3.2. Background

With an estimated 525 000 new cases in 2012, head and neck cancers are the 8th most common non-melanoma cancers globally [9]. This number is expected to grow significantly in the coming decades, resulting in increased demand for treatment [327].

To maximise efficiency, comprehensive cancer treatment facilities are most commonly located in areas where they service the largest proportion of the patient population, generally in large urban centres. This results in a geographical inequity, such that individuals living farther from a cancer treatment centre experience a greater travel burden in order to attend their treatment, particularly those living in rural and remote areas [203]. This travel burden has been shown to have significant effects on patients' tumour stage and grade at the time of diagnosis [35,328–332], decisions concerning treatment [190,203,217,218,333], and survival [334]. The time required for patients to travel from the home to a cancer treatment centre is therefore an important factor throughout the continuum of care, and may inform more efficient and equitable cancer control programmes and policy.

The travel time required for an individual to reach a treatment centre provides a quantitative measure of access [335]. However, an individual's access to a health service may also be measured as the 'degree of fit' between that individual and the health system with which they are interfacing [180]. This broader definition encompasses social, economic, cultural, and structural barriers to entry into a health system [336]. For example, while an individual may live near a hospital, their ability to obtain medical care may be inhibited by vehicle non-ownership, language barriers, cultural norms around health, the economic inability to miss work or obtain child care, poor public transit provision, lack of systemic requirements such as medical insurance or a fixed address, and family caregiver needs, to name but a few. These non-spatial dimensions of access reflect a socioeconomic component that authors argue is a vital ingredient in both the accurate modelling of access to health services and informing policy decisions [184]. Socioeconomic deprivation can therefore be considered a proxy variable for non-spatial access to treatment. Further, while socioeconomic deprivation is a well-established predictor of cancer incidence [233,243,303,337–339], rates of treatment [340], and survival [34,306,339,341,342], there is some evidence that these socioeconomic disparities also reflect poor spatial access to screening, diagnosis, and treatment [330,331,339,343–346].

In order to provide more geographically equitable access to treatment in British Columbia (BC), Canada, the British Columbia Cancer Agency has established five new comprehensive cancer treatment centres since 1995, in addition to the original BC Cancer Centre in the city of Vancouver. Using spatial-temporal mapping of head and neck cancer patients from 1981 to 2009, this study seeks to quantify how the establishment of new cancer treatment centres has affected patients' spatial access treatment, and how these trends vary by socioeconomic deprivation and between urban, suburban, and rural patient populations.

3.3. Data and Methods

Approvals for this study were obtained through both the Simon Fraser University Research Ethics Board (2013s0753) and the British Columbia Cancer Agency/University of British Columbia Research Ethics Board (H08-00839).

HNC incidence data were provided by the British Columbia Cancer Registry, comprising all patients who received a histologically confirmed diagnosis in the province of BC from 1981-2009, inclusive. The following tumour sites were selected, corresponding to the International Classification of Diseases in Oncology, version three site codes for head and neck cancers: C003-5 (mucosa of upper and lower lips); C020-23 (dorsal surface, ventral surface, border and anterior 2/3rd of tongue); C028-29 (overlapping lesions of tongue and tongue); C030-31, 039 (upper and lower gum); C040, 041, 048, 049 (anterior, lateral floor of mouth, overlapping lesions of floor of mouth, floor of mouth); C050-52, 058, 059 (soft palate, hard palate and uvula, overlapping lesions of palate, palate); and C060-62, 068, 069 (cheek, vestibule of mouth, retromolar area, mouth, and unspecified parts of the mouth) [318].

The following patient variables were captured at the time of diagnosis: patient age, sex, primary tumour site, date of diagnosis, and residential postal code. Following the removal of incomplete or erroneous records, 11 050 individual patient records remained for analysis. We calculated age- and sex-adjusted incidence rates per 100 000 for each tumour site and 5-year interval, using the direct method based on the 1996 BC standard population. For the final interval (2005-2009), we estimated a 5-year rate based on a linear extrapolation of the 4-year incidence. Each patient's home location was mapped, based on their postal code at the time of diagnosis.

Geographical information systems were used to compute estimated travel times based on a digital road and ferry network that includes intersections, speed limits, and other features that affect vehicular egress. These data were used to calculate an estimated drive time from each patient's postal code to the nearest cancer treatment centre at their time of diagnosis. To visualise how new cancer treatment centres affected spatial access, we mapped catchment areas around each treatment centre to identify the areas within 30, 60, 120, 180, and 240 minutes of travel time, for each decade since 1981.

Population data were obtained from Statistics Canada for every census year in the study period (5-year intervals from 1981-2006) and mapped by census dissemination area, the smallest geographical unit publicly available, each containing 400 to 700 residents. Population densities were used to classify dissemination areas as urban (>400 persons/km^2), suburban (150-400 persons/km^2), or rural (<150 persons/km^2), according to the definition from Statistics Canada and the Organisation of Economic Cooperation and Development [245]. Patients were thus categorised by their neighbourhood type (urban/suburban/rural) at their time of diagnosis, thereby accurately classifying patients living in rural neighbourhoods that later became suburban, for example.

The local socioeconomic deprivation score for every census dissemination area was calculated using the Vancouver Area Neighbourhood Deprivation Index (VANDIX), a composite metric of health-related deprivation based on the following weighted variables from the 2006 Canadian census: average income, workforce participation rate, unemployment rate, proportion of lone-parent households, high school non-completion, proportion of population without a university degree, and proportion of home owners [347]. Data from the 2006 census were used due to their relatively high accuracy compared to previous census years, though they may inaccurately reflect socioeconomic status for patients diagnosed early in the study period. Every patient was assigned their local neighbourhood deprivation score, and all patients were then classified into deprivation quintiles (Q1= least deprived/highest SES; Q5 = most deprived/lowest SES).

Patient and risk population drive-times to the nearest treatment centre were cross-tabulated by socioeconomic deprivation and neighbourhood type to identify differential patterns between urban, suburban, and rural patients, following from our previous work [338]. To apply parametric tests, we log-transformed drive times to normalise their distributions. Bivariate linear models were fitted to test for correlations between mean travel time and socioeconomic deprivation. We then conducted independent t-tests between contiguous deprivation quintiles to identify where significant differences in mean travel time occurred. Bonferroni-corrected alpha thresholds were used to assess significance (trend tests: $\alpha = 0.017$; difference of means: $\alpha = 0.0125$). Statistical analyses were conducted using SPSS, version 23.

3.4. Results

Of the 11 050 patients records analysed, 33.3% were female. The distribution of patients' neighbourhood types was 76.4% urban, 8.5% suburban, and 15.1% rural, consistent with the population distribution of British Columbia. 62% of patients lived within one hour of a treatment centre at their time of diagnosis, while only 3% lived more than 12 hours by automobile and/or ferry. All of these distributions were temporally stable throughout the study period.

Table 3.1 Study population characteristics

		Urban	Suburban	Rural		
Sex	Female	2882	311	489	**3682**	33.3%
	Male	5559	631	1178	**7368**	66.7%
Socioeconomic Deprivation Quintile	Q1	1813	146	252	**2211**	20.0%
	Q2	1650	170	389	**2209**	20.0%
	Q3	1614	226	372	**2212**	20.0%
	Q4	1648	215	346	**2209**	20.0%
	Q5	1716	185	308	**2209**	20.0%
Year of Diagnosis	1981-1985	988	127	204	**1319**	11.9%
	1986-1990	1199	158	338	**1695**	15.3%
	1991-1995	1405	155	383	**1943**	17.6%
	1996-2000	1646	154	205	**2005**	18.1%
	2001-2005	1679	182	271	**2132**	19.3%
	2006-2009	1524	166	266	**1956**	17.7%
Travel Time to Treatment	0-1 hours	6078	372	372	**6822**	61.7%
	1-3 hours	553	161	297	**1011**	9.1%
	3-5 hours	390	131	277	**798**	7.2%
	5-12 hours	1271	231	598	**2100**	19.0%
	12+ hours	149	47	123	**319**	2.9%
	Total	**8441**	**942**	**1667**	**11050**	
	Per Cent	76.4%	8.5%	15.1%		

Age-adjusted incidence rates were found to vary across the study period, as shown in Figure 1. Suburban and rural rates have increased overall, with the sharpest increase observed for suburban patients, as previously reported for oral cavity cancers [338].

