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Stable Isotope Analysis of Breastfeeding and Weaning Practices in 19th Century Montreal

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Abstract

A plethora of changes occurred in nineteenth century Montreal including industrialization, population growth, urbanization, and women in the workforce. These changes likely affected how infants and children were cared for, including breastfeeding and weaning practices. Using stable carbon and nitrogen isotope analysis of serial dentine sections of 21 teeth from a French-Canadian population interred at Saint Antoine (AD 1799-1854), this study reconstructs infant feeding practices from a low-middle socioeconomic status population. Adult female diet emphasized C_3 foods with variable terrestrial and aquatic protein. Lack of isotope results limited information about the diets of subadults. In one individual, weaning was underway by 1.0 and completed before 2.5 years-of-age. The cause of the poor isotope results has not been identified but could include diagenesis or laboratory procedures. This study demonstrates the importance of limiting sample destruction, as by only using half the tooth the remaining portion is available for future analysis.

Keywords

Stable isotopes, breastfeeding and weaning, Montreal, childcare, Industrialization

Summary for Lay Audience

During the nineteenth century, Montreal experienced pronounced change due to industrialization and urbanization. These changes caused population growth, increased immigration, urban expansion, and women, typically of lower socioeconomic status, to enter the paid workforce. These changes exacerbated already existing health and sanitation problems and contributed to an increase in infant and child sickness and death, leading Montreal to be regarded as one of the deadliest North American cities. These changes likely also affected how infants and children were cared for, including breastfeeding and weaning practices and raises questions about if infants were still breastfed, and, if so, was it for a shorter period? What weaning foods were given and were they safe or contaminated? Breastfeeding and weaning can be investigated using teeth, which begin forming in the womb and finish in our teens. Tooth dentine is formed in incremental layers that are laid down at a known age. These layers do not change after formation thereby preserving a record of a person's life during tooth formation. Using a chemical method that looks at different forms of carbon and nitrogen (called isotopes) in the dentine layers, researchers can tell if a baby was breastfed, for how long, when weaning began, and what weaning foods were used.

This study uses carbon and nitrogen isotopes of dentine sections from subadults (<18 years) who were interred at the Saint Antoine cemetery (AD 1799-1854) in Montreal to determine the breastfeeding and weaning practices of a low to middle socioeconomic group. The mothers consumed a diet of mixed plant sources, as well as a variety of animal proteins and fish. Unfortunately, most of the subadults' results were unusable but one individual demonstrated that the weaning process was completed between 1 and 2.5 years, and that weaning foods were made from wheat, rye, barley, or oats. The cause of the poor results for the remaining subadults could not be concluded, but may include changes from the burial environment, contamination, or laboratory procedures. This study highlights the importance of limiting sample destruction, and the half tooth retained could be used for future study.

Acknowledgments

There is a common turn of phrase that “It takes a village to raise a child.” I would venture to say that the same is true of this thesis, and I would like to take a moment to thank my “village” who supported me throughout.

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Chapter 1

1 Introduction

Bioarchaeologists use archaeological human remains to gain insight into various aspects of human life in the past, including health and disease, migration patterns, care, fertility, and social status. One such avenue of research, diet, can provide information about socioeconomic experiences, as social status is a critical mediator of access to resources such as food and drink. Disparities in socioeconomic status are known to contribute to growth and health disruption during childhood and infancy, which may then go on to influence early life morbidity and mortality (Hodson & Gowland, 2020). Infant feeding and weaning practices exist in a synergistic relationship with infectious disease, as early weaning is associated with higher rates of infant morbidity and mortality, particularly in pre-modern times, due to the increased risk of contamination with diarrheal pathogens (Knodel & Kintner, 1977; Mays et al., 2017). Studying infant feeding and weaning practices, therefore, can provide valuable information regarding infectious disease, morbidity, and mortality in an archaeological population, as well as providing further insight into fertility rates, birth spacing, and weaning foods (Beaumont et al., 2013; Katzenberg & Waters-Rist, 2018).

Diet may be studied by analyses of the main bone protein, collagen. However, bone undergoes remodeling throughout life and will reflect the average diet of an adult over the last ~10 or more years of their life (Hedges et al. 2007; Matsubayashi and Tayasu, 2019). Bone from growing subadults (<18 years-of-age) will reflect less time, from many months in early infancy to many years in adolescence. Thus, bone collagen is not a tissue that can yield precise reconstructions of breastfeeding and weaning or to track changes in an individual's diet over time. A more appropriate tissue for infant paleodiet reconstruction is tooth dentine. Dentine is produced in incremental layers, with deciduous and some permanent teeth beginning to form *in utero* and throughout the first years of life, thus capturing and individual's diet during their early life. Unlike bone collagen, dentine does not undergo remodeling, and as a result remains a static representation of

diet in early life, making it the ideal tissue to investigate infant and child feeding practices in the past (Beaumont et al., 2013).

This thesis uses stable isotope analysis of serial dentine sections, the incremental layers of dentine laid down during development, to reconstruct infant feeding and weaning practices in nineteenth century Montreal. Through stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis, it is possible to estimate the duration of exclusive breastfeeding (if it occurred), when supplementary foods were first introduced (weaning initiation), what those foods might have consisted of, and when weaning was completed (Henderson et al., 2014; Herring et al., 1998).

This thesis analyzes individuals who were interred at Saint Antoine Catholic cemetery in Montreal, from AD 1799-1854. These individuals were most likely French-Canadians of low-middle socioeconomic status (Ethnoscop, 2004). Montreal in the nineteenth century was characterized by increasing industrialization and urbanization, as well as rapid population growth as the city experienced several waves of immigration throughout the first half of the century (Gilliland & Olson, 1998; Sweeny, 2015; Ward & Ward, 1984). It was also a period when Montreal was heavily segregated according to cultural and economic lines, and wealth disparities were becoming more pronounced as the economic system moved away from feudalism and toward capitalism (MacLeod, 2003; Thornton & Olson, 2011). Industrialization has been associated with poor health and increased mortality rates in other Western countries, such as the United Kingdom, Sweden, and the United States (Edvinsson et al., 2005; Pinhasi et al., 2006). Montreal follows this same pattern, as infant mortality was high throughout the nineteenth century and remained high into the beginning of the twentieth century (Bourbeau et al., 1997).

The main goals of this thesis are twofold: to investigate the relationship between infant feeding and weaning practices and (1) infant morbidity and mortality, and (2) cultural variables such as religion, socioeconomic status, breastfeeding alternatives, and maternal employment outside the home. As mentioned, infant feeding practices are strongly linked to infant morbidity and mortality rates, and several demographic studies have linked the absence of breastfeeding and/or early weaning age to high rates of infant mortality (e.g.,

Knodel & Kintner, 1977). Moreover, given the socioeconomic status of the individuals in this sample, some mothers may have worked outside the home, and as such may have been minimally available for breastfeeding (Thornton & Olson, 1991). Such infants are more likely to be weaned earlier than their peers, if they were breastfed at all, and artificial breastfeeding technologies as well as breastmilk alternatives like animal milk might have been used. Thus, the Saint Antoine sample provides the unique opportunity to investigate both research goals outlined above.

To define the terminology used throughout this thesis, 'infants' (and therefore 'infancy') refers to individuals aged from birth to 2 years. 'Children' (and therefore 'childhood') refers to individuals aged from 3 years to 15 years. 'Adulthood' begins at 16 years. Where the term 'subadult' is used, it is referring to all individuals under the age of 16 years, and therefore both children and infants.

To achieve these research goals, a biocultural approach will be used, integrating both biological and cultural information in the interpretation of the results. Breastfeeding is a truly biocultural phenomenon, influenced by both maternal biological factors such as the ability to breastfeed and in what quantities, and cultural factors such as religion, medical advice, and family influence (Holman & Grimes, 2003; Kendall, 2016; Martin et al., 2013). A biocultural approach may be built upon to take a social bioarchaeological approach. Social bioarchaeology considers the relationship between individuals and their economic, social and environmental contexts (Zuckerman & Armelagos, 2011). It is important to use a biocultural approach when investigating breastfeeding practices in the archaeological record so that the full scope of contributing factors may be understood.

Chapter One has provided some of the necessary context and background information regarding this research, including Montreal in the nineteenth century, a brief overview of the sample and method, research goals, and theoretical approaches.

Chapter Two will provide a more in-depth literature review and contextual background. This chapter will explore some of the major changes occurring in Montreal during the nineteenth century, as well as patterns of cultural and economic segregation among Montreal's inhabitants. This chapter will also explore infant morbidity and mortality in

nineteenth century Montreal, and some possible contributing factors including urbanization, industrialization, and infant feeding and weaning practices. This chapter concludes by outlining several relevant bioarchaeological approaches to studying infant feeding and weaning practices, from observations of linear enamel hypoplasia (LEH) to the development of serial dentine sectioning and stable isotope analyses.

Chapter Three will outline the materials utilized for this thesis, including a description of the site and sample at Saint Antoine, and dental scoring and sampling methods.

Chapter Four will outline the methods used for serial dentine stable isotope analysis, including cleaning, embedding samples in resin, sectioning, demineralization, sampling, and mass spectrometry.

Chapter Five will detail the results of both dental scoring and mass spectrometry. This chapter will provide the stable isotope results for the adult female sample, as well as subadult individual 20C-S1.

Chapter Six will discuss the isotopic results for the adult female sample, exploring what the adult female diet might have consisted of, as well as discuss changes in diet over the course of 20C-S1's lifetime, including the early-life period where isotopic values may be reflective of weaning. It will then go into detail about the possibility of diagenetic change occurring in this sample, as well as the potential cause of such changes as arising from the burial environment, preservation, or laboratory procedures This chapter will also discuss the implications of poor results in a graduate research project, as well as the limitations of conducting research as a graduate student with time and financial constraints.

Chapter Seven will conclude this thesis with a brief review of the historical background, research aims, analyzed population, dental and isotope methods. It will conclude by outlining the major findings of this thesis, including findings from the adult female sample and individual 20C-S1. It will also review diagenetic changes that might have occurred and the implications of poor results in graduate-level research.

Chapter 2

2 Literature Review

This chapter will detail the history of Montreal before and leading into the nineteenth century, as well as detailing key changes and shifts happening within the city during this period. Specifically, this chapter will focus on changes related to industrialization and urbanization, in relation to socioeconomic status, cultural segregation, breastfeeding and weaning practices, and infant morbidity and mortality. This section will go on to detail bioarchaeological methods used for estimating the timing and duration of breastfeeding and weaning practices, as well as various methods for stable isotopic analysis in the reconstruction of diet, from these methods' initial emergence and into the present.

2.1 History of Montreal into the Nineteenth Century

Montreal is situated on the traditional territory of the Haudenosaunee and Kanien'kehà:ka First Nations, and its history long predates the arrival of European settlers, with archaeological evidence indicating that First Nations peoples occupied the island as early as 4,000 years ago (Native Land Digital, n.d.). Upon first contact with colonists in 1535, between 1,500 and 2,000 Iroquoians were living in a fortified village called Hochelaga, which was likely located on the southern slopes of Mount Royal in present-day Montreal (Fougères & MacLeod, 2017). In 1640, the French erected the fortress Ville Marie, which would later become known as Montreal, to operate as a fur trading post and the center of French expansion and exploration (Bosworth, 1859). In 1760, during the Seven Years War, Ville Marie was surrendered by the French to the British Army and was renamed Montreal (Bosworth, 1859). The strategic location on the St. Lawrence River continued to be used as a center for the fur trade and the British further expanded and developed the city in the following decades.

Prior to the year 1800, population growth in Montreal was relatively slow, with the population increasing from 4,000 to 6,000 between 1750 and 1782 (Denison, 1955; MacKinnon, 2005). However, between 1782 and 1831, the population of Montreal

rapidly expanded from approximately 6,000 to 37,252 (Armour, 1831; Denison, 1955; MacKinnon, 2005). Between 1800 and 1825 alone, the population increased by 150% (MacKinnon, 2005). Robert (1988) tracked population growth in Montreal using census data, focusing on the Roman Catholic population of Montreal, including the subset of French-Canadians who were Roman Catholic, further demonstrating Montreal's rapid population growth among specific cultural and religious groups (Table 1). This rapid growth was encouraged by several factors, including a prosperous fur trade, as well as an influx of English-speaking merchants and immigrants throughout the first half of the nineteenth century. By the beginning of the nineteenth century, the English-speaking mercantile elite had begun to transform the city's landscape through the construction of churches, homes, and other urban spaces that reflected the British imperial vision (Bradbury & Myers, 2005). Additionally, throughout the nineteenth century, Montreal continued to operate as British North America's major mercantile center, further contributing to rapid population and economic growth during this period (Sweeny, 2015). Between 1815 and 1823, the St. Lawrence Valley, which includes Montreal, received 64% of all immigrants from the British Isles to the British colonies (Oullet, 1980).

Table 1: Annual Population Growth for Montreal, including population growth for Roman Catholic and French-Canadian populations. From Robert, 1988: 23.

Year	**Total**		**Roman Catholic**			**French Canadian**		
	Population Size	Mean Annual Growth Rate	Population Size	% Of Total Population	Mean Annual Growth Rate	Population Size	% Of Roman Catholic Population	Mean Annual Growth Rate
1825	22,540	-	15,300	67.9	-	12,273	80.2	-
1831	22,297	3.24	17,953	65.8	2.7	-	-	-
1842	40,290	3.6	25,699	63.8	3.31	17,108	66.6	1.97
1844	44,591	5.2	29,821	66.9	7.72	19,041	63.9	5.50
1851-52	57,715	3.28	41,464	71.8	4.21	26,020	62.8	3.98
1861	90,323	5.1	65,896	73.0	5.28	43,509	66.0	5.88
1871	-	3.45	-	-	3.6	-	-	3.38

Population growth may be assessed more in detail by focusing on the Old Town and its surrounding faubourgs (suburbs). During the nineteenth century, the city of Montreal consisted of the city center in the Old Town, and six surrounding faubourgs (Figure 1). The rest of the island consisted of various rural villages, which would eventually become

absorbed by the city's urban expansion. From the late 1700s to 1840, the Old Town's population stabilized very quickly, while the faubourgs' population grew from 6,000 residents to about 40,000. To accommodate their growing population, the faubourgs saw the construction of 4,403 homes between the years 1805 and 1844. Meanwhile, the Old Town only saw the construction of 235 new homes in the same period (Fougères & MacLeod, 2017).

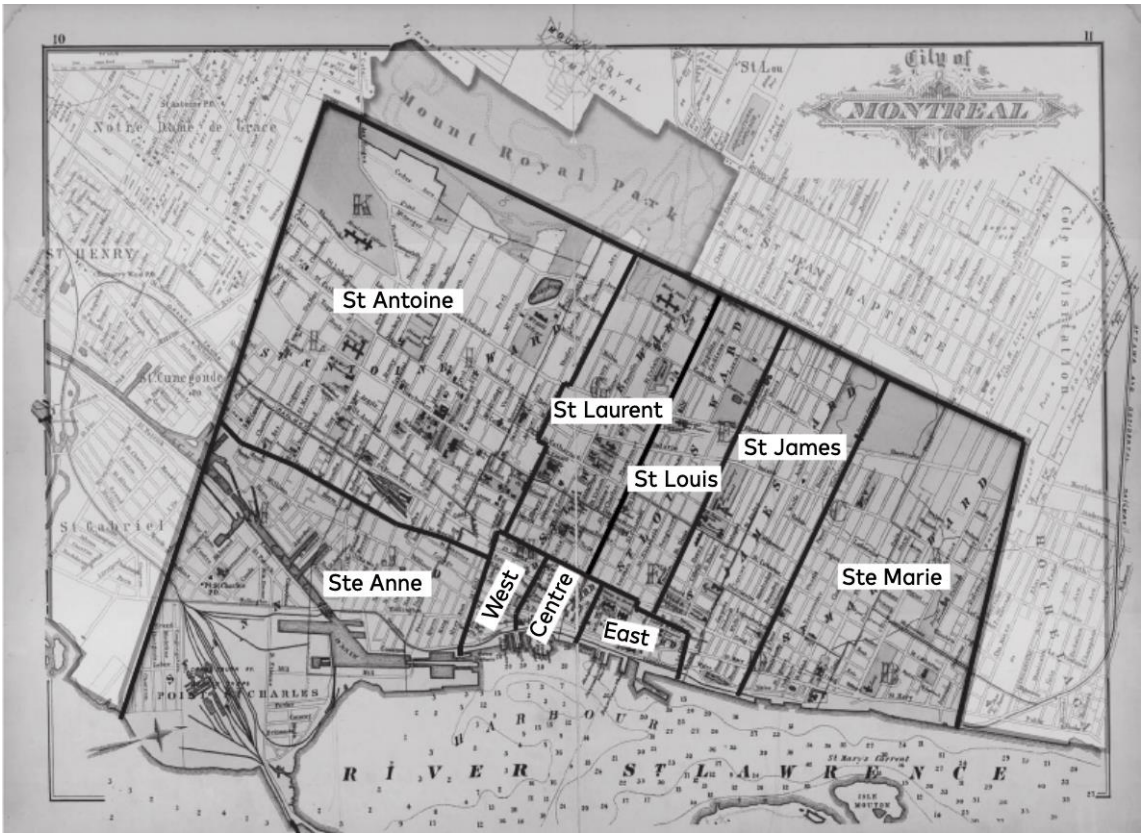

Figure 1: Borders of Montreal's Old Town and its surrounding faubourgs, 1845. From Fougères & MacLeod, 2017: 382.

The period from 1832-1861 was one of marked change, including the transition from feudalism to capitalism, as well as a period with a series of rebellions which influenced economic and political reforms, resulting in increased industrialization and the establishment of a bourgeois democracy (MacLeod, 2003). The completion of the Lachine Canal in 1832, which bypassed the Lachine rapids and connected the city to other continental markets, established Montreal as a major center for trade and industry. Cotton and wood mills, woodworking establishments, nail and spike factories, flour

mills, and iron foundries were founded in the surrounding area (Bradbury, 2007; MacLeod, 2003). The completion of the canal and subsequent establishment of industry on its banks further facilitated the creation of industrial and working-class suburbs, such as Griffintown and Saint Henri, as more workers immigrated to the city throughout the first half of the nineteenth century (MacLeod, 2003). Industrial growth around the Lachine Canal and in other parts of Montreal eradicated some traditional forms of production, increased demand for others, and increased demand for work done by hand, which required more labourers. This increased demand for labourers facilitated the entry of women and children into the workforce, and although wages were already low in Montreal, they typically earned much less than men (Bradbury, 2007; Bradbury & Myers, 2005). By the mid-1850s, the industries established around the Lachine Canal employed about 2,000 men, women, and children (Bradbury, 2007). Moreover, these shifts toward capitalism and growing industry allowed Montreal to shift its focus away from the declining fur trade and toward other, more lucrative, business endeavors such as banking and real estate (Bradbury & Myers, 2005).

In the same year that the Lachine Canal was completed, Montreal was officially established as a city and would go on to serve as the capital of the United Province of Canada from 1844-1849 until political protests in Montreal caused the capital to be moved to Toronto (Fougères & MacLeod, 2017). The combination of industrialization, increased trade, as well as Montreal's status as the political and economic capital of Canada, contributed to continued population growth, as the city received an influx of immigrants throughout the nineteenth century. To support its rapidly growing population, Montreal continued its urban expansion into formerly rural areas, including Saint Antoine. By 1861, Montreal had become the tenth largest city in North America, and in 1880, it would become the largest city in Canada with a population of 175,000 (Bradbury, 2007; Gilliland & Olson, 2010). The rapid population and industrial growth Montreal experienced during the nineteenth century altered the economic landscape of the city, while also profoundly affecting its residents. Industrialization contributed greatly to increased urbanization and further exacerbated the divide between the upper and lower classes.

2.1.1 Cultural and Economic Segregation in Nineteenth Century Montreal

Alongside economic and political shifts, Montreal experienced several instances of mass immigration throughout the nineteenth century, including Anglo-Protestant immigrants in the first half of the nineteenth century and an influx of Irish immigrants in 1831, 1847, and 1849 (Gilliland & Olson, 2010). Nineteenth century writer William Chambers (1854) recounts a conversation with a Scottish immigrant regarding the change in population from majority French-speaking to majority English-speaking correlating with the modernization and industrialization of the city throughout the first half of the nineteenth century. The balance between the French- and English-speaking population would shift again. By the end of the nineteenth century, French-Canadians would comprise of 59% of the population (Thornton & Olson, 2011). French-Canadians mostly occupied middle to low class jobs such as skilled craftsmen, day-labourers, or semi-skilled workers. Meanwhile, Protestants, who made up 23% of the population, occupied high-class jobs. Irish Catholics, who made up 17% of the population, occupied low- and working-class jobs, similar to those of French-Canadians (Thornton & Olson, 2011). Several nineteenth century writers, including Chambers (1854), have commented on the impressive diversity and combination of different cultural groups throughout Montreal. However, despite Montreal being one of the most diverse and economically important cities in nineteenth century North America, it was also heavily stratified across cultural and economic lines.

Cities during the nineteenth century were generally constructed at high densities, with wealthier households occupying row houses, although their lots were larger in size than those of working-class families. Montreal followed this same pattern (Sweeny, 2015). Early nineteenth century Montreal was largely restricted to the Old Town and its surrounding faubourgs, and was characterized by narrow, crooked streets and small stone houses (MacLeod, 2003). Reflective of the high density that was typical of nineteenth century cities, as well as rapid population growth and immigration, between 1825 and 1880 urban density in Montreal increased from 1,650 individuals per square kilometer to 12,850 individuals per square kilometer (Gilliland & Olson, 2010). Despite the proximity of households to one another, Montreal remained heavily segregated based on economic

and cultural lines. Bosworth (1859: 210) notes that the divisions between "caste" have the potential to be "more distinctly drawn, in Montreal, than in other cities of equal magnitude," though he does not elaborate on the point. Nonetheless, this observation emphasizes that divisions between social classes and cultural groups were of note to historic scholars, as well as being of interest to researchers in the present-day.

Historical demographic studies of nineteenth century Montreal by Thornton and Olson (2011) and Gilliland and Olson (2010) illustrate the relationship between rent and cultural group. In an assessment of purchasing power between cultural groups, Gilliland and Olson (2010) demonstrate that French-Canadians and Irish Catholics in Montreal occupied a majority of low rent properties, despite cumulatively comprising more than 70% of the population. Meanwhile, Protestants occupied many high rent properties, despite representing a minority of the population, thus resulting in segregation between and within wards (Figure 2). This aligns with Thornton and Olson's (2011) previously discussed observation that French-Canadians were generally middle to low socioeconomic status (SES) and that Irish Catholics were generally low to working SES, while Protestants were of higher SES, occupying high-class jobs. Generally, the city-center was home to wealthier families, while low-income families were concentrated in suburban neighbourhoods (Sweeny, 2015).

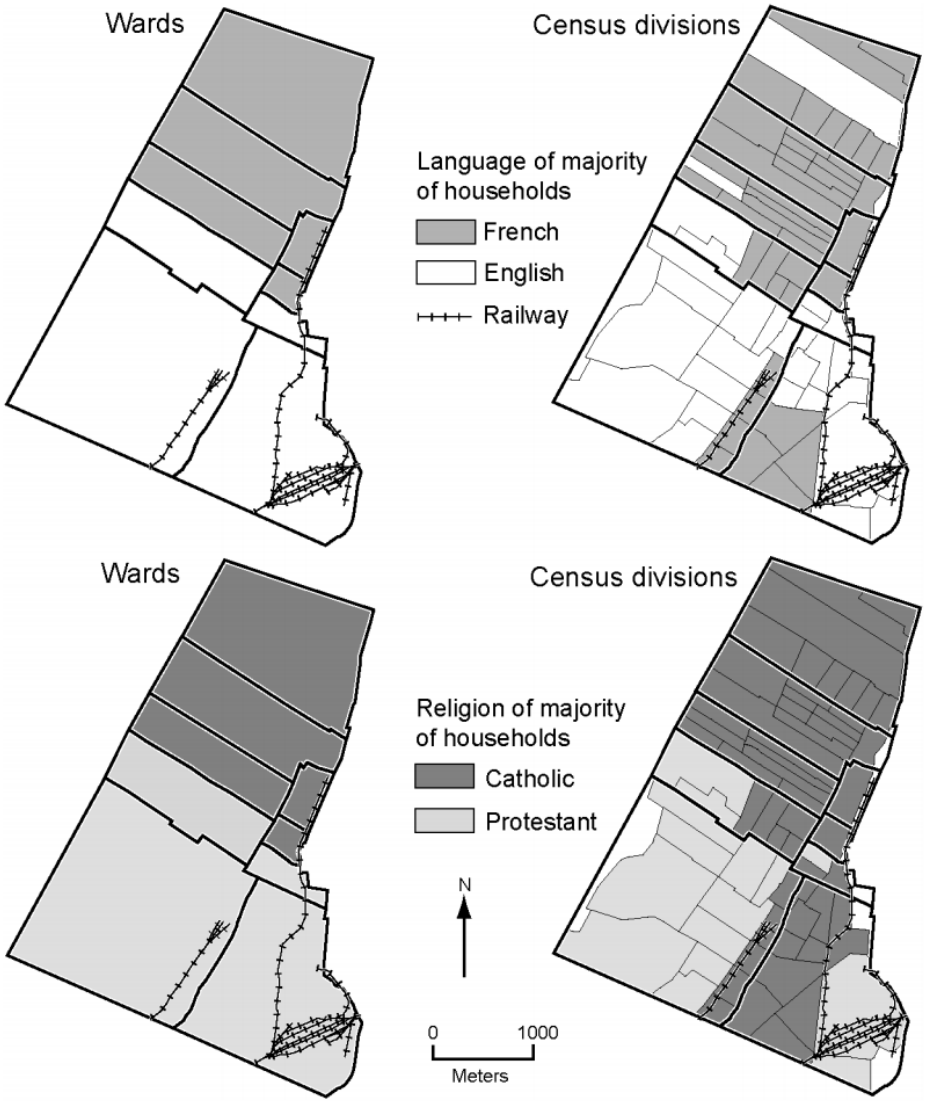

Figure 2: Maps of Montreal demonstrating the concentration of English and French households, as well as Catholic and Protestant households, based on census and ward data from 1881. From Gilliland and Olson, 2010: 37.

In other nineteenth century North American cities, ethnic groups' concentration in certain areas may have been the result of a group's desire to establish their own distinct neighbourhood and community where they would benefit from having relationships with other people of shared religion, language, and cultural norms. This may have been further influenced by other factors, such as income, stage in life cycle, housing availability, household size, and proximity to the workplace. In New York City, another diverse industrial center of the nineteenth century, it is theorized that immigrant segregation in

certain neighbourhoods may have been the result of the concentration of factories in certain parts of the city, coupled with a lack of housing options for low-paid immigrant workers (Gilliland & Olson, 2011). During the nineteenth century, Montreal was generally a low-wage city, with day labourers earning an average of $1 per day, and many working-class and industrial neighbourhoods were established along the Lachine Canal, a center of trade and industry (Bradbury, 2007; Fougères & MacLeod, 2017; Gilliland & Olson, 1998; MacLeod, 2003). For instance, Saint Anne, one such neighbourhood near the Lachine Canal, was largely populated by Irish Catholic families who had immigrated in the 1820s and 1830s, many of whom worked as day labourers in and around the Lachine Canal (Bradbury, 2007). It is possible that the desire to have a shared identity with one's neighbors, as well as a lack of housing availability and the concentration of factories in certain areas, as observed in New York City, contributed to similar patterns of segregation in Montreal.

While cultural groups in nineteenth century Montreal occupied different social and economic classes and different neighbourhoods they further differed in child rearing practices. A historical demographic study by Thornton and Olson (2001) suggests that French-Canadian mothers weaned their children at an earlier age than Irish Catholic or English Protestant mothers. Moreover, French-Canadian mothers married at a younger age resulting in more total births on average than mothers in other cultural groups (Thornton & Olson, 2011). Irish Catholic mothers, who occupied similar SES as French-Canadian mothers, demonstrated lower fertility rates than French-Canadians, which may be partially explained by the longer length of breastfeeding practiced by Irish Catholic mothers (Thornton & Olson, 2011). Longer breastfeeding can contribute to longer birth intervals, as well as contributing to a greater chance of infant survival (Ellison, 2003), which will be explained in greater detail in the following sections.

Of course, cultural, and religious identities were not limited to French Catholics, Irish Catholics, and English Protestants, but these ethnic and cultural groups accounted for approximately 95% of Montreal's population (Watkins, 2002). Additionally, while marriages sometimes crossed cultural and religious borders, most occurred within cultural, religious, and ethnic boundaries (Bradbury, 2007; Bradbury & Myers, 2005).

However, when considering language (French or English) and religion (Catholic or Protestant) there is significant correlation between these identities and which neighbourhoods these groups occupied (see Figure 2). When considering spoken language and religious background separately, it was found that French-speaking Catholics in 1881 primarily occupied neighbourhoods to the north, while English-speaking Protestants occupied neighbourhoods to the south (Thornton & Olson, 2011). This speaks to a broader trend of segregation based on religion, language, ethnicity, and economic background, as well as the close relationship between those factors.

2.1.2 Infant Morbidity and Mortality in Nineteenth Century Montreal

Nineteenth century Montreal was not only recognized as the most economically important city in British North America, but also as one of the deadliest cities in the Western world (Thornton & Olson, 1991). Throughout the nineteenth century, various waves of immigration to the city were associated with epidemics and disease outbreaks. For example, Irish immigration in the late 1840s was associated with cholera and typhus epidemics, and in the 1850s and 1890s, immigration of French-Canadians from rural areas was associated with tuberculosis and typhoid fever (Gilliland & Olson, 1998). The city additionally experienced two cholera epidemics in the summers of 1832 and 1834, with the first being particularly deadly as approximately one-third of those who became ill died (Bosworth, 1859). Carpenter (1869) observed that mortality rates for Montreal in the 1850s were between 8,000 and 9,000 times higher than in Boston or Quebec City, respectively. Rapid settlement and expansion, poor construction of housing, and rapid population growth placed such a great strain on housing and the already-inadequate sanitation systems, that health problems that already existed prior to Montreal's industrial expansion became further exacerbated. This was especially true for working class families who were more likely to live in poorly constructed, small, overcrowded homes, and as such were more susceptible to disease outbreaks (Bradbury, 2007; Robert, 1988). Infants were particularly vulnerable to these disease outbreaks, due to their immature immune systems and reliance on their mothers' breastmilk for passive immunity and nutrition (Simon et al., 2015).

Although infant morbidity and mortality in Montreal remained high into the twentieth century, rates were particularly elevated in the beginning of the nineteenth century. Based on birth cohort life tables from 1801-1861, the life expectancy at birth for females in Quebec steadily increased from 39.56 to 44.15 over this period, while male life expectancy at birth increased from 37.79 to 41.84. The 1801 birth cohort demonstrated the highest overall rates of female infant and childhood mortality, at 170.58 (per 1,000) and 152.12 (per 1,000), respectively, and only 30% of females in this cohort lived to their 65th birthday (Bourbeau et al., 1997). The 1801 male birth cohort demonstrated a higher infant mortality rate compared to females, at 194.66 (per 1,000), while the male childhood morality rate was slightly lower, at 150.18 (per 1,000) (Bourbeau et al., 1997). It is worth noting that these figures represent mortality rates for the entirety of Quebec, including both rural and urban areas. Thus, the mortality rates represented here may be different from what they might have been in Montreal alone, where mortality rates likely would have been (much) higher. In fact, in the second half of the nineteenth century, infant mortality in urban areas was 30% higher than in rural areas (Thornton & Olson, 2011). Though these figures provide a good general overview of high mortality rates in nineteenth century Quebec, to get a more accurate representation of infant mortality in Montreal, it is important to consider urban-rural differences in mortality and morbidity rates.

Pelletier and colleagues (1997) compiled data from various primary and secondary sources to compare mortality rates in Quebec City and Montreal with those of the rest of the province of Quebec and thus included many rural areas. They found both the 1851 and 1861 census results showed that children in Montreal were twice as likely to die in their first year of life than children from other parts of the province. Moreover, crude death rates for the three regions (Montreal, Quebec City, and the Province of Quebec) illustrated this difference in mortality rates across all age groups, with Montreal and Quebec City having considerably higher crude death rates from 1821-1870, at an average of 45.58 (per 1,000) and 34.91 (per 1,000) respectively, than the Province of Quebec whose crude death rate averaged 24.18 (per 1,000) from 1801-1880 (Pelletier et al., 1997). Similar patterns of urban-rural differentials have been observed elsewhere, such as

in comparisons of nineteenth-century industrial and rural regions of Sweden (Edvinsson et al., 2005).

Official reports of infant mortality rates in Montreal exist from the middle of the nineteenth century onward, coinciding with Quebec's first official census in 1851. Prior to this, an 1841 census was conducted, though it was non-nominal and only the heads of household were enumerated (Bellhouse & Genest, 2005). However, there are some reports that reflect on mortality in Montreal that were compiled prior to the first census. One such report, published in 1847, tracked the number of deaths in Montreal by ward (suburb/faubourg) (Figure 3). Those data demonstrated that poor wards, such as Saint Anne, had considerably higher mortality rates compared to wealthier wards such as East and West in the Old City. Mortality rates in Saint Antoine lie somewhere between the wards with the highest and lowest mortality rates, with 188 total deaths (per 1000) in 1846 (Hall, 1847). It should be noted that this 1847 report collected data based on where individuals died, rather than the ward in which they lived and, consequently, wards with hospitals, such as Center, exhibited higher mortality rates than other wards without hospitals. Therefore, it may not be an entirely accurate depiction of death rates per ward.