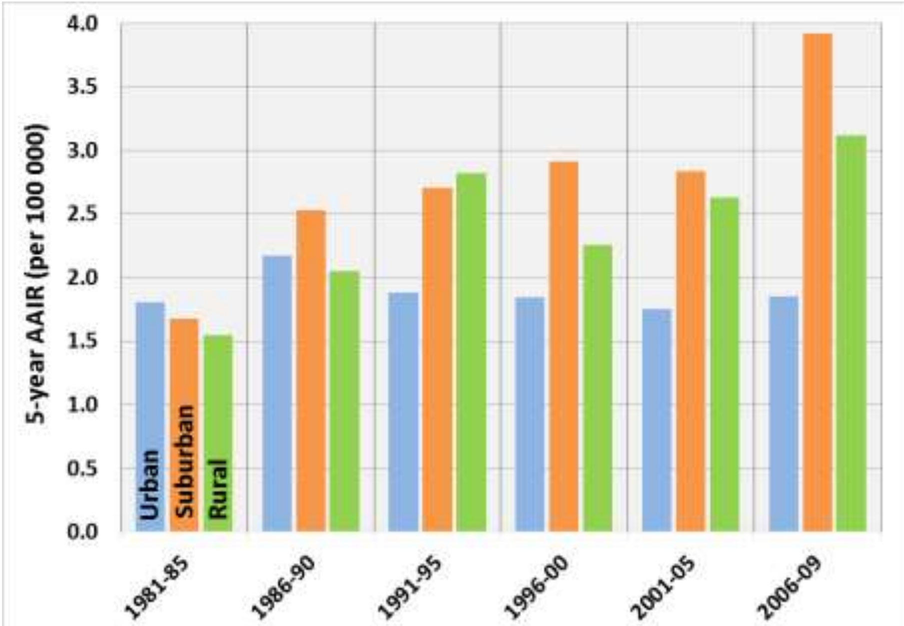

Figure 3.1 Five-year age-adjusted incidence rates per 100 000

The observed socioeconomic gradient of travel time to comprehensive cancer treatment is consistent, with the most significant disparities observed for the most deprived 40% of suburban patients, and the most deprived 20% of rural patients, the majority of whom live in remote regions of Northwestern BC. As shown in Figure 2, the deprivation-travel time trend is linear and significant among patients residing in urban neighbourhoods (R^2=0.98, p<0.001; b=0.2, p<0.001), with a steeper increase among suburban patients (R^2=0.92, p=0.005; b=0.28, p<0.005). In rural neighbourhoods, the trend is non-linear (R^2=0.68, p=0.04; b=0.16, p<0.04) but features an increase in mean travel time among patients residing in the most deprived neighbourhoods (Q4 and Q5).

Significant differences between contiguous socioeconomic quintiles are denoted by asterisks in Figure 2. For urban patients significant increases in mean travel time were identified between all quintiles except for Q4 to Q5. Among suburban patients, a significant break is observed from Q3 to Q4 and is the greatest increase across all categories. Similarly, the only significant increase among rural patients is in the most deprived neighbourhoods (Q4 to Q5), representing patients residing in the most remote communities.

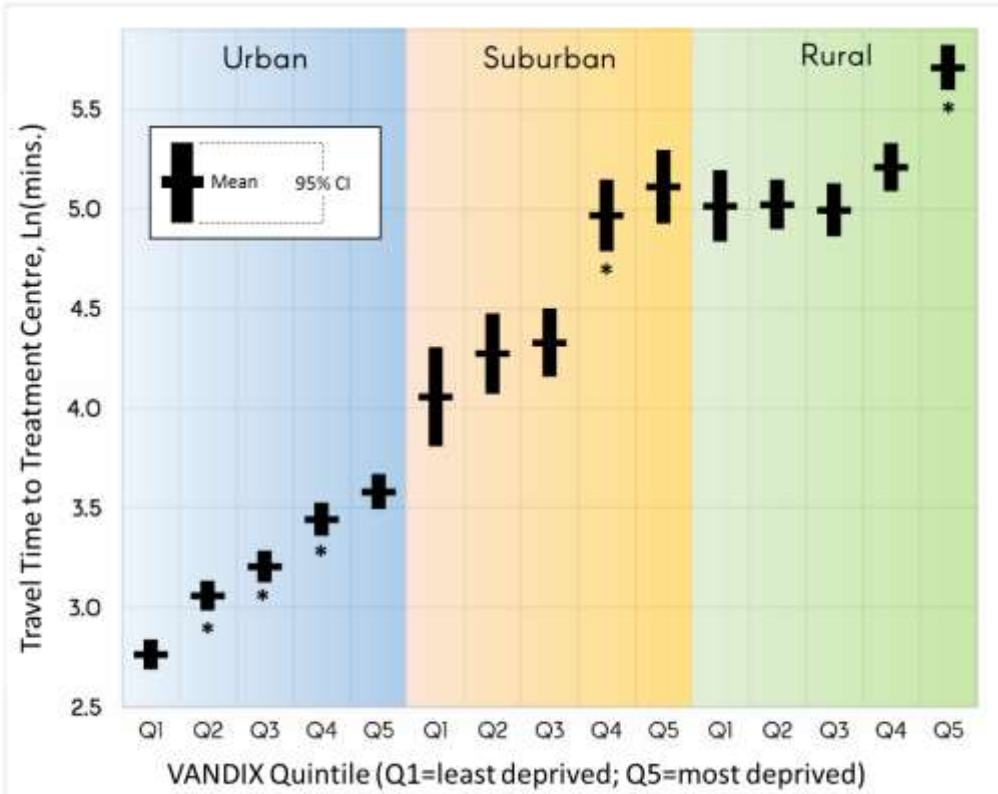

Figure 3.2 Patient travel times by deprivation and neighbourhood type
Log-transformed minutes by neighbourhood type and VANDIX quintile, with means and 95%CI. Asterisks denote statistically significant increases in travel time above previous quintile.

As shown in Figure 3, the time-series maps of the comprehensive cancer treatment centres illustrate both the densification of treatment in Southwest British Columbia (Surrey, opened in 1995, and Abbotsford in 2008), and expansion into less populous regions like the Okanagan Valley (Kelowna in 1998), Vancouver Island (Victoria in 2001), and most recently in the rural and remote north (Prince George in 2012).

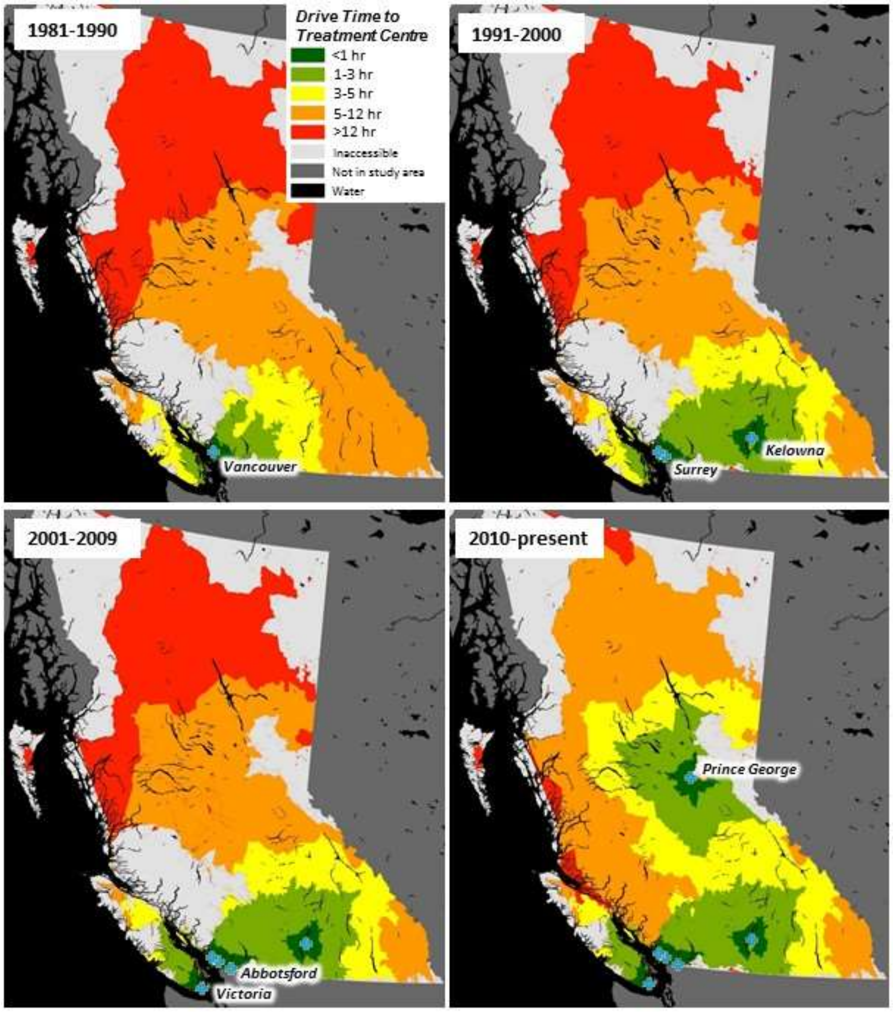

Figure 3.3 ***Time-series maps***
Maps of British Columbia Cancer Agency comprehensive cancer treatment centres, by decade. Coloured regions indicate drive time to the nearest centre.

While the establishment of new treatment centres has contributed to a decreased patient travel times in recent decades, an increase is observed for rural patients from 2005-2009, as shown in Figure 4. Statistically significant differences in travel time were observed between neighbourhood types, as the majority of comprehensive cancer treatment centres are located in BC's major urban centres. A widening disparity between neighbourhood types in the most recent time period (2005-2009) is indicative of a rise in head and neck cancer incidence farther from urban centres.

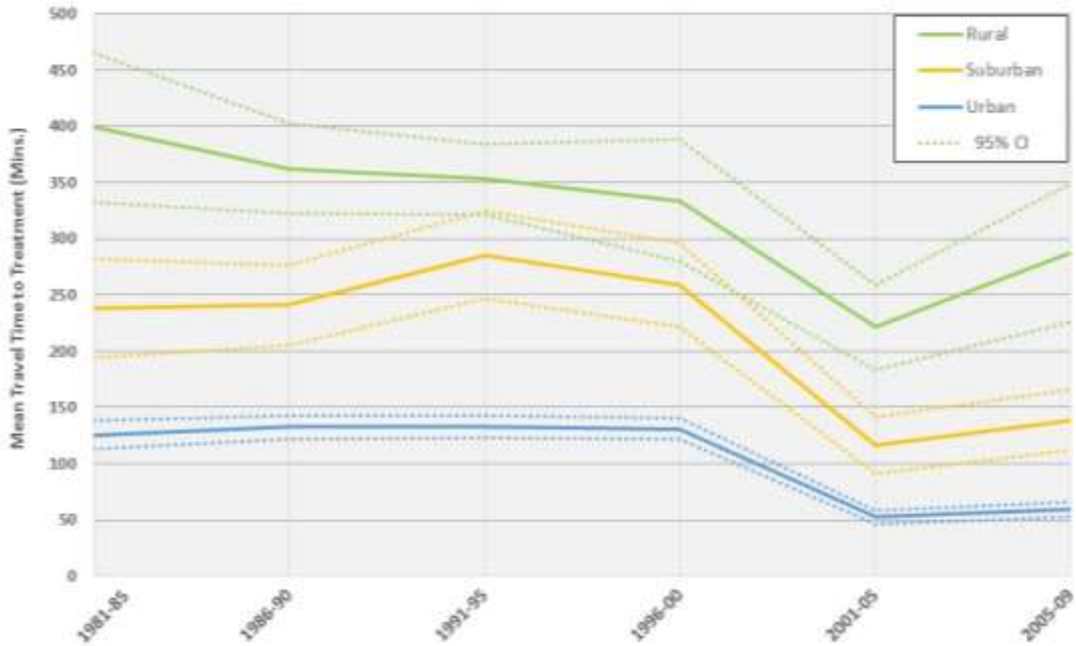

Figure 3.4 Mean travel time to nearest treatment centre
Minutes of travel time for each neighbourhood type by 5-year period, with 95% CI. While overall decreases are observed, the recent increase in travel time for rural patients indicates a growing demand in rural and remote regions.

Similarly, decreases in travel time were observed for all five socioeconomic deprivation quintiles, as shown in Figure 5. However, while average travel times for the three least deprived quintiles are converging around one hour, recent increases are observed among the two most deprived quintiles (Q4 & Q5), demonstrating a clear inequality in access to treatment between socioeconomic groups, particularly in rural and remote regions, despite the densification and expansion of cancer treatment centres across BC.

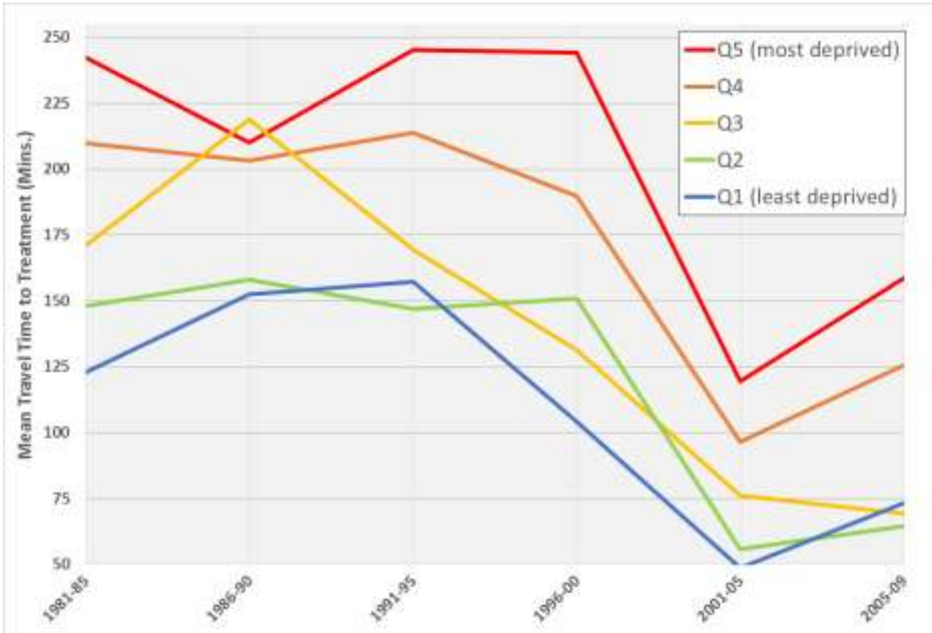

Figure 3.5 Travel time by socioeconomic deprivation quintile
Mean minutes to nearest treatment centre for each socioeconomic deprivation quintile by 5-year period. A convergence of average travel time is observed for the three least deprived quintiles of patients, while recent increases are observed for the two most deprived quintiles.

3.5. Discussion

This study provides evidence of a strong socioeconomic gradient in spatial access to cancer treatment using a composite weighted index of socioeconomic status. The most socioeconomically deprived populations were found to have the longest travel time to treatment. This combination of poor spatial access may be aggravated by non-spatial barriers facing socioeconomically deprived patients, for example, low financial resources and reduced ability to navigate the health system.

By differentiating patients by urban, suburban, and rural residence, we identified a consistent socioeconomic gradient in travel time across all three neighbourhood types. Interestingly, the greatest gap in travel times was observed for suburban patients above the 60th percentile of socioeconomic deprivation. This finding is suggestive of a sharp geographical boundary separating more affluent suburban populations nearer urban cores (where the cancer treatment centres are generally located) from their less affluent counterparts on the suburban periphery [310]. The distinctly higher travel burden observed among rural patients is consistent with previous studies [328], though our findings further identify a socioeconomic difference among these populations. The most deprived quintile of rural patients had a median travel time of six hours: 14 times that of the most deprived urban patients, and 33 times that of the most affluent urban patients. However, it must be noted that the observed degrees of difference in this study may be amplified by BC's large size and remote northern half, a geographically unique configuration when compared to other studies of access to cancer treatment.

Temporally, this study provides evidence that the establishment of new cancer treatment centres in BC has led to overall decreases in patients' average travel time, particularly since the Kelowna centre opened in 1998, greatly expanding the geographical extent of services across the Southern half of the province. However, recent increases in travel time among the most socioeconomically patients may be evidence of growing socioeconomic deprivation in suburban locales most notably in the outer suburban neighbourhoods of major centres such as Vancouver and Victoria. This pattern is consistent with our previous findings but merits further investigation [338].