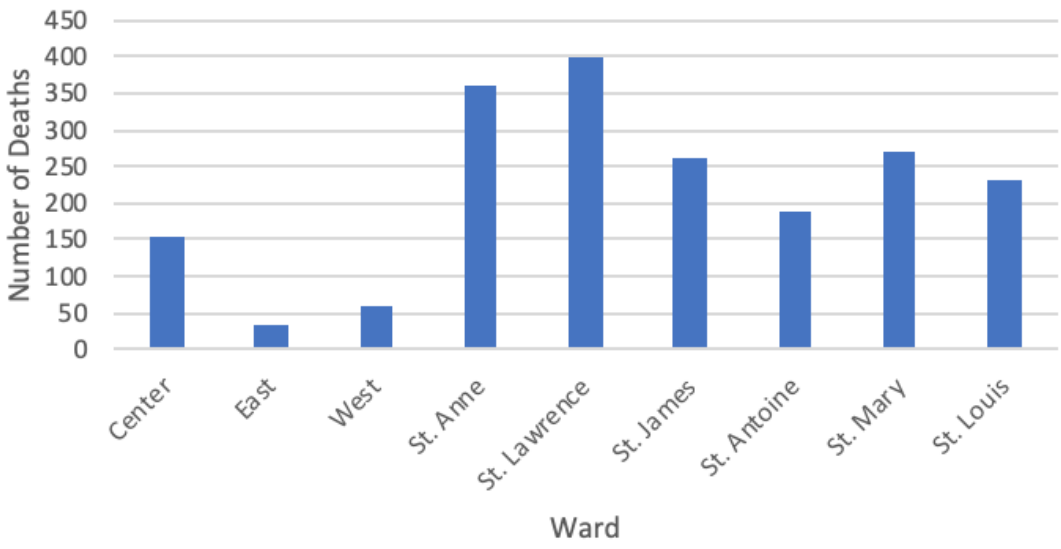

Figure 3: Deaths in Montreal in 1846, organized by ward. Adapted from Hall, 1847.

The same report collected data on mortality per age group and found that children under one year had the highest mortality rates across Montreal, accounting for 732 of 2,118 total deaths in 1846, or about 34% (Hall, 1847). However, there may be some discrepancies in the data, as the total deaths enumerated when considering death by age group was 118 deaths more than the total deaths reported when considering deaths by ward. In a review of nineteenth century statistical reports, Bellhouse and Genest (2005) remark that, while this report may have a somewhat accurate count of deaths in Montreal, it would not have been possible to accurately measure mortality rates due to the absence of population size and distribution data in the 1841 census. While this report provides some insight into mortality rates in Montreal during the first half of the nineteenth century, it is not necessarily the most reliable and should be considered in relation to other contemporaneous reports and demographic analyses.

Using census data, an examination of first-year mortality for an 1859 birth cohort found that 23.75% of infants born to residents of Montreal died within the first year of life, while 1 in 8 infants (12.5%) died within the first month (Hall, 1847). A report from 1869 observed that, in 1867, the average weekly death rate for Montreal children under 1 year was 39.7 deaths (Carpenter, 1869). Meanwhile, children in the 1–5-year age range averaged 4.4 deaths per week (Carpenter, 1869). While there are no weekly birth rate data for 1867, the weekly death rate can be compared with the 5,598 total births that occurred in Montreal (excluding surrounding suburbs) that year, which amounts to an average of 107.65 births per week (Carpenter, 1869). This would mean that 37% of children under 1 year and 4.1% of children aged 1-5 years died in 1867. Carpenter (1869) calculated that there were 76 deaths per 100 births in Montreal (excluding surrounding suburbs) in 1867, and 68 deaths per 100 births in 1866. However, there are not only expected differences between urban and rural populations, but also between cultural groups.

When infant mortality is calculated for each major cultural group in Montreal, French-Canadian families experienced infant mortality rates that are 1.5 times higher than that of Protestant and Irish Catholic families (Thornton & Olson, 1991). There was some speculation in the nineteenth century that high mortality rates in Catholic families might

be the result of exposure to cold and the practice of early christening. However, Carpenter (1869) dispelled this assumption, observing that the coldest months, which would be when the effects of early christening would be most seen, had the lowest death rates by far (higher mortality in hot months is discussed in a subsequent section). These differences in mortality rates may be due to socioeconomic differences between groups but may also be connected to differences in infant feeding and weaning practices, as well as differences in fertility rates and birth spacing, as mentioned in previous sections. The effects of these practices will be further discussed in the next section.

It is worth noting that both census data and parish records from the nineteenth century are widely considered unreliable as, prior to 1851, censuses were not or only partly nominal and enumerated only the heads of household, though parish records are typically considered the more reliable of the two (Library and Archives Canada, n.d; Pelletier et al., 1997). Moreover, census data typically underestimated mortality (Canada, 1884 cited in Pelletier et al., 1997). However, these types of datasets can still indicate broad morbidity and mortality trends, and as such remain valuable sources when considering morbidity and mortality during this period.

2.1.3 The Effects of Breastfeeding and Weaning Practices on Infant Morbidity and Mortality

The earliest written information regarding breastfeeding is found in the Ebers Papyrus (1550 BC), though it does not include prescriptive advice regarding the timing of the cessation of breastfeeding or recommendations on supplementary foods (Fildes, 1986; Fulminante, 2015). Texts from Ancient Greece and Rome, including texts from Galen (AD 130-200), include observations on the length of breastfeeding, stating that it is typical to begin introducing solid foods around 6-12 months of age, when the first teeth begin to appear, and breastfeeding should cease entirely by 3 years of age (Fulminante, 2015; Garrison, 1965; Prowse et al., 2008). In Biblical texts, the weaning age of three years corresponded with the transition into ‘childhood’ and when the child would be permitted entry to the Temple (Fulminante, 2015). Evidence of breastfeeding alternatives has been recovered from the material archaeological record, from the Roman Era to the

Renaissance, with some crude feeding bottles being found that date back thousands of years (Stevens et al., 2009). The practice of animal nursing, where an infant is fed directly from the teat of an animal, has been described in numerous legends and myths, including that of Romulus and Remus, founders of Rome, who were purportedly nursed by a wolf (Radbill, 1981). Prior to the invention of glass bottles, wet nursing was a common alternative to maternal breastmilk, and the practice may date as far back as Ancient Mesopotamia, as written agreements with wet nurses have been found dating back to this period (Fildes, 1986; Fulminante, 2015).

Recommendations against wet nursing begin to appear in Europe between the 16th and 17th centuries with medical professionals, such as French obstetrician Jacques Guillemeau (AD 1550-1613), beginning to advocate for maternal nursing, although the practice remained popular in some regions for two more centuries before falling out of fashion (Wickes, 1953a). In the 18th and 19th centuries, the practice of wet nursing began to decline, and eventually disappear, throughout Europe, with France being the exception where the practice remained highly organized until the 20th century (Sussman, 1982). From 1800 onward, wet nursing shifted to being an alternative of need, as inventions such as glass bottles, formula, and the growing popularity of animal milk led to an increase in artificial feeding and a subsequent decline in wet nursing (Stevens et al., 2009). At the beginning of the nineteenth-century, the most popular methods of infant feeding included the use of pap (semi-solid food consisting of bread crumbs or flour cooked in water) and panada (soup consisting of stale bread boiled to a pulp either in water or other liquids), breastfeeding by the mother (with an early introduction of pap), breastfeeding by wet nurses (although there were fears that the wet nurse may pass on her temperament to the child via breastmilk), and the use of animal milk (Thulier, 2009; Wickes, 1953b). The 1800s also saw more prescriptive literature published on the topic of infant feeding (Thulier, 2009). However, literature regarding breastfeeding and the ability to seek expert advice was largely relegated to wealthy, white, elite mothers who possessed the means to seek it out, if they chose (Thulier, 2009).

During pre-modern times, infants who were given alternatives to breastmilk were less likely to survive than their peers who were breastfed (Knodel & Kintner, 1977). Not only

is breastmilk clean, where alternatives might become contaminated with diarrheal pathogens, but it also provides passive immunity to the infant as well as nutritional benefits and factors that promote the maturation of the gastrointestinal tract (Eerkens et al., 2011; Hodson & Gowland, 2020; Thornton & Olson, 2011). In modern times, several studies have linked early weaning or the lack of breastfeeding from birth to 6 months with increased diarrheal morbidity and mortality in developing countries (Dettwyler & Fishman, 2003; Lamberti et al., 2011). Researchers suggest that excess infant deaths from diarrheal and respiratory infections may be avoided if exclusive breastfeeding continues through 4-6 months of age, thus reducing the infant's risk of exposure to potential contaminants while continuing to provide infants with passive immunity (Dettwyler & Fishman, 2003).

The decision to breastfeed, and for how long, is influenced by various external and internal factors, such as culture, SES, recommendations from healthcare professionals, access to breastmilk alternatives, family and community norms, employment status, religion, among many others. Considering the number of factors that contribute to decisions surrounding breastfeeding, it is expected that breastfeeding practices will vary between communities and households. For nineteenth century mothers who were either unable to breastfeed, or chose not to, alternatives included hiring a wet nurse, gruel (liquid porridge, often with meat added), animal nursing, pap, animal milk, and porridge (Radbill, 1981; Stevens et al., 2009; Wickes, 1953b). Until the invention of formula in the latter half of the nineteenth century, animal milk was the most common artificial alternative to breastmilk, but it is important to note that it differs from human milk in many ways that make animal milk a poor substitute for human milk (Stevens et al., 2009).

It has already been established that Montreal was regarded as one of the deadliest cities in the Western world, subject to various disease outbreaks and epidemics throughout the nineteenth century, and that infants were particularly vulnerable to these outbreaks. While infant mortality was generally high in the nineteenth century, it was particularly high in Foundling Hospitals, largely due to the popular practice of 'dry nursing' within these institutions (Fildes, 1986). Dry nursing refers to the practice of feeding of prepared

foods to an infant as an alternative to breastmilk (Thulier, 2009). At Foundling Hospitals in New York and Montreal, 89.6% and 89.9% of infants, respectively, who were given alternatives to breastmilk, died. Meanwhile, infants at these same hospitals who were breastfed experienced comparatively lower rates of infant mortality at just 20% (Carpenter, 1869). The better survival rate of infants who were breastfed may be due, in part, to passive immunity passed on through breastmilk, but may also be explained by the cleanliness of breastmilk when compared to alternatives, which will be discussed in greater detail below.

Carpenter's (1869) report further observed that infant mortality increased in the summer months, a finding that has been shared elsewhere (Carpenter, 1869; Hall, 1847; Thornton & Olson, 1991). The report states that, in summer months, there is "scarcely a square yard of ground which is not charged with effete matter, ready to generate poisonous gasses under the influence of summer sun", thus placing the blame for excess infant deaths on pollution and poor air quality, a belief in line with the period's popular miasma theory of disease, which stated that disease is primarily caused by bad air rather than germs and pathogens that may be transmitted through various disease pathways (Carpenter, 1869, p. 205). Truly, the increase in mortality during summer months is likely due to an increased risk of water contamination, which thus increases the risk that supplemental foods given to infants has been contaminated with diarrheal pathogens (Thornton & Olson, 1991). Similar trends of high infant mortality in summer months have been observed elsewhere in nineteenth century Canada (e.g., Herring et al., 1991). Weinberg (1993) also suggests that the increase in deaths over summer months may be influenced by the spoiling of milk left in bottles. Census data from the time demonstrated that children under the age of 1 year (the most affected by high mortality throughout the year) had especially high mortality rates in the summer months compared with children between 1 to 12 years of age (Figure 4) (Carpenter, 1869).

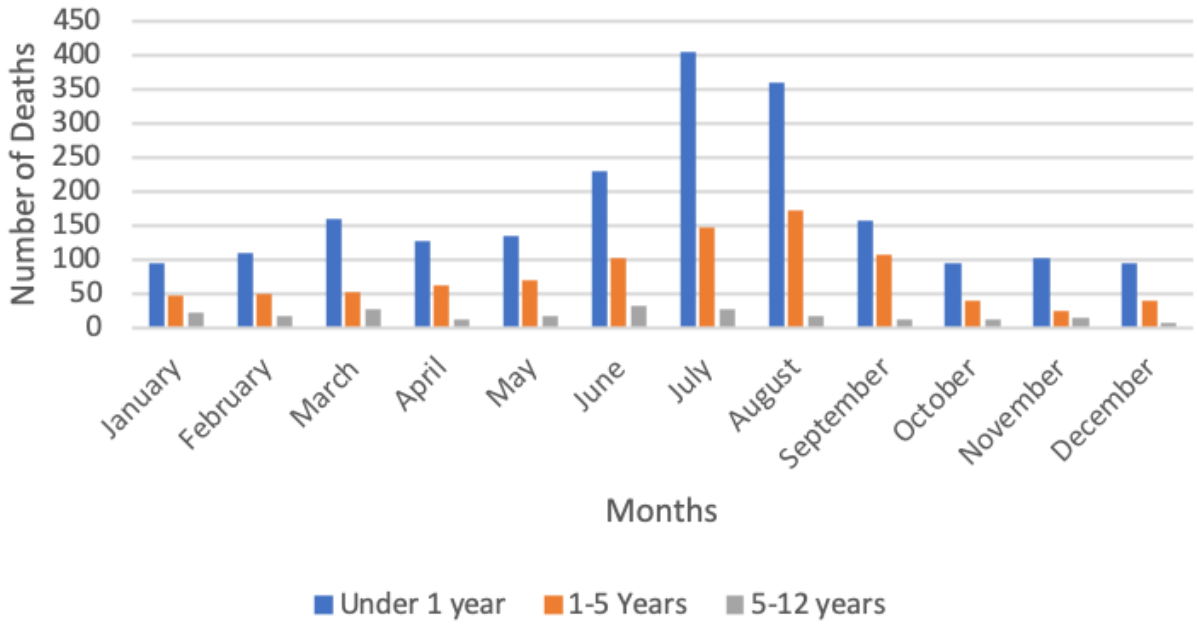

Figure 4: Monthly deaths for children under twelve years of age in Montreal in 1867, according to age group. Adapted from Carpenter, 1869.

Exclusive breastfeeding is only nutritionally adequate for about the first six months of life, after which, supplemental foods must be introduced to the infant's diet to support their growth and development (Fildes, 1995; Humphrey., 2014; Sandberg et al., 2014). If supplemental foods are not introduced, the infant is at risk for growth faltering (Katzenberg et al., 1996; Newman & Gowland, 2017). Yet, termed the 'weanling's dilemma', if supplemental foods are introduced, the infant is at increased risk for infection from contaminated foods (Katzenberg et al., 1996; Knodel & Kintner, 1977). Thus, the risk of illness must be weighed against the risk of growth faltering when deciding whether to initiate the weaning process. As mentioned in the previous section, the weekly death rate in Montreal in 1867 for children under one year of age was 39.7, whereas for children between the ages of 1-5 years it was much lower, at 4.4 deaths per week (Carpenter, 1869). I propose this difference between the two age groups is due to the weanling's dilemma, in that some infants were fed contaminated supplementary foods within their first year which led to their death. If an infant survived this precarious period, it is expected that by around one year of age their immune system and gastrointestinal tract were far more developed and thus able to fight off pathogens more effectively (Simon et al., 2015).

Breastfeeding also affects infant morbidity and mortality rates due to its role in preventing pregnancy. Breastfeeding has a high energetic cost of approximately 700 kcal per day, meaning that caloric energy must be diverted away from other bodily functions to maintain an energetic investment in current offspring (Ellison, 2003). Thus, energy may be diverted away from other reproductive functions, which then results in lactational amenorrhea, or the absence of menstruation (Ellison, 2003; Henderson et al., 2014). Consequently, the high energetic cost of breastfeeding can prevent pregnancy by reducing fecundity. This allows the mother to remain energetically invested in their current offspring rather than in preparing for new offspring, and so improves the chance of survival for current offspring (Ellison, 2003; Katzenberg et al., 1996).