While this study does provide strong evidence of socioeconomic and geographical disparities in spatial access to cancer treatment among head and neck cancer patients, there are several limitations that merit attention. Aetiological differences between different head and neck cancer sub-types may be reflected in their geographical distributions across the study area. However, the number of cases was not sufficient to conduct a sub-analysis by tumour site. Because this study used estimated driving and ferry times from patients' residential postal code, the actual travel time a patient experiences may differ, particularly in remote regions, where air travel may be necessary. The actual placement of cancer treatment centres is determined by a wide range of factors, including population forecasts and economic calculation. Limited chemotherapy treatments have recently become available in small community centres across the province. However, further data are required in order to examine the effect these centres have on patient access across the province.

3.6. Conclusion

Significant socioeconomic disparities in patients' estimated travel time to a comprehensive cancer treatment centre were observed in urban, suburban, and rural areas, with a consistent and increase by deprivation quintile. This combination of spatial and socioeconomic barriers may significantly impact low-SES patients' ability to receive treatment. However, while the expansion and densification of comprehensive cancer treatment centres in British Columbia has led to decreases in travel time from 1981 to 2009, socioeconomic disparities in access remain throughout the study period, meriting further investigation.

Chapter 4.

Cancer Resection Rates Vary Between Urban, Suburban, and Rural Populations: Socioeconomic and Geographical Access to Surgery for Five Cancer Types Across Canada, 2004-2012

4.1. Abstract

High-risk cancer resection surgeries are increasingly being performed at fewer, higher-volume institutions across Canada. The resulting increase in travel time for patients to obtain treatment may be exacerbated by socioeconomic barriers to access. Focussing on five high-risk surgery types (oesophageal, ovarian/fallopian, liver, lung, and pancreatic cancers), this study examines socioeconomic trends in age-adjusted resection rates and travel time to surgery location for urban, suburban, and rural populations across Canada, excluding Québec, from 2004 to 2012.

Significant differences in resection rates were observed between urban (14.9 per 100 000 person-years [95% CI: 12.2, 17.6]), suburban (40.7 [40.1, 41.2], and rural (32.7 [29.6, 35.9] populations, with consistently higher rates in suburban and rural areas throughout the study period for all cancer types. When stratified by socioeconomic deprivation, resection rates did not differ between the patients among the least deprived quintile of the population (Q1: 13.3 [12.2, 14.4]) and the most deprived (Q5: 12.0 [10.7, 13.4]), with higher rates among middle-SES patients (Q2: 27.3 [25.6, 29.0]); Q3: 39.6 [37.4, 41.8]; Q4: 37.5 [35.3, 39.7]). Patients' mean travel times to treatment were consistently higher among the most socioeconomically deprived patients, most notably in suburban and rural areas, representing a double-burden of low geographical and socioeconomic access to surgery.

Low resection rates among geographically isolated, socioeconomically deprived patient populations may indicate poor access to treatment. Suburban patterns of resection rates, travel times, and socioeconomic status were more similar to rural neighbourhoods

than urban. This suggests that the conventional inclusion of suburban with urban areas in health research may obfuscate important trends for public health policy and programmes.

4.2. Background

Cancers are the leading cause of death in Canada, with 197 000 new diagnoses and 78 000 deaths per year [10]. However, improvements in tumour detection and treatment continue to extend patient survival; nearly two-thirds of patients survive at least five years post-diagnosis [10].

Surgical tumour resection is an effective treatment modality, but comorbidities, high-risk surgical procedures, and other complicating factors often demand a high level of operative specialisation and medical facilities. To meet these demands, many high-risk resection procedures are increasingly being performed at fewer, more specialised centres in major Canadian cities. This process of regionalisation to high-volume institutions has been shown to reduce overall patient mortality rates and post-operative length of stay [348–350], including in Canada [351]. However, the average travel time for a patient to reach their location of surgery has increased as a result [351].

Patient access describes an individual's ability to interface with medical systems in order to receive treatment [180]. Access therefore relies both on a patient's ability to physically reach a treatment centre (spatial access) and their social and economic position, e.g., language barriers or financial inability to travel (socioeconomic access) [182][187]. Spatial access has been shown to be a significant predictor of tumour stage at diagnosis [177], choice of treatment [203,217,352], and mortality [353], with greater travel time to treatment observed for rural patients [354]. Socioeconomic status is also a known predictor of cancer survival [353,355] and surgery rates [356,357], and though the causative pathway is unclear, the burden of long-distance travel to treatment may be exasperated by a lack of social and financial resources [351][354]. Few studies to date have considered both spatial and socioeconomic measures of access in combination, with several notable exceptions [353][179,185], though the identification of socioeconomically deprived and spatially isolated patient populations has significant implications for cancer control policy.

The binary categorisation of study populations into urban and rural patients has highlighted important differences in choice and outcome of cancer treatments [354,358–360]. However, there is a growing body of evidence suggesting that suburban neighbourhoods are becoming increasingly socioeconomically deprived in North America [310,361], with many of the deprivation-associated health risks and outcomes [7,307,362,363]. Our recent work differentiates suburban neighbourhoods from their urban and rural counterparts, documenting elevated oral cancer incidence rates, high levels of health-related socioeconomic deprivation [338], and low access to treatment centres (as shown in the previous chapter).

Identifying geographical and socioeconomic disparities in access to cancer treatment is important for improving health equity. The regionalisation of high-risk cancer resection surgeries during the study period may increase disparities in access among socioeconomically deprived rural and suburban populations, who already face additional barriers to spatial and socioeconomic access. This study therefore sought to identify socioeconomic patterns in cancer resection rates between urban, suburban, and rural populations, and to examine socioeconomic differences in urban, suburban, and rural patients' geographical access to surgery.

4.3. Data and Methods

Approvals for this study were obtained through both the Simon Fraser University Research Ethics Board (2014s0154) and the Hamilton Integrated Research Ethics Board (13-790).

Patient data were obtained from the Canadian Institutes of Health Information Discharge Abstract Database, comprising all surgeries reported by hospitals in Canada, excluding Québec, Included were all patients discharged from 1 April 2004 to 31 March 2012 following a tumour resection surgery for the sites corresponding to the ICD-10 diagnosis codes for oesophageal, ovarian/fallopian, liver, lung, and pancreatic cancers, with the surgical intervention codes shown in Table A. Patient data comprised the following fields: age, sex, home postal FSA (the first three digits of a Canadian postal code), institution where the surgery was performed, date of discharge, and all ICD-10 diagnosis and intervention codes.

Table 4.1 ICD-10 diagnosis and intervention codes selected for analysis.

Tumour Site	ICD-10 Diagnosis Codes	ICD-10 Intervention Codes
Oesophageal	C150-155, C158-159, D377	1NA89DB, 1NA89FA, 1NA91DB, 1NA91FA, 1NA88DCXXG, 1NA88FCXXG, 1NA87FB, 1NA87FC, 1NA87DC, 1NA87DD, 1NA87EY, 1NA87EZ, 1NA87QG, 1NA87QH, 1NA88LBXXG, 1NA88QFXXG, 1NA89LB, 1NA89QF, 1NA90LBXXG, 1NA90LBXXG, 1NA90QFXXG, 1NA91LB, 1NA91QF, 1NA92LBXXF, 1NA92LBXXG, 1NA92QFXXG, 1NA87LD, 1NA87LE, 1NA87QC, 1NA87QD
Ovarian/ Fallopian	C560-561, C569, C5700-5701, C5709, C571-574, C578, D391	1RB87DA, 1RB89DA, 1RD89DA, 1RB87LA, 1RB89LA, 1RD89LA, 1RD89RA, 1RB87RA, 1RB89RA, 1RF87DA, 1RF89DA, 1RF87LA, 1RF89LA, 1RF87RA, 1RF89RA, 1RM87BAGX, 1RM89CA, 1RM87CAGX, 1RM91CA, 1RM89AA, 1RM87DAGX, 1RM89DA, 1RM87DAAG, 1RM91AA, 1RM91DA, 1RM89LA, 1RM87LAGX, 1RM91LA, 1OT87LA, 1OT87DA
Liver	C220-224, C227, C229, C787, D376	1OA87DA, 1OA87LA, 1OA87LAAZ
Lung	C3400-3401, C3409-3411, C3419, C342, C3430-3431, C3439, C3480, C3489, C3490-3491, C3499, C390, C398-399, D381	1GR87DA, 1GR87PN, 1GT87DA, 1GR87NW, 1GR87QB, 1GT87NW, 1GT87QB, 1GR89DA, 1GR89NW, 1GR89QB, 1GR91NW, 1GR91NWXXA, 1GR91NWXXG, 1GR91NWXXN, 1GR91QB, 1GR91QBXXA, 1GR91QBXXF, 1GR91QBXXG, 1GR91QBXXN, 1GR91QBXXQ, 1GT89NW, 1GT89QB, 1GT91NW, 1GT91NWXXF, 1GT91NWXXG, 1GT91NWXXN, 1GT91NWXXQ, 1GT91QB, 1GT91QBXXF, 1GT91QBXXG, 1GT91QBXXN, 1GT91QBXXQ, 1GT89DA
Pancreatic	C250-254, C257-259	1OJ87LA, 1OJ87VK, 1OJ87VC, 1OJ87DA, 1OK87LA, 1OK87VZ, 1OK87WA, 1OK87XN, 1OK91LA, 1OK91XN, 1OK89LA, 1OJ89LA, 1OJ89VZ

This study used a geographical data linkage methodology to assign each patient's neighbourhood type (urban/suburban/rural) and socioeconomic deprivation score, described as follows. Population data from the 2006 census were obtained from Statistics Canada for every dissemination area (DA; n=39445; each has 400-700 residents) in the study area. Each DA was categorised by its neighbourhood type using the multivariate method by Gordon and Janzen [5], based on a validated combination of Organization for Economic Cooperation and Development and Statistics Canada definitions [245] and transportation variables, as outlined in Table B.

Table 4.2 Neighbourhood type definitions, from Gordon and Janzen [5]**.**

Neighbourhood Type	Definition
Rural	Population density < 150 persons/km^2
Urban Core	In a Statistics Canada Census Metropolitan Area (CMA); and % of population that commutes via active transit modes (walking, cycling, etc.) >= 1.5 times the CMA average
Suburban	Neither rural or urban

A socioeconomic deprivation score was also calculated for every DA using the Vancouver Area Neighbourhood Deprivation Index, a multivariate weighted index for health-related socioeconomic disadvantage based on seven material and social variables from the 2006 census: average income, secondary school completion, university degree attainment, lone-parent families, home ownership, employment ratio, and unemployment rate [319].

Patient data were available only at the FSA scale (n=1635, the median FSA population is 17433). Approximately the size of a neighbourhood in urban areas and a county in rural regions, FSAs are geographically larger than DAs, containing an average of 24 DAs. As a result, DA-level neighbourhood types and deprivation scores were aggregated to derive averages for each FSA in the study area as follows: the DA-level neighbourhood types were coded as 1=urban, 2=suburban, 3=rural; these values were then population-weighted by the number of adults (18+ years) in each DA. The mean population-weighted neighbourhood type for all DAs within an FSA was then calculated to derive an index value ranging from 1 to 3. This value was rounded to the nearest integer to assign a neighbourhood type to an FSA. Similarly, each FSA was assigned the mean population-weighted deprivation score of all its DAs within. The resulting FSA-level neighbourhood type and deprivation score was then linked to each patient in the dataset by patient home FSA code.

Resection rates provide a useful indicator of patient access [364,365]. Age- and sex-specific resection rates were calculated for each cancer type (tumour site), socioeconomic deprivation quintile, neighbourhood type, and 3-year interval (2004-2006, 2007-2009, 2010-2012). These rates were all adjusted to the 2006 Canadian standard population using the direct method, with 95% CI estimated using the binomial approximation method used by the International Agency for Research on Cancer [366].

For ovarian/fallopian cancers, only the female denominator and standard populations were used.

Each patient's travel time to the location where their surgery took place was calculated using geographical information systems. The shortest-time route was calculated along a road and ferry network dataset comprising intersections, speed limits, and other transportation network features, but excluding air travel. The resulting travel times were tabulated for each neighbourhood type and socioeconomic deprivation quintile, and their means with 95% CI were calculated.

4.4. Results

As shown in Table C, over 61% of cases were female, due largely to the inclusion of ovarian cancers. Nearly three-quarters of all patients were found to reside in predominantly suburban areas, compared to 65% of the Canadian population. Similarly, only 6.9% of patients resided in urban areas, less than half the population proportion (16%). A lower proportion of patients were observed in the most and least socioeconomically deprived quintiles, a pattern consistent for all five cancer types. Lung cancers comprised half of all cases, and despite prevalence only among the female population, ovarian/fallopian cancers were over a quarter of the total. While the total case volume for each cancer type has increased throughout the study period, the number of institutions at which resections were performed has declined as a result of regionalisation.

Table 4.3 Number of patients by cancer site, with proportions of total cases for each categorical variable and number of unique institutions at which a surgery was performed.

		Oesoph.	Ovarian	Liver	Lung	Pancreatic	All Sites	Per Cent
Sex	Female	566	16575	3220	15487	1880	**37728**	61.7%
	Male	2187	0	4898	14304	2010	**23399**	38.3%
Neighbourhood Type	Urban	131	1286	565	1991	270	**4243**	6.9%
	Suburban	2003	12279	6230	21581	2921	**45014**	73.6%
	Rural	619	3010	1323	6219	699	**11870**	19.4%

Socioeconomic Deprivation Quintile	**Q1 (high SES)**	242	2120	1031	2563	491	**6447**	10.5%
	Q2	557	3798	1997	5866	876	**13094**	21.4%
	Q3	914	4969	2484	9102	1226	**18695**	30.6%
	Q4	832	4470	2068	9280	1000	**17650**	28.9%
	Q5 (low SES)	208	1218	538	2980	297	**5241**	8.6%
No. of Surgeries	**2004-2006**	866	5387	2159	9191	1094	**18697**	
	2007-2009	883	5353	2564	10030	1233	**20063**	
	2010-2012	1004	5835	3395	10570	1563	**22367**	
No. of Institutions	**2004-2006**	67	197	85	69	67		
	2007-2009	53	194	70	64	60		
	2010-2012	46	184	68	55	57		
	Total	**2753**	**16575**	**8118**	**29791**	**3890**	**61127**	
	Per Cent	4.5%	27.1%	13.3%	48.7%	6.4%		

When categorised by socioeconomic deprivation quintile, age- and sex-adjusted resection rates were approximately equal for patients among the most deprived (Q5: 12.0 per 100 000 person-years [10.7, 13.4]) and the least deprived (Q1: 13.3 [12.2, 14.4]) quintile of the population, with higher rates among middle-SES patients (Q2: 27.3 [25.6, 29.0]; Q3: 39.6 [37.4, 41.8]; Q4: 37.5 [35.3, 39.7]). When stratified by cancer site and 3-year period, this pattern rates was found to be consistent for all five cancer types (Figure 1). The socioeconomic gradient is particularly pronounced for lung cancers.