Infant morbidity and mortality rates were highest among French-Canadian families, who were generally of lower SES than English Protestants, who exhibited lower infant morbidity and mortality (Thornton & Olson, 1991). The effects that the cessation of breastfeeding has on the infant, such as whether the infant falls ill, depends on the quality and quantity of supplementary foods, sanitary conditions, and overall health conditions of their environment (Knodel & Kintner, 1977). Therefore, it might be expected that infants and children from wealthier families survived more often than their poorer peers due to better access to resources such as wet nurses and adequate weaning foods. The observation of differential infant morbidity and mortality between French-Canadians and English Protestants supports the notion that infants and children of higher SES survive better than those of lower SES. However, if infant morbidity and mortality rates were influenced by SES alone, then it would be expected that Irish Catholics would exhibit similar, if not worse, rates of infant morbidity and mortality when compared to French-Canadians. This is not the case, as Irish Catholics exhibited lower infant morbidity and mortality rates than French-Canadians of similar SES (Thornton & Olson, 1991; Thornton & Olson, 2011). Instead, this difference between the two cultural groups may be explained by differences in childrearing practices.

It has been observed that longer periods of breastfeeding among Irish Catholic populations contributed to longer birth intervals which then increased the chances of infant survival (Thornton & Olson, 1991; Thornton & Olson, 2011). Meanwhile, French-

Canadian mothers, who generally married younger and weaned their children earlier, experienced overall higher fertility and shorter birth intervals (Thornton & Olson, 2011). Birthing more children in a shorter span of time, as well as an earlier weaning age, contributed to higher and more premature infant mortality among French-Canadian families when compared to their Irish Catholic counterparts (Thornton & Olson, 2011). Further, given that birth spacing is influenced by the duration of breastfeeding, as the high energetic cost of breastfeeding can reduce fecundity, it is likely that Irish Catholics were breastfeeding their infants for longer periods when compared to French-Canadians, thus protecting them from the risk of contaminated weaning foods and contributing to the greater survival of their children (Ellison, 2003; Thornton & Olson, 2011).

2.2 Bioarchaeological Approaches to Infant Feeding and Weaning Practices

2.2.1 Estimating Infant Feeding Using Skeletal Stress Markers

Early studies attempting to reconstruct the breastfeeding and weaning practices of past populations, focused on the appearance of physiological stress makers such as linear enamel hypoplasia (LEH) (e.g., Cook & Buikstra, 1979). LEH is a deficiency in enamel thickness that is caused by a period of stress during dental development that disrupts enamel matrix secretion (Bereczki et al., 2019; Goodman & Rose, 1990; Kreshover, 1960). It appears as horizontal, or nearly horizontal, bands where the enamel is significantly thinner than the surrounding area; hypoplastic pits, randomly distributed or in roughly horizontal bands, can also occur (Bereczki et al., 2019; Ritzman et al., 2008). As LEH will only occur on the portion of the tooth crown that is developing at the time of the stressor event, and since dental development occurs at a stable and known rate, it can be linked to a certain period of early life (Ritzman et al., 2008). It is important to note that LEH will only appear if the individual survives the stress event, as the tooth needs to have continued growing after the period of stress for it to be detected. It has been theorized that since weaning can be a period of pronounced nutritional stress for an infant, one would expect the appearance of skeletal stress markers to correlate with the time of weaning (Buikstra & Cook, 1989; Cook & Buikstra, 1979). However, the

appearance of stress markers is not limited only to nutritional stress brought on by weaning but can be caused by other factors such as post-weaning nutritional stress, fever, infectious disease, and diabetes, among others (Bereczki et al., 2019; Katzenberg et al., 1996; Kreshover, 1960). Additionally, several archaeological studies investigating the validity of stress markers in estimating weaning have found that LEH developed too long after the beginning of the weaning process to attribute its appearance to weaning alone, and, as such, other factors must have been the cause (e.g., Katzenberg et al., 1996; Moggi-Cecchi et al., 1994; Wood, 1996).

While LEH alone may not be a reliable method of estimating weaning age, it may still be useful for understanding morbidity during the weaning process. As noted, several studies have found that LEH appear after the beginning of the weaning process, and so they may not be attributed to weaning alone (e.g., Moggi-Cecchi et al., 1994; Wood, 1996). However, it may be the case that the beginning of the weaning process is not the most physiologically stressful period, but rather later stages of the process or even when the weaning process is complete, thus explaining why LEH do not appear at the onset of weaning. Weaning is usually a gradual process that occurs over varying periods of time If the process gradual is gradual, then there isa fairly slow and steady loss of the nutrients and immunity from breastmilk (Moggi-Cecchi et al., 1994). Therefore, it is possible that it takes time for LEH to manifest within the enamel. Blakey and colleagues (1994) suggest that a 6–9-month delay between historically documented cessation of breastfeeding and the onset of LEH may be explained by post-weaning stress. Post-weaning stress is associated with an increase in language and motor skills, which can increase a young child's contact with other individuals and new substances, thus increasing a child's risk of exposure to pathogens and infection (Blakey et al., 1994). It should not be assumed that LEH are always associated with or directly caused by weaning, though it is possible that they may be in some cases, and as such it is useful to compare LEH data with isotopic data to investigate if the two are associated.

2.2.2 Estimating Infant Feeding Using Stable Isotope Analysis

Methods to estimate weaning using bone chemistry began to develop in the 1980s and became further refined in the 1990s as continuous flow mass spectrometry was developed, thus decreasing the cost of analysis, and allowing for a greater volume of research (Makarewicz & Sealy, 2015). Early methods used bone collagen, commonly extracted from the ribs, to measure trace element ratios. Bone collagen is produced using dietary proteins, and as such, trace elements measured in bone collagen can be expected to reflect an individual's diet (Hedges et al., 2007; Roberts et al., 2018). One early study using this method measured strontium and calcium in infants and children who lived in the Middle East between AD 800-1300, observing that both trace element ratios peaked between 1.5 and 3.5 years of age. This was interpreted as indicating that the beginning of weaning occurred between these ages (Sillen & Smith, 1984). Following this, other studies began to combine bone chemistry methods with the observation of skeletal stress markers to estimate weaning age (Hühne-Osterlohe & Grupe, 1989).

Fogel and colleagues (1989) were among the first to use δ^{15}N values to approximate the duration of breastfeeding by observing the trophic level effect. During gestation and at birth, the assumption is that an infant's δ^{15}N isotopic level will be like that of their mother, as their diet is essentially identical during the *in utero* period. Following birth and with the initiation of breastfeeding, δ^{15}N levels of the infant will become elevated above that of their mother (Fogel et al. 1989). This elevation is referred to as the trophic level effect and is due to a breastfeeding infant's diet consisting of the mother's nutrients and tissues delivered via breastmilk (Crowder et al., 2019; Fogel et al., 1989; Fuller et al., 2006; Reynard & Tuross, 2015;). The weaning process may be indicated by either a steep or gradual decline in δ^{15}N depending on how quick or gradual the weaning process was (Burt & Garvie-Lok, 2013).

The study from Fogel and colleagues (1989) tested this effect in a living population by collecting fingernail clippings from both breastfed and formula-fed mother infant pairs throughout the breastfeeding and weaning process, and subsequently measuring isotopic ratios. It was found that breastfed infants had an average 2.4‰ δ^{15}N increase compared to

formula-fed infants, who did not demonstrate any trophic level enrichment (Fogel et al., 1989). Following this initial study, these researchers tested the trophic level effect in two pre-horticultural and horticultural prehistoric populations from the United States to compare infant feeding practices. In both groups, there was an observed decline in $\delta^{15}N$ around 18 to 20 months of age and this decline is interpreted as signaling that breastmilk was no longer the predominant source of protein in an infant's diet (Fogel et al., 1989).

While $\delta^{15}N$ provides estimates for the duration of breastfeeding, $\delta^{13}C$ can provide estimates of when weaning foods were first introduced, signaling the beginning of the weaning process (Figure 5). Using fingernail clippings and hair samples collected throughout the first year of life from mother-infant pairs, Fuller and colleagues (2006) measured $\delta^{15}N$ and $\delta^{13}C$ to observe how isotope ratios changed throughout the feeding and weaning process. They found that $\delta^{13}C$ values were increased by ~1‰ due to breastfeeding. However, because $\delta^{13}C$ values reflect the carbohydrate, protein, and lipid components of the diet, they typically return to a baseline quicker than $\delta^{15}N$ values, suggesting that $\delta^{13}C$ could be used as a reliable measure of when carbohydrate-rich weaning foods are first introduced, while $\delta^{15}N$ may be used to indicate how long breastmilk consumption continued (Fogel et al., 1989; Fuller et al., 2006;). It is further possible to use $\delta^{13}C$ values to distinguish what type(s) of weaning foods an infant's diet might have contained (i.e., marine-based vs. terrestrial-based; C_3 vs. C_4 plants).

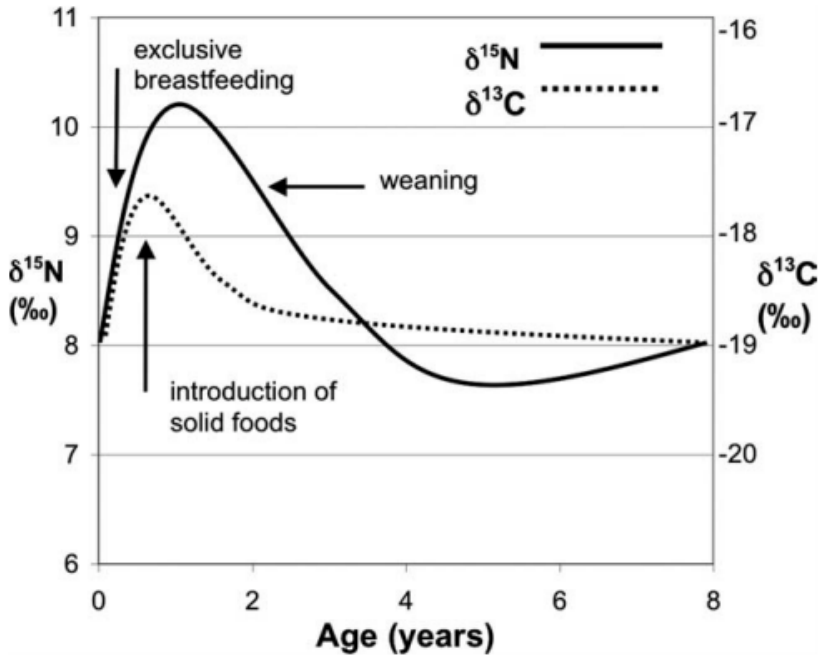

Figure 5: Graph showing what a reconstruction of breastfeeding and weaning might look like using δ^{13}C and δ^{15}N. Note the spike in δ^{13}C when weaning foods are first introduced, as well as the peak in δ^{15}N prior to the initiation of the weaning process. From Nitsch et al., 2011.

The studies outlined above focus largely on bone collagen to measure stable isotope ratios. However, bone collagen is remodeled throughout life, and represents an individual's diet from the last ~10 or more years of life (Hedges et al., 2007; Matsubayashi & Tayasu 2019). Consequently, studies of breastfeeding and weaning practices that use of bone collagen require samples from individuals who did not survive into adulthood. This presents various complications, including the possibility that non-survivors were weaned differently (earlier or later than their peers who survived) or were fed a different diet than those who did survive. The complications of using bone collagen can be avoided through the analysis of dentine, which does not remodel once it is laid down and thus stores a stable record of diet from the beginning of end of tooth formation, a process that begins *in utero* and ends in the early 20s (Beaumont et al., 2013; Hedges et al., 2007; Ubelaker, 1989). A small amount of secondary dentine is added near the pulp cavity in adulthood, and like primary dentine, does not remodel once it is laid down (Sealy et al., 1995). Further, teeth are generally well-preserved in the archaeological record and, when compared to bone, are less vulnerable to changes from the burial

environment (Crowder et al., 2019). As such, dentine is the ideal tissue to conduct stable isotope analyses of infant feeding practices in both survivors and non-survivors (Beaumont et al., 2013).

Initial studies of dentine used an inter-tooth approach, focusing on several teeth that developed at different times during life. This approach, however, captures isotope ratios formed over several years of life, and does not allow for a precise examination of the breastfeeding and weaning process in the same way as an intra-tooth approach (Henderson et al., 2014; Sandberg et al., 2014). An intra-tooth approach allows for the sampling of tissues that developed over the course of the tooth's formation period (Sandberg et al., 2014) For example, because an intra-tooth approach is able to use different developmental layers of dentine from just one tooth, it allows for the analyses of diet in early infancy and childhood from an individual who died in late adulthood. Intra-tooth approaches allow researchers to study tissues from those who survived infancy and childhood (Sandberg et al., 2014).

Primary dentine, located within the inner portion of the tooth, is secreted at a known rate of approximately 3-5μm per day, becoming fully mineralized within 5-8 days (Crowder et al., 2019; Dean & Scandrett, 1995; Kawasaki et al., 1980; Schour & Poncher, 1937). Using serial dentine sections, the incremental layers of primary dentine that are laid down during development, researchers can track breastfeeding and weaning much more precisely. Moreover, this method allows researchers to measure isotopic signatures at specific periods in life, and track how they changed over time, rather than methods involving the whole tooth or bone collagen, that only provide researchers with an average isotopic signature.

In a study of early life diet at medieval Wharram Percy in the U.K., Fuller and colleagues (2003) sectioned teeth into 3-4 sections spanning several years of development. This allowed researchers to observe changes in diet over time, though these sections reflected diet over several years rather than several months. As methods for serial dentine sectioning became more refined, researchers began to use smaller and more precise sections, allowing for a more detailed examination of changes in diet over time. More

recent studies have made use of 1mm-wide sections representing approximately 200 days or 9 months of life (Beaumont et al., 2013; Henderson et al., 2014). These smaller sections allow researchers to study the weaning process more closely than previous approaches.

2.3 Conclusion

Rapid population growth and industrialization in Montreal throughout the nineteenth century contributed to increased wealth disparities between the wealthy and non-wealthy and to the segregation of Montreal along cultural and economic lines. It additionally contributed to high rates of morbidity and mortality, particularly among infants, who were especially vulnerable to disease outbreaks due to their underdeveloped immune systems (Gilliland & Olson, 2010; Simon et al., 2015; Thornton & Olson, 2011; Thornton & Olson, 1991).

An important factor in the consideration of infant mortality in nineteenth century Montreal is breastfeeding and weaning. While infant mortality was generally high during this period, it was especially high among infants who were not breastfed, as illustrated by high rates of infant mortality in a Foundling Hospital in Montreal, where 89.9% of infants who were fed alternatives to breastmilk died, compared to a 20% mortality rate among those who were breastfed (Carpenter, 1869). Infant mortality was especially high during summer months, likely due to the contamination of supplemental foods with diarrheal pathogens from unclean drinking water and spoiled animal milks (Carpenter, 1869; Thornton & Olson, 1991). High mortality rates among those under the age of one were likely impacted by weaning, as breastmilk is only nutritionally adequate for the first six months of life, after which supplementary foods must be introduced to an infant's diet or growth stunting may occur (Katzenberg et al., 1996; Newman & Gowland, 2017). However, the introduction of supplementary foods comes with a risk of illness, and the decision between continuing breastfeeding or introducing supplementary foods manifests in the weanling's dilemma (Knodel & Kintner, 1977).

Bioarchaeological studies have investigated and reconstructed infant feeding and weaning practices using various methods, such as estimating the timing of weaning using the appearance of LEH on dentition and measuring $\delta^{13}C$ and $\delta^{15}N$ in bone collagen (e.g., Fogel et al., 1989; Mogi-Cecchi et al., 1994; Wood, 1996). $\delta^{13}C$ can provide information regarding the timing of the introduction of supplemental foods, and what these foods might have consisted of, while $\delta^{15}N$ can provide information regarding how long breastfeeding occurred and when it ceased completely, by looking at the trophic level effect (Fogel et al., 1989; Fuller et al., 2006; Nitsch et al., 2011). However, neither of these methods allow for a precise measure of the timing of weaning, from onset to the completion. A preferable method is to use dentine as teeth are minimally affected by burial environment, develop at a known rate, and do not remodel throughout life, therefore remaining a stable tissue from which to reconstruct early-life diet (Beaumont et al., 2013; Crowder et al., 2019; Dean & Scandrett, 1995; Kawasaki et al., 1980; Schour & Poncher, 1937). By sectioning dentine into developmental sections, $\delta^{13}C$ and $\delta^{15}N$ can be measured to reconstruct breastfeeding and weaning at and across specific periods of life (Beaumont et al., 2013; Fuller et al., 2003). This method is especially advantageous as it allows researchers to collect data from those who survived infancy and childhood, rather than methods using bone collagen that rely on samples from those who died while in the process of breastfeeding and weaning (Sandberg et al., 2014).

Chapter 3

3 Materials

This study is focused on a sample of French-Canadian subadults and some adult females who were interred at Saint Antoine (AD 1799-1854) cemetery in Montreal. This section details Saint Antoine cemetery, the population and community which it served, as well as the settlement of the neighbourhood surrounding the cemetery, also named Saint Antoine. It will further go on to provide a brief overview of the excavation of the site, based on already-existing excavation reports, as well as detailing how individuals were sampled for this study.