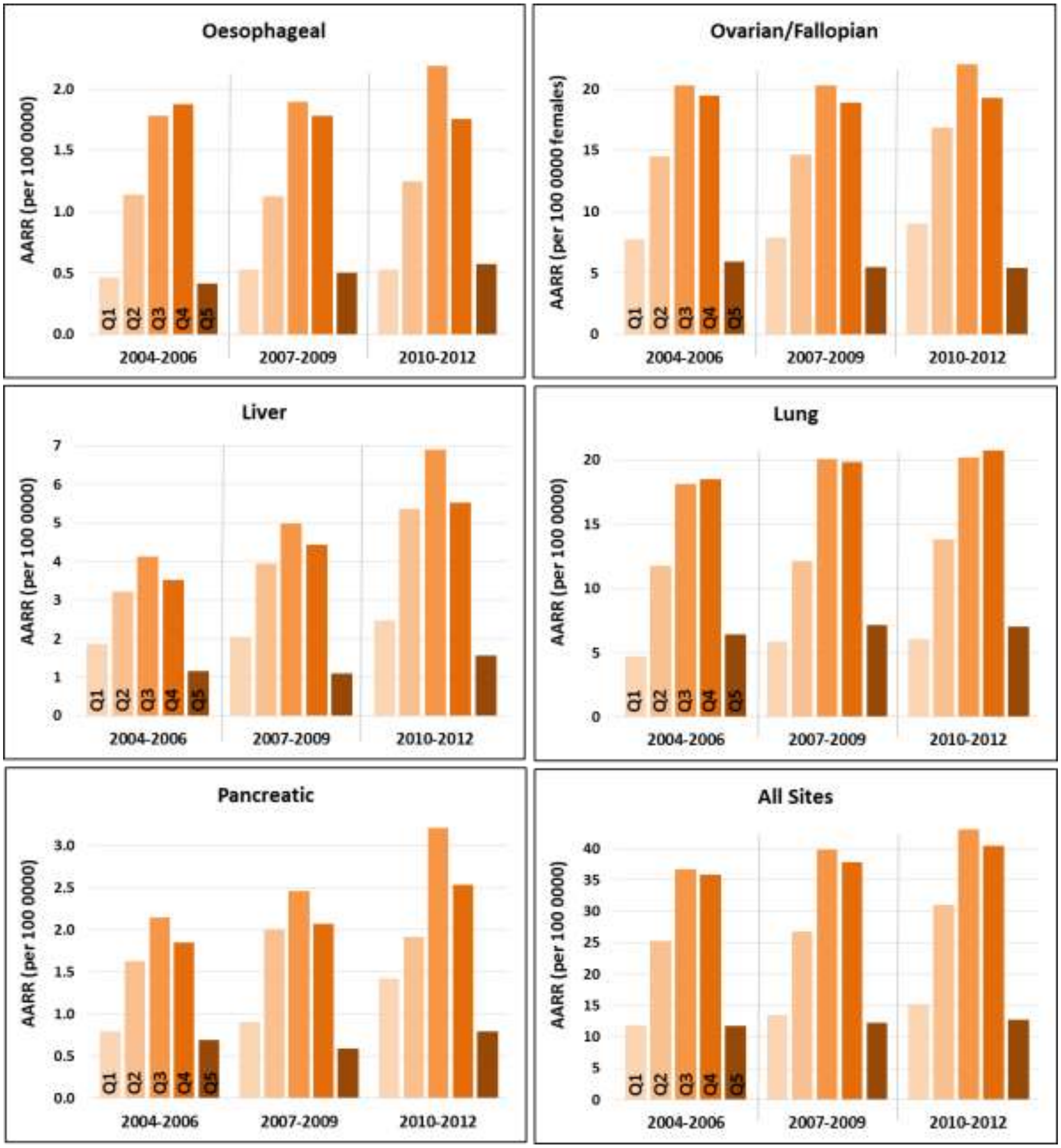

Figure 4.1 Age- and sex-adjusted resection rates by cancer type and socioeconomic deprivation quintile.

Three-year intervals from 2004-2012.

Significant differences in resection rates were observed between urban (14.9 [12.2, 17.6]), suburban (40.7 [40.1, 41.2]), and rural (32.7 [29.6, 35.9]) populations, with consistently higher rates in suburban and rural areas throughout the study period. When categorised by neighbourhood type, the highest adjusted rates were observed in suburban areas for all cancer types across the entire study period (Figure 2). The urban-suburban disparity is particularly pronounced for oesophageal cancers, for which a decline in urban rates was observed, in contrast to increasing suburban and rural rates. Large suburban-rural differences appear for liver and pancreatic cancers but are relatively minor for other tumour sites.

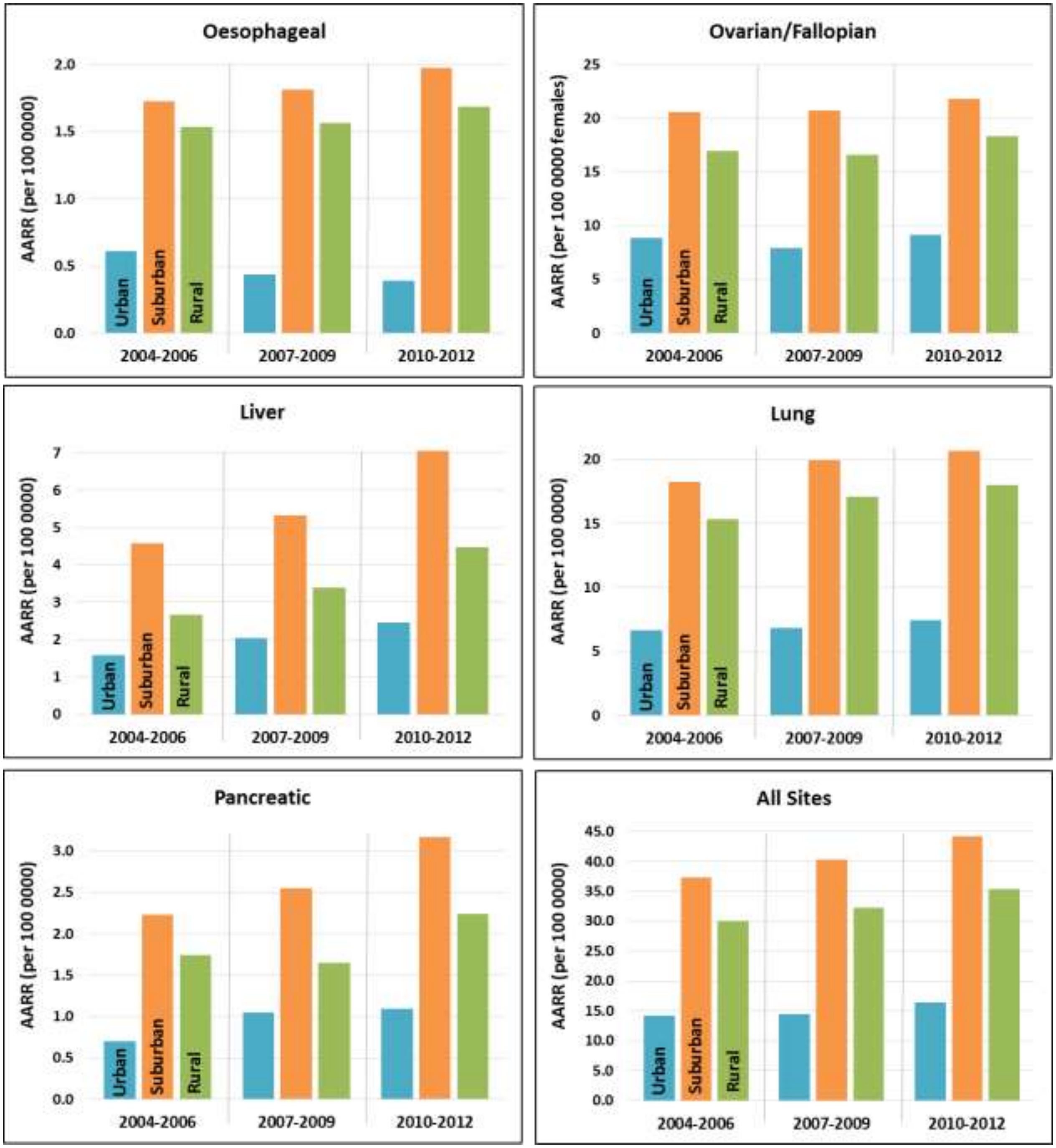

Figure 4.2 Age- and sex-adjusted resection rates for five cancer types
AARR by neighbourhood type, in three-year intervals from 2004-2012. Rates with 95% CI are available in Appendix B.

When pooled, resection rates for all five cancers types exhibit highly significant differences between socioeconomic groups in both suburban and rural neighbourhoods

(Figure 3). A low number of urban cases resulted in confidence intervals too wide to enable meaningful inference, though the observed rates follow a gradient such that increasing deprivation is associated with decreasing resection rates. Suburban and rural resection rates exhibit similar distributions across the socioeconomic gradient, with relatively low rates among the most affluent rural patients.

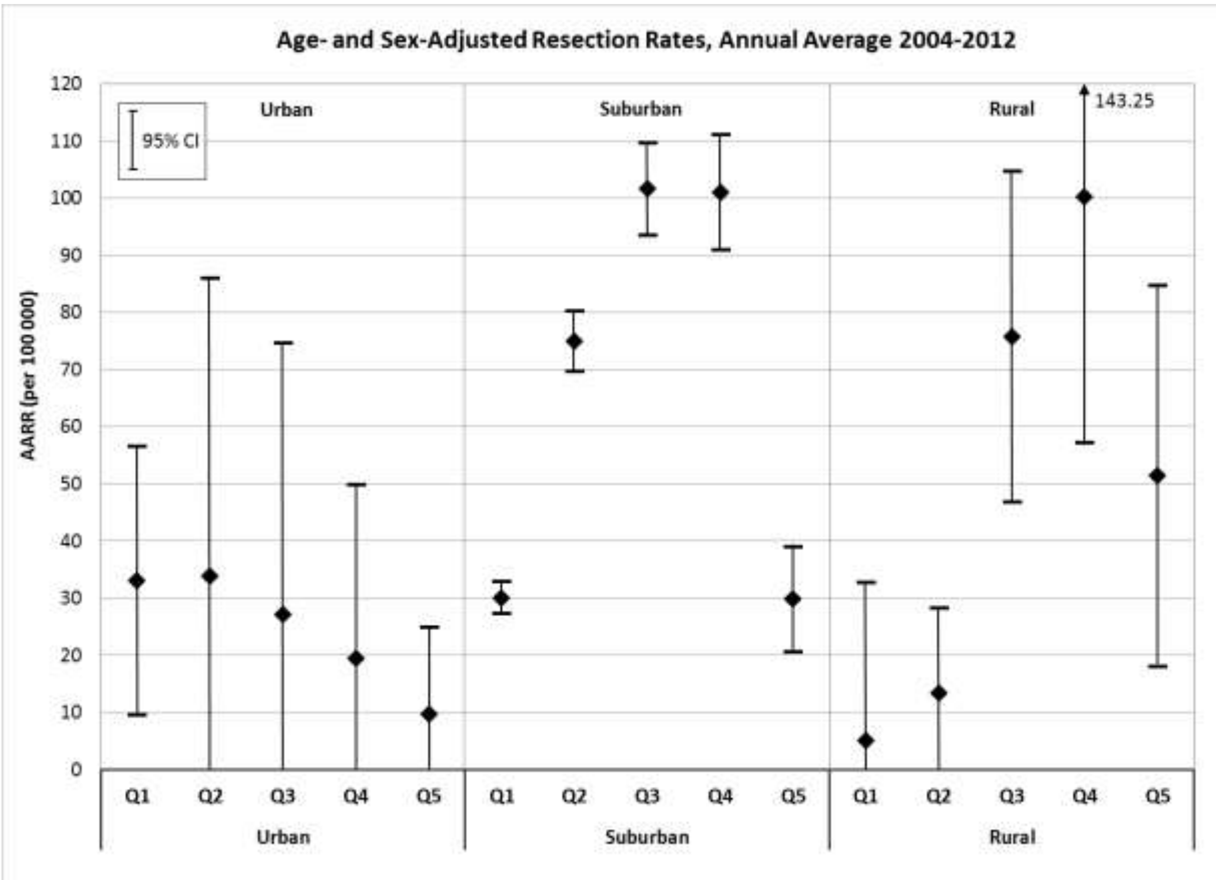

Figure 4.3 ***Age- and sex-adjusted resection*** **rates**
AARR per 100 000 person-years, with 95% CI, by neighbourhood type and socioeconomic deprivation quintile (Q5=patients among the 20% most deprived adults in the Canadian population).

Mean patient travel times for all five cancer types exhibit a socioeconomic gradient such that the greatest burden of spatial access is experienced by patients in the most socioeconomically deprived quintiles of the population, as shown in Figure 4. This pattern is relatively weak among urban patients, with more distinct differences observed for those living in suburban and rural neighbourhoods. Significant differences in incidence between urban, suburban, and rural populations are detected only among middle-SES groups.

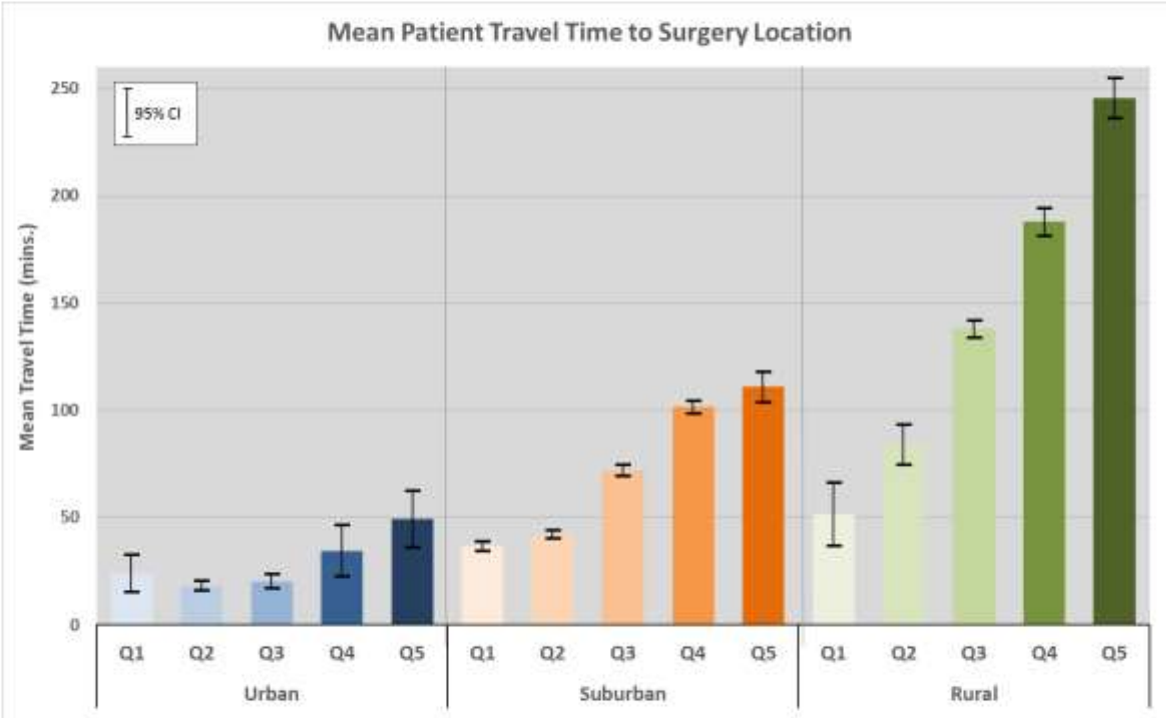

Figure 4.4 Mean patient travel time from resection surgery location

4.5. Discussion

This study identifies a significant difference in resection rates and their relationship with socioeconomic deprivation between urban and suburban areas. For most cancer types, previous studies have observed consistently higher incidence and treatment rates among urban populations compared to rural [358,367][360]. Our results demonstrate the inverse for oesophageal, ovarian/fallopian, liver, lung, and pancreatic cancers. However, this difference may be due to our categorisation scheme; whereas previous studies have classified urban areas such that they include suburban areas, we distinguish suburban neighbourhoods from their urban cores. Interestingly, suburban resection rates and travel times, and their relationships to socioeconomic deprivation, are more similar to rural areas than urban.

The observed relationship between travel time and socioeconomic deprivation is consistent with our previous study evaluating potential spatial access to cancer treatment centres for head and neck cancer patients (previous chapter). By conducting this study with actual patient data, we are able to confirm a concentration of high travel times among the most socioeconomically deprived patient populations. This pattern reflects the socioeconomic geography of Canada, where the mean deprivation score is highest is rural areas (0.32) and lowest in suburban neighbourhoods (-0.19), with urban residents experiencing relatively average socioeconomic deprivation (-0.01). Regardless, our findings confirm that patients facing the greatest burden of travel for treatment may also face the greatest socioeconomic barriers to interfacing with the health system; this hypothesis has been explored for urban/rural contrasts, but more geographically refined analysis is needed [357,359].

Increases in resection rates throughout the study period are coincident with decreasing incidence rates for most cancer types [10]. This trend may be interpretable as evidence that a higher proportion of patients are receiving surgical treatment. However, it is possible that these trends reflect higher overall prevalence. Similarly, the disparities in resection rates between different socioeconomic quintiles may be explained by variable prevalence and differential stage at diagnosis. Individuals living in urban centres often are diagnosed at an earlier stage due to improved access [177]; this effect may account for some of the variance in resection rates. However, oncologist and patient decision-making is highly complex and varies on a case-by-case basis, dependent on tumour stage/grade, patient comorbidities and history, availability of facilities and personnel, personal preference, ability to travel for treatment, etc. All of these factors are geographically and socioeconomically relevant. In order to explore these associations with greater clarity, researchers should use a sophisticated statistical modelling approach supported through the use of focus groups and interviews.