3.1 The Site

The suburb of Saint Antoine was initially settled between AD 1683 and 1713 and is among one of the earliest settlements on the island of Montreal. It is located on the southern slope of Mount Royal's western summit, and like the rest of nineteenth century Montreal, was segregated based on economic status (Fougères & MacLeod, 2017). In the 1800s, as Montreal became increasingly industrialized, Saint Antoine received an influx of British mercantile elite as the city expanded, though there was still a considerable French-Canadian population (Fougères & MacLeod, 2017; MacKinnon, 2005). Many of these upper-class British households lived in the northern portion of Saint Antoine, which offered views of the city and the river, while the lower-class inhabitants of the faubourg lived toward its southern border with the working class faubourg of Saint Anne. Of the three wards in the west of Montreal, Saint Antoine was among the most populous as well as the largest in geographic size (Fougères & MacLeod, 2017). According to the 1825 census, the population of Saint Antoine was 145 individuals, though this would grow to 45,000 by the end of the century (Dominion of Canada, 1825; Fougères & MacLeod, 2017; MacKinnon, 2005). By the 1840s, the population of Saint Antoine was 70% Catholic (Ethnoscop, 2004). By the mid-1800s, Saint Antoine was increasingly urbanized with single family homes being constructed and individual lots being re-zoned (MacKinnon, 2005).

In 1799, the city of Montreal discontinued burials within the old city's walls, and the Saint Antione Catholic cemetery opened, with the cemetery's first burial being that of Claire Petit on December 25, 1799 (Ethnoscop, 2014; Fougères & MacLeod, 2017; Mondou, 1887; Ville de Montreal, 2002). The land for the cemetery was purchased from Pierre Guy, a merchant and member of the Legislative Assembly (Mondou, 1887; Ville de Montreal, 2002). Neighbouring cemeteries were also established for Montreal's Protestant and Jewish communities (Fougères & MacLeod, 2017). Saint Antoine cemetery's opening was predicated by two main factors: the urban expansion of Montreal leading to an increased fear of contagion, particularly when said expansion encroached on already-existing burial grounds as had happened in the old city, as well as the growing popularity of and fascination with rural cemeteries (Fougères & MacLeod, 2017; Mondou, 1887). At the time that the cemetery opened, the area surrounding it consisted largely of rural fields and orchards, therefore making it a suitable location for a new burial ground (Figure 6) (Charland, 1801 cited in Ethnoscop, 2004; Ethnoscop, 2004; Ville de Montreal, 2002). The cemetery continued to expand throughout the period of its use to keep up with demand, and neighbouring lots were purchased in 1807, 1823, and 1842 (Figure 7) (Ethnoscop, 2004; Ville de Montreal, 2002). When the old city walls were removed in 1817, population growth and rapid urbanization quickly overtook Saint Antoine, encroaching on the burial grounds. City maps from 1825 and 1846 reflect this rapid construction and urban expansion in Saint Antoine and the areas immediately surrounding the cemetery (Figure 8) (Figure 9) (Adams, 1925 cited in Ethnoscop, 2014; Cane, 1846 cited in Ethnoscop, 2014). Discussions regarding the potential closure of the cemetery first began in the 1840s (Ethnoscop, 2004). In 1854, the cemetery officially closed due to overcrowding and its proximity to residences (Mondou, 1887; Watkins, 2002). In response to the closure of Saint Antoine, Notre-Dame-des-Neiges cemetery opened on Mount Royal in 1854 and became established as the primary burial ground for Montreal (Mondou, 1887; Watkins, 2002).

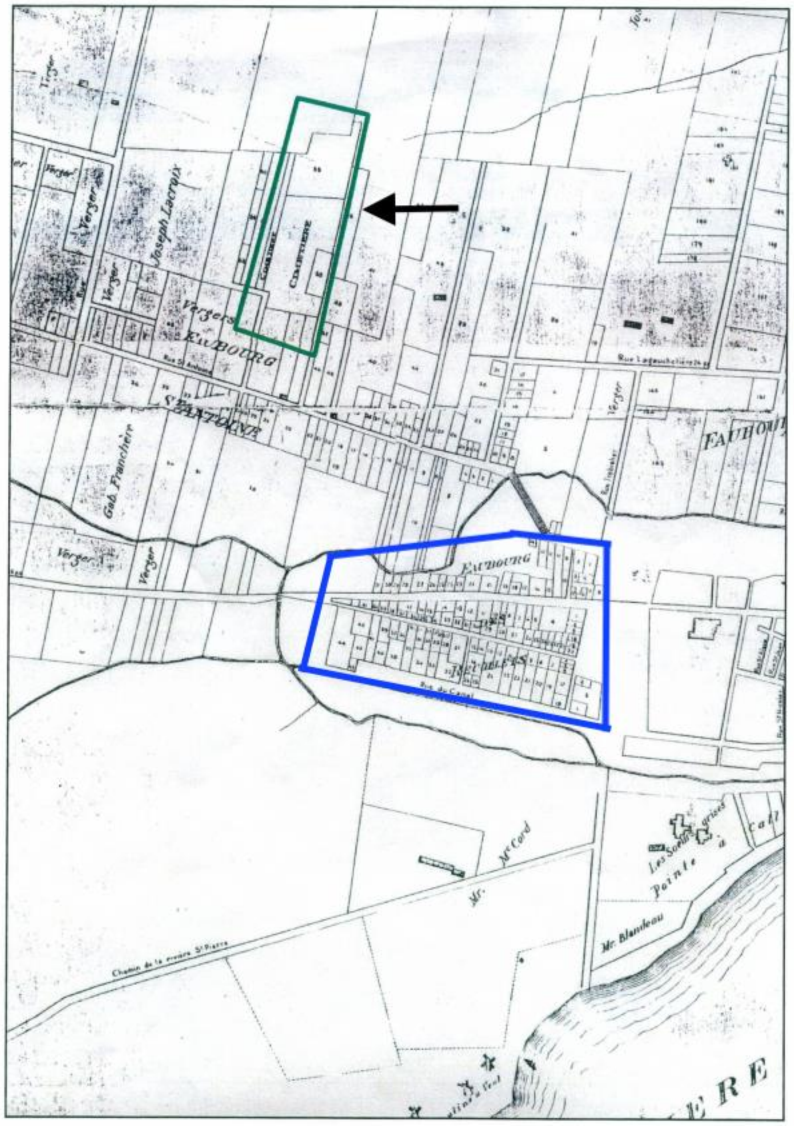

Figure 1: Map illustrating Saint Antoine cemetery's location in 1801 in reference to surrounding buildings. The cemetery’s location is indicated in green and by an arrow. Note the difference in density between the area surrounding Saint Antoine in the north and the Old City (outlined in blue) in the south. The areas surrounding the cemetery are much less densely constructed, consisting of large, rural plots of land, while the Old City demonstrates a much higher density. Adapted from Charland, 1801 cited in Ethnoscop, 2014.

Figure 2: Schematic map demonstrating land use of Saint-Antoine cemetery between 1799 and 1824. Land purchased from (1) Pierre Guy in 1799, (2) Augustin Lemieux in 1799, (3) Marie Magdalene Bourget in 1800 (4), Jean-Baptiste Champeau (1807), (5) the Pierre Guy Estate in 1812, and (6) Paschal Persillier in 1824 are all included. Cemetery limits are outlined in a dashed line. Adapted from Ethnoscop, 2004.

Figure 3: Map illustrating the location of Saint Antoine cemetery in 1825 in reference to its surroundings. The cemetery is outlined in green and indicated by an arrow. Black shapes represent human-made structures, including but not limited to homes and churches. Note that much of the area surrounding the cemetery still consists of large, rural plots of land, with little construction. From Adams, 1925 cited in Ethnoscop, 2014.

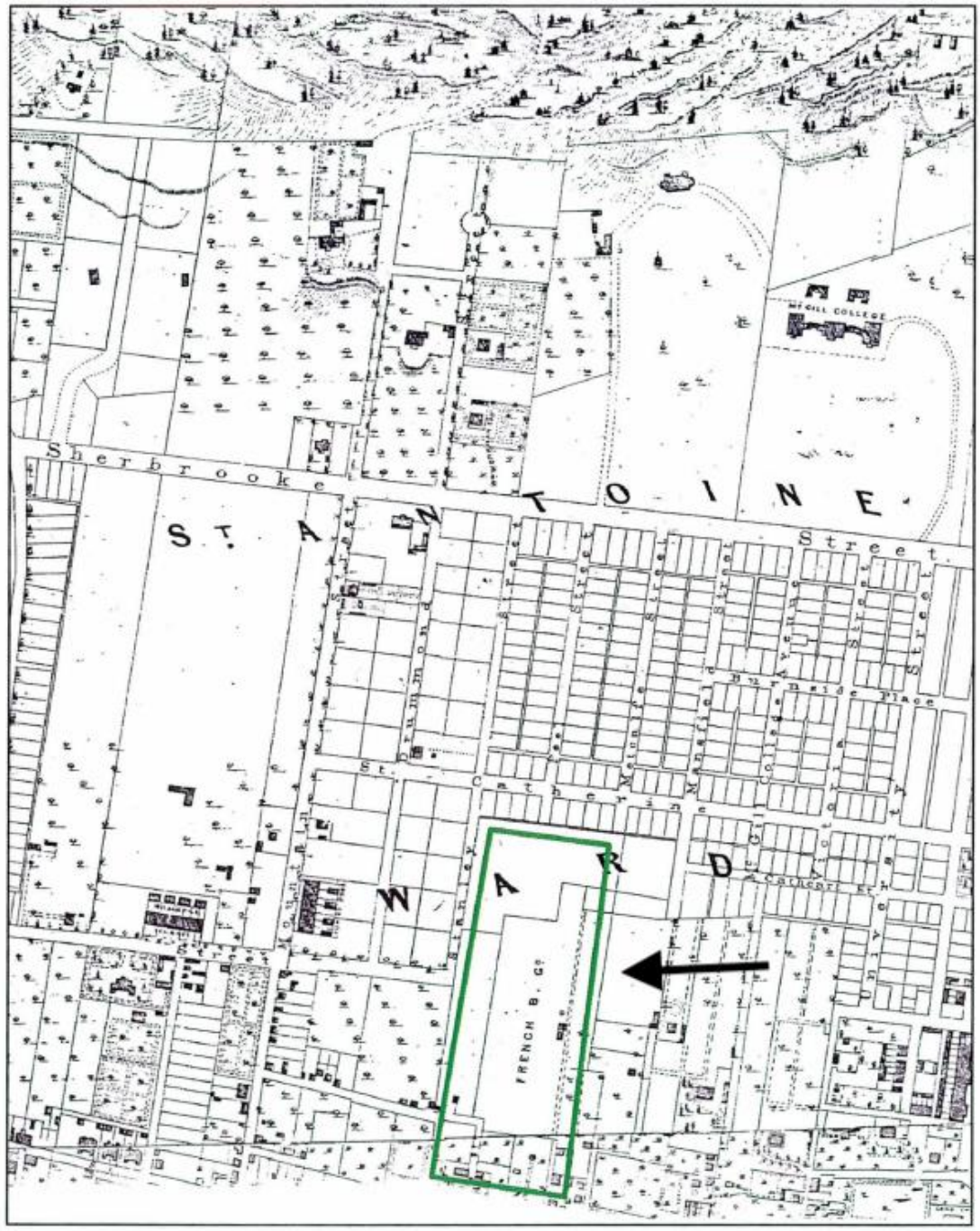

Figure 4: Map indicating the location of Saint Antoine cemetery in 1846 in reference to buildings surrounding it. Saint Antoine cemetery is outlined in green and indicated by an arrow. This map shows a much higher density of the area immediately surrounding the cemetery when compared to earlier maps (see Figures 7, 8). Surrounding buildings consist primarily of row houses. The southern slopes of Mount Royal can be seen in the very top portion of the map. From Cane, 1846 cited in Ethnocop, 2014.

During its use, Saint Antoine was a modest and simple burial ground, with few to no monuments or commemorations aside from a cross planted in the southwestern part of the lot; tombstones were only erected after 1811. Additionally, much of the cemetery was left free of trees and shrubs (Ethnoscop, 2004). In 1807, a chapel and caretaker's home were constructed on the property (Bourder, 1807 cited in Ethnoscop, 2014).

Records from Saint Antoine are limited, but regulations outlined for Notre-Dame-des-Neiges cemetery (AD 1854-) at the time of its opening may provide some indications of what regulations were enforced at Saint Antoine. Notre-Dame-des-Neiges allowed for 50 square foot family plots, individual plots that may be used for a maximum period of 30 years, mass graves (or graves where more than one individual was interred) were permitted for those who were entitled to a Catholic burial but for whom payment was not made, as well as a separate piece of land that could be used for ordinary pits (individual burials, likely for the wealthy) where monuments were permitted. This final plot of land used for ordinary pits would have been further divided into two sections: one for adults and the other for children. Based on these regulations, one can infer that the richest were able to be buried in ordinary pits on permanent lots where they would be able to erect monuments, while the poor would be buried anonymously in mass graves (Ethnoscop, 2004). Further, it was typical of Montreal cemeteries at the time to divide themselves into two sections: one for those who died "in possession of their religious state" and another for those who died in a "purely civil state" and as such were not entitled to an ecclesiastic burial (Ethnoscop, 2004, p. 25). Children who died before they could receive their baptismal rites along with Catholics who were public sinners would have been included in this second group (Ethnoscop, 2004).

Plans from 1821 for Saint Antoine cemetery indicate the presence of two pieces of land reserved for those who were denied ecclesiastic burial, and while the identity of the individuals buried within these distinct areas is unknown, the larger of the two plots was likely reserved for infants who died before their baptism (Turgeon, 1821 cited in Ethnoscop, 2004). Archaeological surveys indicate that most burials in Saint Antoine were ordinary pits that were paid for, but reused after seven years, along with mass graves consisting of many anonymous burials (Ethnoscop, 2004). This reflects the

general SES of those who made use of the cemetery, suggesting they belonged to the middle- or lower-classes rather than the upper-class who could afford more elaborate and permanent individual burials.

Archaeological evidence, as well as evidence from cemetery and church records, provide no indication of mass death among infants or children, although the records kept by a parish officer who attended burials note that, of the 1,287 graves attended in 1844, 629 involved the free burial of adults and children. Of these simple burials, the parish officer stated that 75 were adult burials while 441 were child burials (Ethnoscop, 2004). It should be noted that the total of these child and adult burials does not equate to the 629 burials the parish officer allegedly observed. It is unclear what the other 110 burials consisted of, though the burials totaled here demonstrate that many of these free burials were for children. This further reflects the high rates of infant and child mortality that were prevalent throughout Montreal during the nineteenth century, as noted elsewhere (e.g., Carpenter, 1869; Hall, 1847). There is no evidence of disease epidemics, such as the typhus and cholera outbreaks from the first half of the nineteenth century, either within the limited cemetery records or within the cemetery layout. In its first year of operation, Saint Antoine saw 342 burials. Annual burials steadily increased throughout the cemetery's operation, and in the year of its closure, there were 3,210 burials (Figure 10). Overall, a total of about 54,000 individuals would be buried at Saint Antoine while it was in operation (Ethnoscop, 2004).

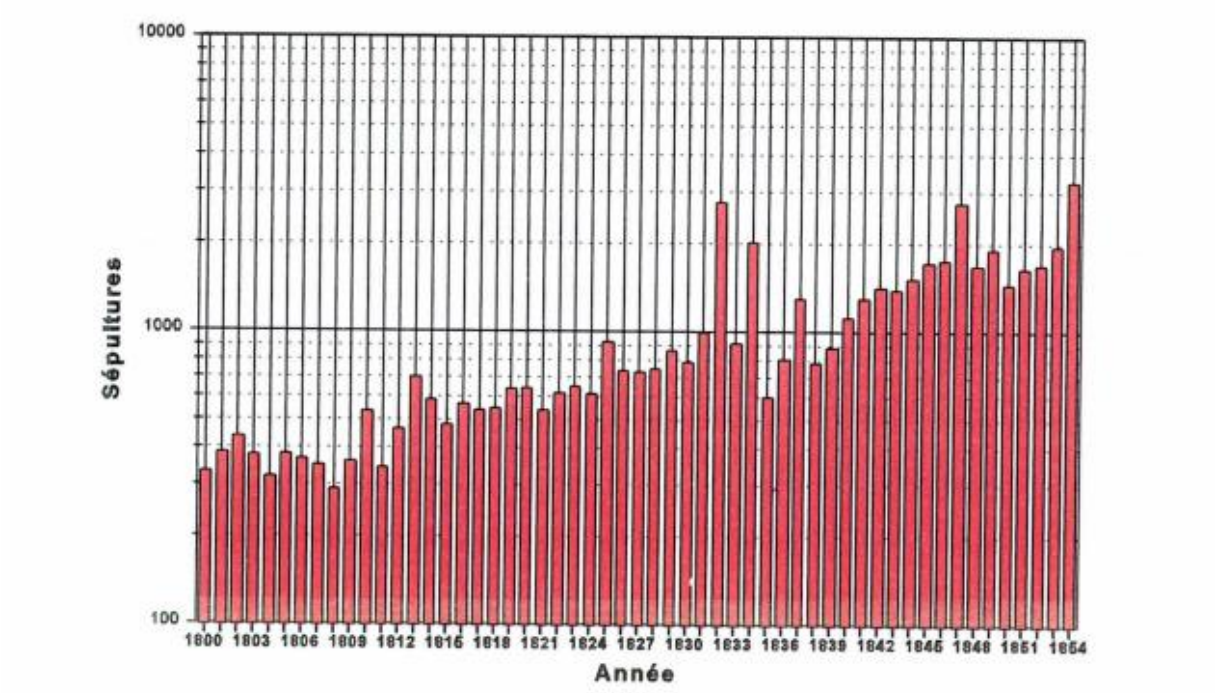

Figure 5: Quantity of burials from the parish of Notre-Dame in Montreal for each year from 1800-1854. Sèpultures=burials, année=year. From Ethnoscop, 2004.