A series of three citizen focus groups conducted in Edmonton, Hamilton, and Charlottetown underscored concerns about patients living in rural/remote regions [351]. Despite a general preference for regionalisation of cancer treatment, participants highlighted a need for local patient support networks for pre- and post-operative care. The majority of participants also indicated a willingness to travel great distances to receive high-quality treatment, although travel costs, a desire to receive care close to home, and family commitments were all significant concerns. It must be recognised that the participants were primarily from cities and had a socioeconomic status was more similar to the central quintiles in our study, and therefore may not adequately represent the needs and preferences of patients living in rural/remote deprived areas.

While our overall study population was relatively large (N=61 227), the number of patients for some categories was insufficient to enable inference. However, it must be noted that these data represent a population of patients, not a sample; the reported rates therefore reflect the true population resection rates for the study area. Another important limitation in this study is the method used to calculate travel times. This model does not include air travel, which may have caused an overestimation of travel times for patients residing in Northern Canada.

4.6. Conclusion

This study identified a double-burden of spatial and socioeconomic access among the most deprived suburban and rural populations in Canada, for five high-risk cancer surgeries. Contrary to previous studies, we observed the highest resection rates among patients in the central quintiles of socioeconomic deprivation. This may be due to the differentiation of suburban patients from their urban counterparts, which yielded patterns of resection rates, travel times, and socioeconomic deprivation more similar to rural patients than urban ones. This novel categorisation has important implications for cancer control policy, specifically when targeting vulnerable communities in the most deprived and geographically isolated communities across Canada. So while regionalisation has led to improved outcomes overall, particular focus on low-access patient populations is necessary to maintain health equity across the country.

Chapter 5.

Conclusion

This dissertation sought to determine whether the categorisation of suburban neighbourhoods from their urban and rural counterparts is useful for epidemiological studies of cancer incidence and treatment. In response to the first research question, I sought to identify some of the trends and forces active in the production of suburban health in Canada by tracing a socioeconomic geography of suburban history. This was not a conclusive nor comprehensive unpacking of the means of health production, nor was it meant to be. In order to serve as a practical research framework, one could not interrogate these processes in their entirety. However, a cursory review of Canadian suburban history provides a qualitative basis for this separate categorisation.

The second research question sought to identify the ways in which the contextual forces implicated in the production of Canada's suburban socioeconomic landscape reflect patterns in cancer incidence. Focussing on oral cavity cancers, chapter two identified statistically significant case concentrations emerging in socioeconomically deprived suburbs across British Columbia coincident with a high proportion of immigrants from betel-consuming regions. Concentrations of oral cavity cancers were also identified in the more affluent outer suburbs of British Columbia, particularly in the Lower Mainland, coincident with an older population. Both the production of deprived immigrant suburbs and wealthy outer suburbs were described in chapter one. In this way, it may be posited that transportation technologies, infrastructure, and social and economic policies collectively contribute to spatiotemporal patterns of cancer incidence. A conclusive test of this hypothesis will require a more directed study design.

To examine these patterns further down the continuum of cancer care, the third research question sought to address how the socioeconomic disparities observed reflect patients' access to treatment. The study featured in chapter three identified a socioeconomic gradient of spatial access to comprehensive cancer treatment centres for head and neck cancer patients, such that the most deprived patient populations also faced the greatest travel times to treatment. This study period spanned a time of expansion of cancer treatment services, in which five new centres were built across British Columbia. The overall decrease in travel time as a result of these new centres was greatest for socioeconomically deprived patients, relative to their affluent peers.

Interestingly, the greatest socioeconomic disparity in spatial access was observed among suburban patients, the two most deprived quintiles of whom had significantly greater travel times to treatment. This is of particular importance because patients with low social and economic resources may have a limited ability to travel for treatment, a factor known to influence both choice of treatment and outcome. As a result, these populations are at heighted risk of adverse cancer outcomes and are therefore a priority for health equity.

Conversely, the study presented in chapter four spans a period of regionalisation, in which the number and geographical extent of cancer treatment centres decreased. Resection rates were concentrated among patients living in socioeconomically average neighbourhoods for five cancer types across Canada. Suburban resection rates were more similar to rural areas than urban, evidence that the conventional classification of suburban neighbourhoods as urban is not appropriate for analysing socioeconomic patterns of cancer treatment. Spatial access to treatment was consistently poorest among patients residing in the most socioeconomically deprived neighbourhoods, with steeper gradients observed among suburban and rural patients.

It is important that the interpretation of these results is tempered by an acknowledgement that cancer care facilities are not randomly sited. Location allocation is a complex process seeking to maximise the utility of a treatment centre by serving the greatest proportion of the population while simultaneously seeking to improve equity of access between various populations. Given the concentration of middle- and high-SES populations in urban centres, cancer treatment facilities are almost exclusively sited in cities. Middle- and high-SES populations are therefore naturally expected to have better access to cancer care. The results presented in chapters three and four are largely influenced by the fact that a large proportion of the most deprived populations reside in rural and remote regions of British Columbia. However, examining the magnitude of difference facilitates the identification of regions with poor access and may serve to inform community-based programmes in both prevention and treatment.

The five cancer types studied in chapter four are known to feature similar socioeconomic patterns of incidence, such that incidence is concentrated among middle- and low-SES populations. Conversely, a study of breast cancers would have introduced particular nuance to this study, as they tend to concentrate in low- and high-SES populations, featuring an essentially bimodal distribution. This does, however, vary by tumour type. How these patterns manifest geographically is yet to be studied, and given the relatively high incidence of breast cancers, constitutes an important research direction.

The broader overarching research question of this dissertation was to evaluate whether there is a geographically and epidemiologically valid basis for analysing suburban neighbourhoods in contrast to urban and rural neighbourhoods. A quantitative medical geography approach yielded positive evidence in chapters two, three, and four: suburban neighbourhoods feature several distinct patterns of incidence, surgery, and access to treatment, although not in every instance. For example, the socioeconomic pattern of travel times to surgery was similar for urban, suburban, and rural patients in chapter four, such that spatial access was consistently lower among more deprived patients. In this way, there was no meaningful distinction to be made for suburban neighbourhoods, except for a general increase in travel times. However, the majority of findings did identify suburban patterns of both incidence and access to treatment that were distinct from urban patterns. This should be interpreted as evidence for an epidemiologically valid distinction.

Of potentially equal importance as the quantitative results of this study is the contextual evidence as presented in chapter two, where the qualitative basis for this distinction is presented. The suburban and urban neighbourhoods' demographically and spatially divergent histories provide the basis for unique consideration, although the health literatures focussing on suburban risk factors are young. Given that over 60% of Canada's population and over half of the US population live in suburban neighbourhoods, this lack of quantitative evidence is somewhat unexpected. This dissertation therefore seeks to address the gap by providing some first steps in this direction. However, this work does not claim to provide a conclusive survey of suburban cancer epidemiology. Rather, I envision it as the first substantive steps and a tentative framework for developing a comprehensive suburban spatial epidemiology.

5.1. Contributions and Implications

Distinguishing suburbs from urban and rural neighbourhoods will enable more geographically nuanced patterns of health and health care to be detected. The ability to spatially target risk populations with greater precision may serve to improve health equity, both in terms of risk and delivery of care. This is particularly true when socioeconomic factors are included.

Health and medical geographies are considered to be mutually separate (or at least distinguishable) by many, and this is a reasonable distinction due to their divergent epistemologies. There have been calls for combined health-medical geography research since the early 1990s, predicated on understandings of placemaking in health and the value of quantitative evidence. Despite these calls, the number of studies that engage with both of these concepts is surprisingly minimal. This dissertation, while not containing any substantive qualitative methodologies, draws of theories and concepts from health geography to support the three quantitative studies herein. I believe that this is a pragmatic and readily implementable approach for conducting theoretically grounded spatial epidemiological research. Engaging with health geography concepts like placemaking, social determinants of health, spatial mechanisms of health production (e.g., zoning policy) can facilitate researchers' navigation of epidemiological practicalities like model specification, variable definition and selection, and interpretation of statistical results.

Importantly, Canada's suburbs are not representative of their equivalent low-density commuter neighbourhoods in other parts of the world. Future research towards the development of a substantive suburban spatial epidemiology will require a more global perspective. The gentrification of urban cores and migration of foreign-born and otherwise socioeconomically disadvantaged populations into urban peripheries is not exclusive to Canada or the United States. Rather, it is part of a broader global trend in which the concentration of social and financial capital are played out on the map.

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