Archaeological surveys from 2004 observed that most individuals were buried in coffins, and oriented north-south (Ethnoscop, 2004). However, due to poor preservation, observations regarding the size, shape, and construction of the coffins are limited. From the few graves that allowed for analysis of the coffins, it was determined that individuals were interred in simple, undecorated coffins that possessed no handles or hinges. Rather, the lids were likely nailed on (Ethnoscop, 2012). There is no evidence of any individuals having been buried without a coffin (Ethnoscop, 2012). Individuals were buried in an extended position, lying on their back, with the most common orientation of the forearms being extended at the deceased's side (Ethnoscop, 2012). Burials were found to be of low-depth, and the density of mass graves was expressed vertically, with individuals being buried on top of one another rather than next to each other (Ethnoscop, 2004). Additionally, there was a lack of artifacts associated with burials, and most artifacts that were found were determined to have been associated with the clothing the deceased wore at the time of burial, such as buttons (Ethnoscop, 2012). One sub-area, 25C (located in the original plot of land purchased in 1799), had some associated grave markers, indicating that individuals buried within this area might have been of slightly higher SES

(Ethnoscop, 2012). These characteristics of simple burials with very little to no ornamentation again supports the general low SES of by individuals interred at Saint Antoine.

Following its closure, the City of Montreal originally intended to rezone Saint Antoine cemetery and sell the lots (Ethnoscop, 2004; Ville de Montreal, 2002). The city began to exhume and relocate burials beginning in 1856, first removing the gravestones and then beginning to remove the burials themselves to relocate them to Notre-Dame-des-Neiges cemetery (Ethnoscop, 2014; Ville de Montreal, 2002). However, public fear that exhuming the bodies would cause disease outbreaks, along with further recommendations from the Sanitary Association, halted those plans (Mappin, 1995; Watkins, 2002). In 1869, the Sanitary Association recommended that the land be used for a public park, with the remaining bodies being left where they lay (Mappin, 1995). Since the 1880s, the site has served as a public park, formerly as Dominion Square, and now as Place Du Canada and Dorchester Square.

The individuals in this sample were excavated from the site during the restoration and renovation of the park beginning in the early 2000s and ending in 2019 and were largely buried within the original plot of land purchased for the cemetery in 1799, with a smaller number of individuals being buried in land purchased in 1807 and 1812 (Arkéos, 2008; Arkéos, 1997; Ethnoscop, 2012; Ethnoscop, 2014). In addition, some sub-operations, including sub-operation 17Z and 25C (both located within the original plot of land purchased in 1799), demonstrate a high number of burials, indicating that those portions of the cemetery experienced a high level of burial and activity during their use (Ethnoscop, 2012). Sub-operation 17Z demonstrated a significant amount of scattered bone, both within and outside the boundaries of burial/exhumation, with a large number of these scattered bones coming from babies, infants, and fetuses (Ethnoscop, 2012). Uncovered graves were cleared, recorded, and collected by means of detailed notetaking, altimetric and planimetric photographic documentation, along with descriptive sheets (Ville de Montreal, 2002). The sample is currently housed at the University of Montreal.

Given what is known about the cemetery, individuals in this sample are expected to be French-Canadians of middle to low SES. It is possible that mothers belonging to this group participated in the workforce, and as such may have been minimally available for breastfeeding (Thornton & Olson, 1991). As a result, infants within this population may have been weaned earlier than infants from other contemporaneous populations, if they were breastfed at all. Early weaning onto unsuitable breastmilk alternatives, such as pap or gruel, contributed to higher rates of infant morbidity and mortality due to the increased risk of infectious disease associated with weaning, as well as associated nutritional deficiencies (Knodel & Kintner, 1977; Thornton & Olson, 1991; Thornton & Olson, 2011). The prevalence of infant morbidity and mortality as associated with early weaning will be tested within this population using stable isotope analysis of $\delta^{15}N$ and $\delta^{13}C$ in dentine.

3.2 Dental Scoring and Sample Selection

Ethical approval for this course of study was obtained from the Non-Medical Research and Ethics Board at Western University in London, Ontario (Appendix 1).

Dental inventories of subadults within this sample were collected using the methods outlined by Buikstra and Ubelaker (1994). Caries, calculus, enamel defects, development, and dental wear were recorded alongside measurements of crown height, medio-distal diameter, and buccal-lingual diameter. Dental development for deciduous teeth was determined following the methods outlined by Liversidge and Molleson (2004). Additionally, where age-at-death had not already been recorded by the University of Montreal, it was estimated based on dental development and eruption (Buikstra & Ubelaker, 1994; Ubelaker, 1989; White & Folkens, 2005). Dental scoring was recorded in Microsoft Excel, as well as on paper.

Initially, it was expected that 59 subadults aged from birth to 15 years of age would have dentition sampled for the purposes of this study. However, upon arrival to the University of Montreal, it became evident that only 38 subadults had dentition suitable for sampling and collection, with the remaining 21 lacking any associated dentition. As such, a total of

38 subadult samples were collected and brought to Western University for subsequent analysis.

To ensure that samples captured the earliest months of life, and the greatest amount of dentine, preference was given to elements that begin development early in life. These selections were made based on dental development and eruption as outlined in White and Folkens (2005), Ubelaker (1989), and Buikstra and Ubelaker (1994). Sampling methods differed for children under the age of two years and children over the age of two years. For children younger than two years, deciduous teeth that began development *in utero* were prioritized as these are most likely to capture the early months of life when breastfeeding was most likely to occur. For children over the age of two years, adolescents, and adults, permanent teeth are the most suitable for analysis (Figure 11). Where the first preferred element was not present, or was otherwise damaged, then the second would be selected, and so on. Upper dental elements were additionally prioritized over lower elements, as maxillary teeth have a range of development that is typically a few months longer than the corresponding mandibular teeth (White & Folkens, 2005). This slight difference in development means that maxillary dentition is more likely to capture a greater period of development, including those early months of weaning. There was no preference for elements from the right or left side.

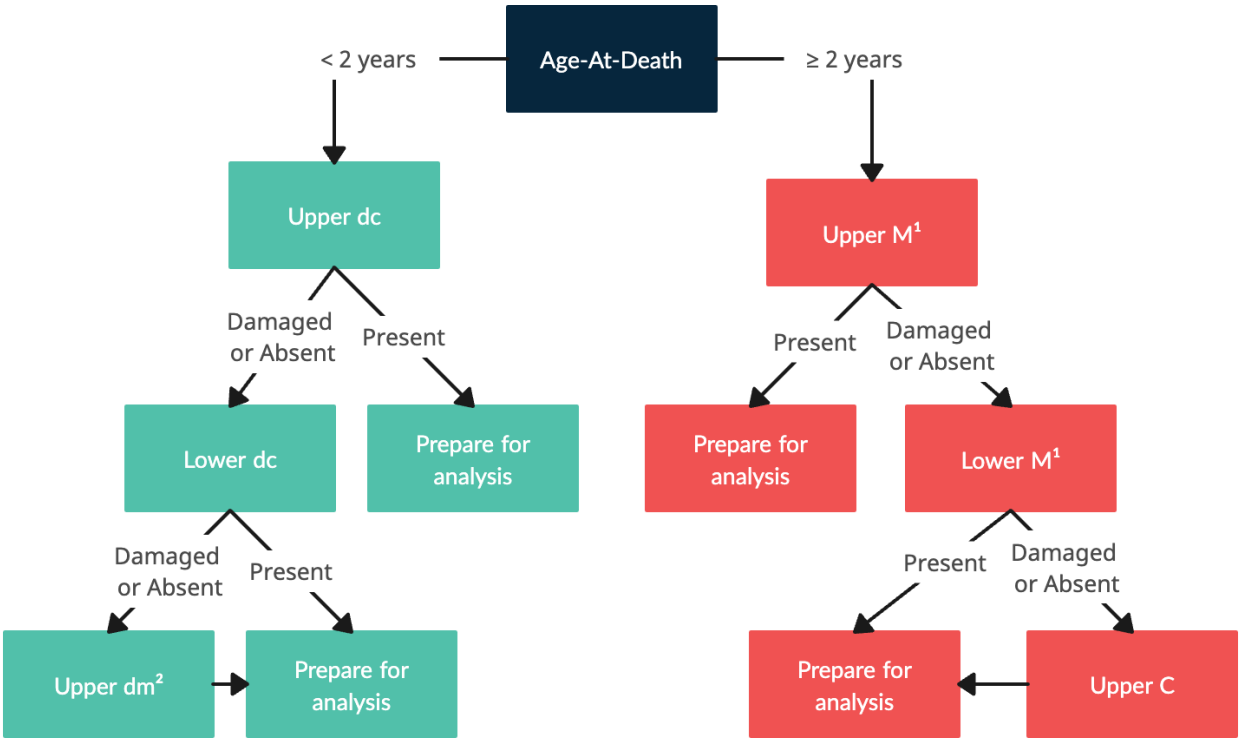

Figure 6: Order of preference for sampling subadult teeth. M^1 refers to the First Permanent Molar, dc refers to the deciduous canine, dm^2 refers to the second deciduous molar, and C refers to the permanent canine.

A portion of the dentition associated with individuals in this sample consisted of unerupted tooth cusps, which might have appeared alongside other, more developed, dentition. In these cases, although the first preference might have been present as a tooth cusp, a more developed tooth would be collected as it contains more dentine and as such more material to analyze. To preserve as much archaeological material as possible, only one dental element was collected per individual (Table 2). All dental elements were photographed at the time of sampling, prior to serial dentine sectioning and stable isotope analysis. Some elements were not selected for isotopic analysis due to being underdeveloped, or too small. In total, 21 dental samples from subadult individuals were analyzed with mass spectrometry.

Table 2: List of dental elements collected from each subadult for consideration for isotopic analysis.

Burial ID	Age at Death	Dental Element Sampled	Side	Stage of Development	Selected for isotopic analysis?
8JS4.2	1 year +/- 4 months	Upper deciduous canine	Right	9	No
20T-S1	12 years +/- 1 year	Upper deciduous central incisor	Right	14	Yes
10A-S3(2)	6 years +/- 1 year	Upper Permanent First Molar	Left	9	Yes
25C-S19	4 years +/- 1 year	Upper deciduous central incisor	Right	13	Yes
21E-S14	5 years +/- 1 year	Upper Permanent First Molar	Left	11	Yes
24G-S1	2.5 years +/- 6 months	Upper deciduous canine	Right	12	Yes
25C-S73	9.5 years +/- 6 months	Lower Permanent First Molar	Right	10	Yes
20E-S10	20 years +/- 2 years	Upper Permanent Canine	Right	14	Yes
S31	10 years +/- 1 year	Upper Permanent First Molar	Right	10	Yes
21U-S6	8 years +/- 1.5 years	Upper deciduous first molar	Left	9	Yes
9M-S1	Birth-1.5 months	Upper deciduous second molar	Right	3	Yes
10A-S2	11 years +/- 6 months	Upper Permanent Canine	Left	12	Yes
17L-S4	1 year +/- 4 months	Upper deciduous canine	Right	6	No
21N-S11	7.5 months +/- 2 months	Upper deciduous canine	Check	9	
21N-S12	7.5 months +/- 2 months	Upper deciduous canine	Right	6	Yes
21N-S3	8 months-1 year +/- 4 months	Upper deciduous central incisor	Right	11	No

24H-S2	12 years +/- 2.5 years	Upper Permanent First Molar	Right	13	Yes
20C-S1	15 years +/- 3 years	Lower Permanent Central Incisor	Right	14	Yes
20Z-S5	3 years +/- 1 year	Lower deciduous canine	Right	12	No
20F-S39	6 months +/- 3 months	Upper deciduous central incisor	Left	10	Yes
21E-S4	3 years +/- 6 months	Upper deciduous canine	Right	12	Yes
20F-S31(2)	18 months +/- 6 months	Upper deciduous central incisor	Left	9	Yes
30R-S7	8 years +/- 1 year	Upper Permanent First Molar	Left	7	Yes
21E-S8	11 months +/- 2 months	Upper deciduous canine	Left	7	Yes
20F-S25	40 weeks +/- 4 weeks	Upper incisor	Right	2	No
21R-S5	5.5 years +/- 6 months	Upper deciduous first molar	Left	13	Yes
20A-S3	3 years +/- 6 months	Upper deciduous first molar	Right	11	Yes
9M-S3	7 months +/- 1 month	Upper deciduous first molar	Check	5	No
17T-S1(2)	8.5 years +/- 6 months	Upper deciduous second molar	Right	9	Yes
17T-S3	35 weeks in utero +/- 5 weeks	Lower deciduous central incisor	Left	5	No
17Z-S2(1)	10 years +/- 1.5 years	Upper First Premolar	Right	13	Yes
20F-S1	2 years +/- 6 months	Upper deciduous lateral incisor	Right	12	Yes
21F-S5(1)	4.5 years +/- 6 months	Upper Permanent First Molar	12	6	No
25C-S9	12.5 years +/- 6 months	Upper Permanent Canine	Right	11	Yes
17Z-S2(2)	1 year +/- 6 months	Upper deciduous canine	Right	9	Yes

20F-S6	1 year +/- 6 months	Upper deciduous central incisor	Left	10	Yes
20F-S9	3 years +/- 12 months	Upper deciduous lateral incisor	Right	12	No
20F-S2	6.5 years +/- 6 months	Upper Permanent First Molar	Right	13	Yes
21N-S2	7.5 months +/- 6 months	Upper deciduous canine	Left	6	No

To contextualize the results of the subadults within this sample, an additional 11 adult females aged between 16 and 30 years were sampled. The research plan had accounted for the sampling of recently formed alveolar bone from around the third molar (M^3), as this would capture an individual's recent diet from the last few years of life. There was no preference for mandibular or maxillary, nor right or left. However, as seen in the subadults lacking associated dentition, not all 11 adult females had associated alveolar bone. When there was no alveolar bone associated with the M^3, the M^3 itself would be collected, as its last formed dentine layers contain a record of diet from early adulthood (~18-22/23 years) (Ubelaker, 1989). If there was no alveolar bone or M^3, then a sternal rib end would be collected which should give a record of diet over the last five or so years of life (Hedges et al., 2007; Tsutaya & Yoneda, 2015). If none of those options were available, then a portion of a long bone with large amounts of trabecular bone would be collected which should also hold a dietary record from the preceding 5 or so years depending upon tissue remodeling rates (Figure 12). One individual lacked all these options so was not sampled. Thus, in total 10 adult females had tissues suitable for sampling: six had alveolar bone, one an M^3, two had sternal rib ends, and one had a long bone fragment with trabecular bone (Table 3). All samples were photographed prior to collection.

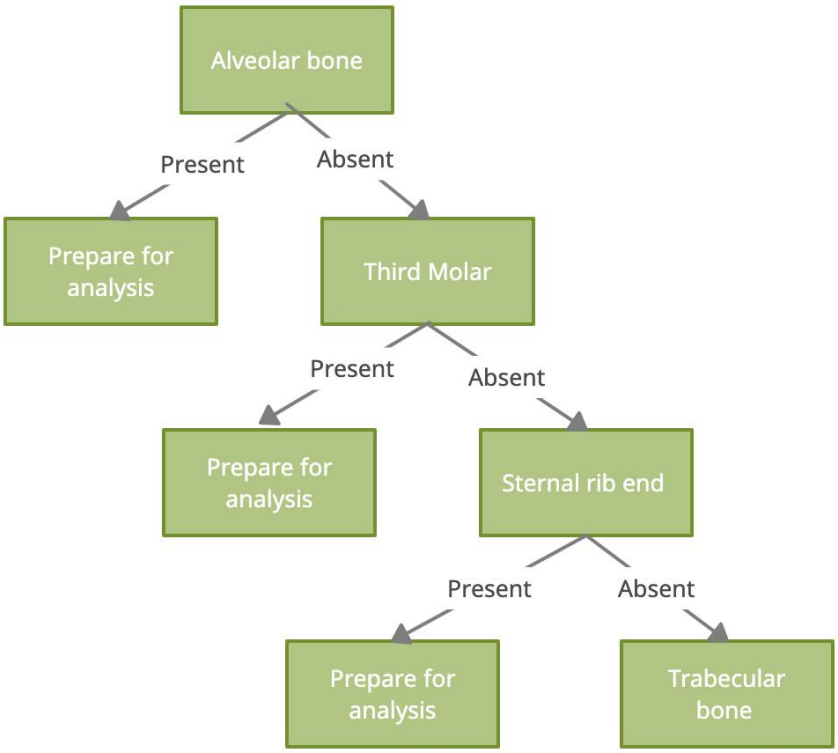

Figure 7: Order of preference for sampling adult females.

Table 3: Samples for 10 adult females for isotopic analysis.

Burial ID	Age (years)	Element Sampled
20C-S23	20-30	Right humeral head
12C-S1	20-29	Sternal rib end
21M-S6	20-29	Left maxillary alveolar bone
23E-S10	16-29	Sternal rib end
17Z-S6	18-29	Right maxillary alveolar bone
9M-S2	18-20	Left mandibular alveolar bone
20A-S13	16-29	Left mandibular alveolar bone
23B-S2	20-30	Right mandibular alveolar bone
22A-S1	20-29	Upper Third Molar
20C-S6	20-29	Right mandibular alveolar bone

Chapter 4

4 Methods

This chapter will outline the methods used in this course of study, including those used to detect and measure dental pathologies like enamel defects and dental caries. It will also detail laboratory procedures used to clean and demineralize samples prior to mass spectrometry, in addition to describing dentine sectioning procedures, before concluding with a short discussion of mass spectrometry.

4.1 Dental Pathology

4.1.1 Enamel Defects

Measurements of LEH were taken from the cementoenamel junction (CEJ) to the part of the defect that was closest to the CEJ (i.e., the last forming aspect of the enamel defect). For defects such as vertical grooves and other enamel defects that do not occur horizontally, this means that age-at-formation was calculated based on when the defect would have finished forming, i.e., when the stress event was resolved. LEH and other defects that formed within 3-4 months of each other were grouped together as one stress event. Measurements were collected using Hillson-Fitzgerald dental calipers and recorded to 2 decimal places.

The age-of-resolution for each horizontal enamel defect was calculated based on Reid and Dean's (2006) paper on human enamel formation, in which they assessed tooth growth in a Northern European population. This method is histologically derived and produced a decile-based chart. Dabrowski et al. (2021) tested multiple methods of aging LEH formation and found that, for LEH formed around 2-3 years of age, different methods yielded similar results. However, for LEH formed early or late in life, differences became more pronounced (Dabrowski et al., 2021). Dabrowski et al. (2021) produced a tool to estimate the age-at-formation for LEH based on data from Henriquez and Oxenham (2019) along with Reid and Dean (2006) using exponential regression

equations. Ages produced here using the method from Reid and Dean (2006) were checked using the method from Dabrowski et al. (2021) to ensure accuracy. The method put forward by Dabrowski et al. (2021) only accounts for LEH the on anterior teeth (central and lateral incisors, canines), and so age of resolution for defects on premolars were calculated using Holt et al. (2012). Reid and Dean (2006) included molars in their study, so was used herein to estimate age-at-resolution of enamel defects on molars.

4.1.2 Dental Caries

Dental caries was assessed and recorded for each individual and each individual tooth. The location and type of caries was recorded according to Buikstra and Ubelaker (1994), using their numerical scale of classification from 1-7.

4.2 Laboratory Methods

4.2.1 Cleaning and Sample Preparation

Bone samples and teeth were transported to Western University in London, Ontario, and first processed in Bioarchaeology Chemistry Lab in the Department of Anthropology. The 10 adult female samples were cleaned via sonication in distilled water (dH_2O) for a minimum of 8 minutes and left to air-dry for minimum of 24 hours. Samples that required more cleaning were sonicated for multiple 8-minute intervals until sufficiently clean (e.g., sonicated water lacked discolouration or sediment). Alveolar bone collected from 21M-S6, 17Z-S6, and 9M-S2 were too fragmented to undergo sonication, and as such were removed from the cleaning process. Subadult teeth were cleaned using the same techniques as the adult female bone samples and left to dry for a minimum of 24 hours. Dried teeth and bone samples were weighed prior to subsequent sample preparation. The tooth collected from 20F-S25 was fragmented, and further unlikely to contain any viable dentine. As such, this sample was removed from this course of study, but has been retained for potential future analyses.

Dried and weighed teeth were then embedded in resin. Teeth were oriented within plastic moulds to ensure that the roots were parallel with one side of the container, and that the

occlusal surface was parallel to the other. Teeth were laid on one surface within the container, either on the mesial, distal, buccal, or lingual surface (it was not necessary to have them laying on the same surface). A small number of tooth samples consisted of only the crown, and as such were oriented differently, with the occlusal surface oriented superiorly (upward), and the mesial-distal plane oriented parallel to two sides of the plastic mould. EpoThin 2 Epoxy Resin and EpoThin 2 Epoxy Hardener were combined in a dixie cup at a 5:1.95 ratio and then applied to the samples within the moulds. The tooth from 17L-S4 was already broken into mesial-distal halves at the time of sampling, so it was not necessary to embed it for sectioning. Once the remaining 36 teeth were embedded in resin, they were left for a minimum of 48 hours to ensure the resin had fully hardened, before being sectioned.

Embedded teeth were sectioned into mesial and distal portions of approximately equal size using an Isomet slow-speed saw. The portion with the most seemingly viable dentine was chosen for analysis. The portions not selected for analysis will be returned to the University of Montreal, where they will be kept for potential future analyses.

4.2.2 Demineralization

Samples collected from the subadults were removed from resin by soaking them in 100% acetone. Duration of acetone treatment ranged from 48 hours to 9 days, with acetone being changed approximately every 24 hours (acetone was thus changed anywhere from 2 to 9 times). Moreiras et al. (2022) found a small effect when acetone and other polar solvents were used to remove consolidated materials from samples when it was applied for more than 48 hours, with $\delta^{15}N$ increasing by up to 0.9‰ and $\delta^{13}C$ decreasing by 0.3 to 0.6‰. Meanwhile, other studies support the use of acetone to remove various preservation materials from bone and teeth (e.g., France et al., 2011; France et al., 2015). France and colleagues (2015) tested the effect of acetone, ethanol, and xylenes on modern whale bone samples embedded in common consolidates (Butvar B-98 and Paraloid B-72) and found that neither $\delta^{15}N$ nor $\delta^{13}C$ values were affected. Other tests of the effects of acetone on stable isotopes on both animal and human samples have found similar results, indicating that, while a small isotopic effect may occur, acetone is a safe

and appropriate solvent to use in the removal of resin from samples (Moore et al., 1989). Once removed from the resin and solvent, samples were air-dried for at least 24 hours, or until completely dry.

During the resin removal process, 10 samples became fragmented. I was not confident that crown and root could be distinguished if these samples were included in subsequent steps of demineralization, and as such elected to exclude these samples from the remainder of the research process. They may, however, be useful for future studies, and were retained for this purpose. The following steps thus applied to 26 tooth samples.

Macroscopic inspection of the teeth suggested they were well-preserved given the absence of post-mortem cracking, surface erosion, and discolouration (the discoloured tooth from 21U-S6 mentioned earlier was not chosen for isotopic analysis). The adult female bone samples also appeared to be well-preserved. While the macroscopic appearance of a bone or tooth does not necessarily indicate the presence or degree of chemical degradation (Turner-Walker, 2007), it is usually the indicator upon which the choice of chemical processing is based. Given the good macroscopic preservation of the teeth and bone samples, the ‘Sealy method’ was chosen as the best protocol to follow.

The ‘Sealy method’ is outlined in Sealy et al. (2014), which relies on the notion that, in well-preserved bones or teeth, demineralization is expected to produce a ‘pseudomorph’. A pseudomorph occurs because a sample’s mineral, or inorganic, component is lost during demineralization, leaving behind translucent and flexible collagen (which is expected to contain relatively large amounts of nitrogen) in roughly the same shape and size as the original sample (Schurr, 1998; Sealy et al., 2014). The presence of a pseudomorph is a good indication of the structural integrity of the sample, as demineralization of poorly preserved bones and teeth will not result in a pseudomorph; rather, the sample will disintegrate (Czermak et al., 2020; Sealy et al., 2014). The ‘Sealy method’ does not require subsequent processing by gelatinization/solubilization or ultrafiltration, steps which are used in other methods (e.g., protocols derived from the Longin method or when working with ground bone) and especially with poorly preserved samples (Jørkov et al., 2007; Longin, 1971). Thus, the ‘Sealy method’ is less labour-

intensive, while producing collagen yields of sufficient quantity that are equal to, or higher, than yields from methods that do include gelatinization/solubilization (Sealy et al., 2014).

The first step of the 'Sealy method' as applied to intact teeth was demineralization in a solution of, first, 0.5M hydrochloride solution (HCl), later shifting to a 1M and 2M HCl solution after the samples retained their shape so to accelerate the process. The intent was to make the tooth soft enough that it could be manually sectioned into ~1mm slices using a scalpel (described below). Teeth were soaked in HCl solution for several days/weeks, with the solution being changed approximately every 24 hours, until the demineralization process was complete. The length of time each sample was in the HCl solution varied, and as a result some were removed from the solution sooner than others. Once sufficiently soft, all samples were rinsed with dH_2O a minimum of five times, and then left to sit in dH_2O for at least a day.

Once sectioned, each ~1mm tooth slice was put into a 15mL vial where they received two additional 1M HCl washes to ensure all dentine mineral and inadvertently retained enamel were sufficiently removed. Samples were then rinsed in dH_2O a minimum of three times until they reached neutrality prior to being soaked in sodium hydroxide (NaOH) to remove any humic contaminants. This stage followed the protocol outlined in Czermak et al. (2020), with dentine samples being soaked in 0.125M NaOH for 30 minutes. Following the NaOH treatment, samples received an additional three or more dH_2O washes, until reaching neutrality. Samples were then left in dH_2O for a minimum of 24 hours until they could be packed for mass spectrometry.

Adult female samples were not embedded in resin, and as such did not necessitate acetone treatment prior to demineralization. The adult female samples were demineralized using a 2% HCl solution that was changed approximately every 24 hours. Following this, a 0.125M NaOH solution was applied to the bone samples for 20 hours, after which samples were removed from the NaOH solution and rinsed an additional five times with dH_2O before being left to soak in dH_2O for at least one more day. The use of NaOH to remove humic contaminants has been supported in various publications,

including Jørkov et al. (2007), which suggested that NaOH was more effective than ultrafiltration in the removal of humic contaminants. Any additional contaminants, such as rootlets, were carefully removed by hand using a scalpel and tweezers.

4.2.3 Serial Dentine Sectioning

Following initial demineralization, the remaining crown enamel of each tooth was carefully removed using a no. 23 scalpel blade and set aside in scintillation vials for potential future analyses. Next, the scalpel was used to remove ~1mm dentine slices following approximate developmental (growth) lines from root to crown (Figure 13). Thus, teeth were not sectioned horizontally, which would result in significant blurring between developmental increments. Following the pattern in which developmental layers of dentine are laid down, rather than using horizontal cuts, allows for a more precise analysis of diet during specific periods of time in an individual's life, though there is still some blurring between the different age points during the sectioning process (Eerkens et al., 2011). The number of sections yielded from each sample was dependent on a variety of factors such as tooth size (length), developmental stage, and overall preservation of the sample, with some yielding more sections than others. Dentine sections were chronologically and alphabetically labelled, with section 'A' representing the earliest stage of development in the crown portion of the tooth.

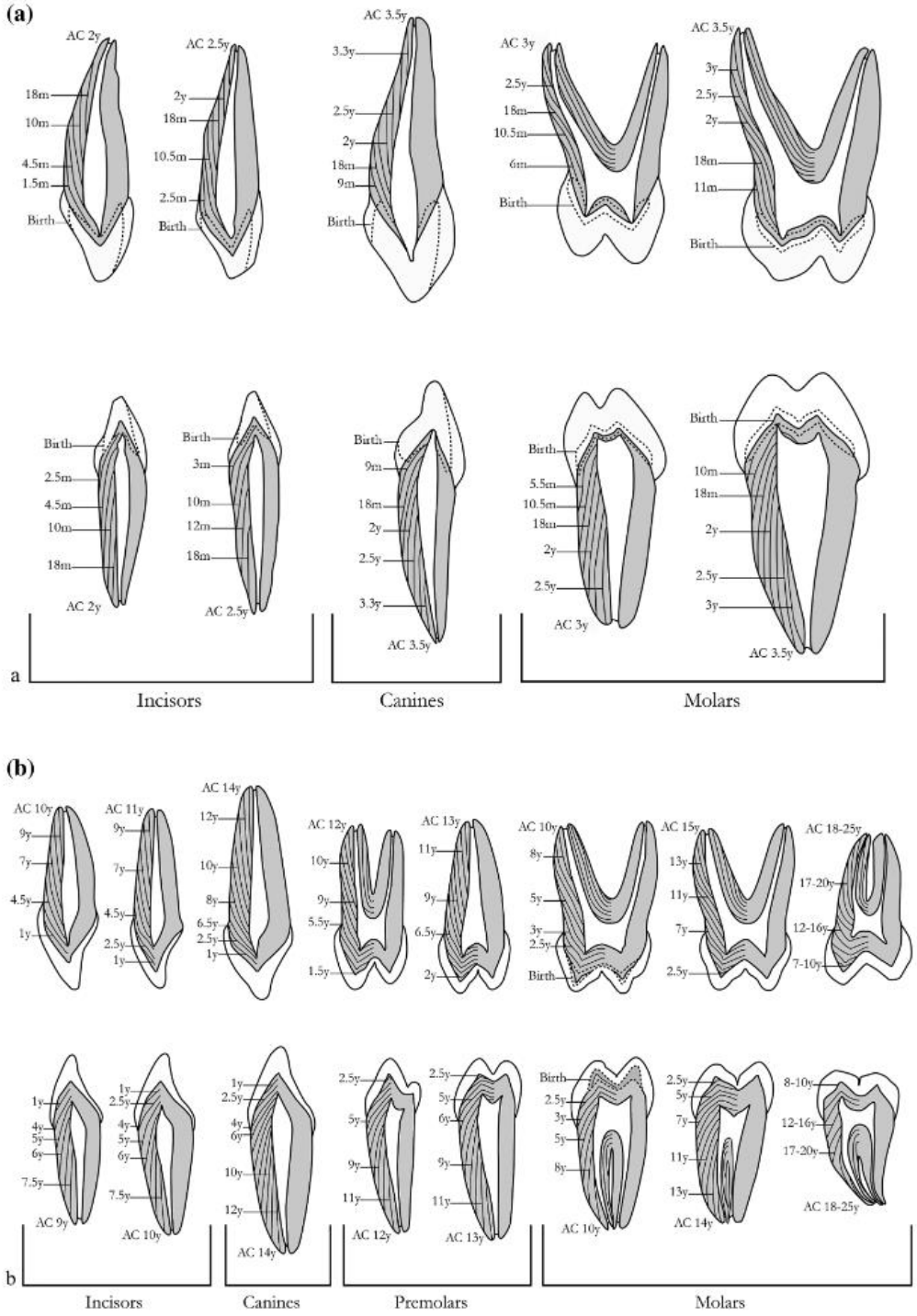

Figure 13: Incremental pattern of growth and approximate ages for mineralization of deciduous (a) and permanent (b) human teeth. Samples were sectioned approximately along increments of growth (indicated by solid lines). From Brickley et al., 2019: 347.

4.2.4 Mass Spectrometry

Following serial dentine sectioning, samples were prepared for mass spectrometry. Excess water was removed from the vials using a low-powered suction, and samples were then freeze dried overnight prior to being weighed into tin capsules for mass spectrometry.

A collagen yield of >2% is considered to indicate well-preserved collagen appropriate for stable isotope analysis, though other studies have found that collagen yields as low as 1% can still produce acceptable C/N ratios (Ambrose, 1990; Van Klinken, 1999). Collagen yields were calculated using the following equation:

$$collagen\ yield\ (\%) = \left(\frac{collagen\ weight\ (mg)}{dry\ sample\ weight\ (mg)}\right) \times\ 100$$

The range of collagen yields per tooth is 0.5% to 5.9%, with an average of 2.16% +/- 1.3, which are lower than would be expected in teeth of this age, although still acceptable. Low collagen yields could be the result of a wet burial environment, although specific information regarding the soil type at Saint Antoine could not be found. Thus, it cannot be concluded with any certainty whether the collagen yields were, indeed, affected by a wet burial environment. A collagen yield of 20% would be ideal.

Based on weight required for mass spectrometry (~0.36 mg), 21/26 teeth produced dentine sections with enough tissue to produce an acceptable weight and were chosen to undergo mass spectrometry. Dentine sections from the remaining 5 teeth had weights that were too low for mass spectrometry. Although 4 out of 21 samples demonstrated collagen yields below 1%, all 21 samples underwent isotopic analysis. Calculated collagen yields for subadult samples can be found in Table 4.

A Thermo Scientific Delta V continuous flow isotope ratio mass spectrometer coupled to Costech Elemental Analyzer was used for analyses of dried and weighed samples in the Laboratory for Stable Isotope Studies at Western University. Keratin, Szpak SRM-14, USGS-40, and USGS-41a were used as standards to calibrate isotope compositions. Duplicate samples were included approximately every 10 samples.

Table 4: Collagen yields for subadult tooth dentine samples.

Sample	Collagen Yield (%)
S31	1.7
20F-S1	1.07
25C-S9	5.9
17Z-S2(2)	0.82
24H-S2	0.81
20T-S1	2.16
25C-S19	0.5
20C-S73	3.4
21N-S11	3.24
20F-S39	4.06
21E-S8	3.14
21E-S4	1.31
17T-S1(2)	1.61
21E-S14	2.18
10A-S3(2)	0.69
20C-S1	1.85
21U-S6	2.19
30R-S7	1.49
20F-S2	1.73
20F-S6	2.27
20F-S31	3.3

Chapter 5

5 Results

This chapter will present results of analyses of enamel defects and dental caries among the subadults assessed for isotopic sampling. It will then present stable isotope results for the adult female sample, followed by the subadult sample with acceptable preservation indicators. Results for subadult samples with unacceptable isotopic compositions will then be presented. The chapter will outline the results of the standards packed into each tray, allowing for the mass spectrometer to be ruled out as a cause of the problematic results.

5.1 Dental Scoring

For full dental scoring results, including enamel defects, quantity of teeth present vs. absent, dental measurements, and carious lesion details, please see Appendix 2.

5.1.1 Enamel Defects

Enamel defects were recorded following the standards outlined by Buikstra and Ubelaker (1994). Of the 38 subadult individuals assessed, only 3 had enamel defects. These defects consisted of vertical and horizontal linear hypoplastic bands, linear horizontal pits, and non-linear pits. In terms of linear defects that can be measured to estimate age-of-formation or age-of-resolution (when the stress event ended), there were 2 LEH bands and 6 lines of horizontal pits. Individual 21R-S5 had the highest number of enamel defects (total=32), with a high occurrence of non-linear pits (n=30) alongside vertical hypoplastic bands (n=2). These defects affected 7 teeth in total. Individual 21E-S14 had 6 enamel defects, consisting of linear horizontal pits, affecting 2 teeth. Finally, the third individual with enamel defects, 20Z-S5, only had a single vertical hypoplastic groove (thus affecting 1 tooth). A more detailed quantification of observed enamel defects among these 3 individuals can be found in table 5 below. Linear defects were measured from the CEJ to the aspect of the defect appearing closest to the CEJ. For thin horizontal defects, this is reflective of the onset and resolution, and thus duration, of the stress event.

For non-horizontal defects, such as non-linear pits, this means that the measurements represent when the stress event resolved itself, rather than its onset (Buikstra & Ubelaker, 1994; Riztman et al., 2008).

Table 5: Prevalence of enamel defects in the three affected individuals. Legend for defect type: 1=linear horizontal grooves, 2=vertical grooves, 3=linear horizontal pits, 4=non-linear pits. CEJ=cementoenamel junction.

Sample	Age-At-Death	Tooth	Defect Type (1-4)	Quantity	Distance of apical extent from CEJ (mm)	Approx. Age of resolution (end of stress event)
20Z-S5	3 years +/- 1 year	Upper m2	2	1	235.32	2.5 years
21E-S14	5.5 years +/- 6 months	Lower left I1	3	2	235.45	4 years
		Lower left PM1	3	4	235.95	4.2 years
21R-S5	5.5 years +/- 6 months	Upper left M1	4	20	236.90	2.7 years
		Upper right M1	4	20	237.29	3 years
			1	1	239.80	2.8 years
		Upper left I1	1	1	239.98	3.8 years
		Upper right I1	4	2	240.74	4 years
			4	4	346.73	3.7 years
		Upper right C	4	4	241.80	4.6 years

From this, we can infer that individual 20Z-S5 experienced one stress episode that ended at 2.5 years of age. Individual 21E-S14 also experienced a single stress event that resolved around 4.0 to 4.2 years of age. Finally, individual 21R-S5 experienced three separate stress events evident as enamel defects, the first ending between 2.7 to 3.0 years of age, the second around 3.7 to 4.0 years, and the last around 4.6 years of age.

5.1.2 Dental Caries

The prevalence of dental caries is relatively low in this sample, with 10 out of 38 subadults (26%) exhibiting caries (Table 6). Of the 520 teeth that were observable and able to be assessed for the presence or absence of caries (i.e., not concealed within the crypt), 41 (7.9%) had caries. Of the 41 teeth affected, 13 (32%) were canines, 5 (12%) were incisors, 17 (41%) were molars, and 6 (15%) were premolars. There was little difference in the number of caries occurring in the upper vs. lower teeth, with 21 in the maxillary teeth and 20 affecting mandibular teeth. For the upper teeth, 6 (28%) of the 21 caries occurred in the canines, 4 (19%) were in the incisors, 8 (38%) were in the molars, and 3 (14%) were in premolars. Of the lower teeth with caries, 7 (35%) were canines, 1 (5%) was an incisor, 9 (45%) were molars, and 3 (15%) were premolars. Molars were the most affected tooth for both the maxilla and mandible.

Table 6: Dental caries for all affected individuals, including scoring type on a scale of 1-7. Legend for types of dental caries: 1=Occlusal surface, 2=Interproximal surface, 3=Smooth surfaces, 4=Cervical caries, 5=Root caries (below CEJ), 6=Large Caries, 7=N

Sample	Age-at-death	Tooth	Type (1-7)
30R-S7	8 years +/- 1 year	Upper right c	2
		Upper left i2	2
		Upper left c	2
		Upper left m1	2
		Lower right c	6
		Lower left c	2
		Lower left m2	6
20F-S2	6.5 years +/- 6 months	Upper left m1	2
		Lower right m2	2
		Lower left m2	6
24H-S2	12 years +/- 2.5 years	Upper right M1	1
		Upper right PM1	5
		Upper right C	2

		Upper left C	2
		Upper left I1	2
S31	10 years +/- 1 year	Upper right M2	2
20E-S10	20 years +/- 2 years	Upper right M2	3
		Upper right PM1	2
		Upper right I1	2
		Upper left I1	2
		Upper left C	2
		Upper left PM1	6
		Upper left M2	3
		Upper left M2	1
		Lower right M1	1
		Lower right M1	1
		Lower right PM2	5
		Lower right I2	2
		Lower left PM1	2
		Lower left PM2	2
		Lower left PM2	4
21E-S14	5 years +/- 1 year	Lower right m1	2
		Lower right c	2
		Lower left c	2
		Lower left m1	2
10A-S2	11 years +/- 6 months	Lower right M2	3
21U-S6	8 years +/- 1.5 years	Upper right M1	2
		Lower right m2	2
		Lower right c	2
		Lower right c	6
		Lower left c	2
		Lower left m1	2
20F-S1	2 years+/- 6 months	Lower left c	1
		Lower left c	3
21R-S5	5.5 years +/- 6 months	Upper right m2	2
		Upper right c	2

The majority of caries present in this sample (29/41 =71%) are on the interproximal surfaces (mesial and distal cervical regions). These most commonly occur on canines, with 11 occurrences, although molars follow closely with 10. Interproximal caries were slightly more common on the maxillary teeth (16/29 = 55%) than mandibular teeth (13/29 = 45%). The next most common caries location is the occlusal surface (5/29=17%). Large caries also occur in 5 individuals but the large size of these lesions precludes determination of the surface on which they originated. Occlusal surface and large caries

each represent 12% of the total. For caries on the occlusal surface, lower molars were the most affected (n=3). Large caries affected lower canines (n=2) and molars (n=2) equally, with one upper premolar also affected. Caries on smooth surfaces represent 0.5% of all caries and affected a lower canine and upper molar. Root caries (occurring below the CEJ) also represent 0.5% of all caries and affected an upper and lower premolar. Finally, there was only one (0.2%) instance of a cervical caries, affecting a lower premolar.

A deciduous first molar from 21U-S6 exhibited a blue-green tint (Figure 14). There was no associated trauma to the maxillary bone that may have caused the discouloration. Therefore, this could be caused by an interproximal caries that reached the pulp cavity, resulting in tooth death. There is no indication that this discolouration was the result of copper or other metal staining. The other possibility is that the discolouration is the result of the burial environment, although no other teeth from this individual, or within the greater sample, were discoloured in this way.

Figure 8: Deciduous first molar from 21U-S6 demonstrating blue/green tint. Interproximal caries is not pictured here.

5.2 Isotopic Results

5.2.1 Adult Female Values

Aside from 12C-S1 and 22A-S1, who had C/N ratios of 6.4 and 23.5 respectively, 4 out of 6 of the individuals in the adult female group demonstrated acceptable preservation and quality control indicators, including C/N ratios between 2.9 and 3.6 (DeNiro, 1985).

From these 4 individuals, the average $\delta^{13}C_{col}$ is –19.9 +/- 0.07‰ and the average $\delta^{15}N_{col}$ is +11.1 +/- 1.08‰. To account for collagen-diet offset, the adult female $\delta^{13}C_{col}$ may be corrected by –5‰ and $\delta^{15}N_{col}$ may be corrected by –3‰ (DeNiro and Epstein 1978, 1981; Keegan and DeNiro 1988; Moreiras et al., 2020). When isotopic compositions are corrected, the average $\delta^{13}C_{diet}$ is –24.9 +/- 0.07‰ and the average $\delta^{15}N_{diet}$ is +8.1 +/- 1.08‰. These values are consistent with a diet predominately consisting of predominantly C_3 terrestrial foods (Pfieffer et al., 2016). The $\delta^{13}C_{diet}$ values cluster closely together (range to –25.1 to –24.9‰) while the range of $\delta^{15}N_{diet}$ values is wider (+7.3 to 9.7‰). This suggests more variation in sources of dietary protein, whether from terrestrial animals at different trophic levels or because there was occasional consumption of aquatic foods (e.g., riverine or marine fish).

The Suess Effect, a phenomenon caused by burning of fossil fuels and deforestation following the Industrial Revolution, results in decreased $\delta^{13}C$ in atmospheric CO_2 and results in isotopically lighter (lower) $\delta^{13}C$ values in modern plants and animals when compared to archaeological plants and animals. To account for this effect when comparing stable isotope data from both modern and archaeological datasets, stable isotope compositions derived from modern samples were corrected by +1.6‰ (Morris, 2015; Yakir, 2011). Modern stable isotope compositions were only used where archaeological values could not be found. All archaeological isotopic compositions were measured from bone collagen, although marine fish values from Lesage et al. (2001) were measured using flesh tissue (muscle). As such, all $\delta^{13}C$ isotopic compositions collected from bone collagen were corrected by –2‰ in order to reflect flesh $\delta^{13}C$ (DeNiro & Epstein, 1981). There is no difference in $\delta^{15}N$ between bone collagen and flesh. These corrections make bone collagen directly comparable to flesh. Isotope data for archaeological samples, as well as the corrected modern samples, are plotted against adult female stable isotope results below (Figures 15 and 16). Full results for the adult females can be found in Table 7.

Figures 15 and 16 were made using data published elsewhere (references provided in figure titles). Foods that were likely consumed by this population, such as pig and cow, were included where data were available for the region. However, isotopic data for other

foods that were likely a part of the diet, such as chicken, turkey, duck, sheep, goat, were lacking and were thus not included in the calculation of the isotopic ranges of different food groups. Moreover, as animal by-products like butter, milk, and cheese are not typically archaeologically recovered, and thus not isotopically studied, they were not included. The studies that these data were retrieved from covered the geographical regions of the St. Lawrence River, southwestern Ontario, and Illinois.

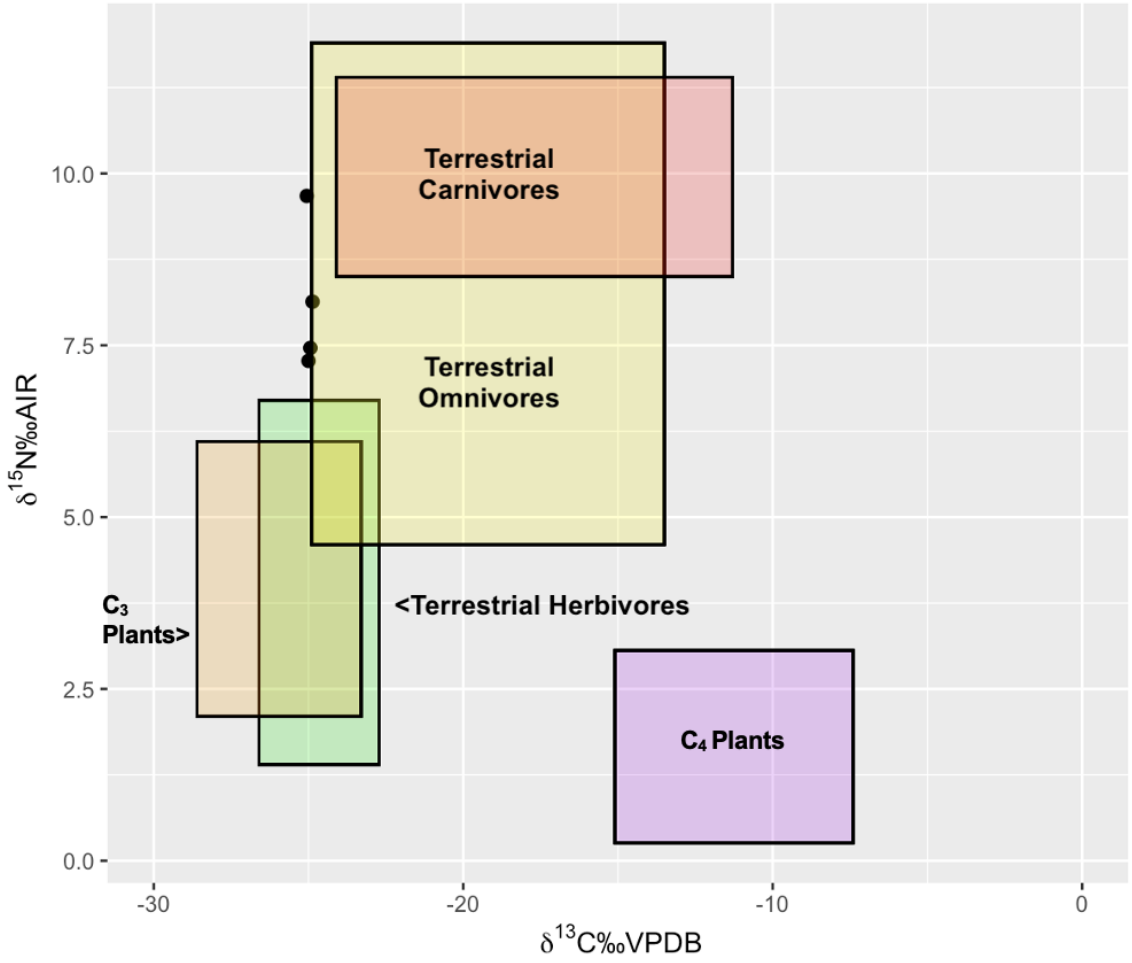

Figure 9: Stable isotope results for adult females with acceptable C/N ratios plotted against stable isotope data for C_4 (purple) and C_3 (orange) plants in Southwestern Ontario and Illinois, alongside terrestrial trophic groups in Ontario that consumed a mixed C_4 and C_3 diet (data from Glencross et al., 2022; Guiry et al., 2017; Morris, 2015;). Human $\delta^{13}C_{col}$ was corrected by –5‰ and $\delta^{15}N_{col}$ was corrected by –3‰. $\delta^{13}C$ from animal bone collagen was corrected by –2‰ (DeNiro & Epstein, 1981).

Data from modern samples were corrected by Morris (2015) by +1.6‰ in order to correct for the Suess Effect (Feranec and Hart, 2019; Morris, 2015).

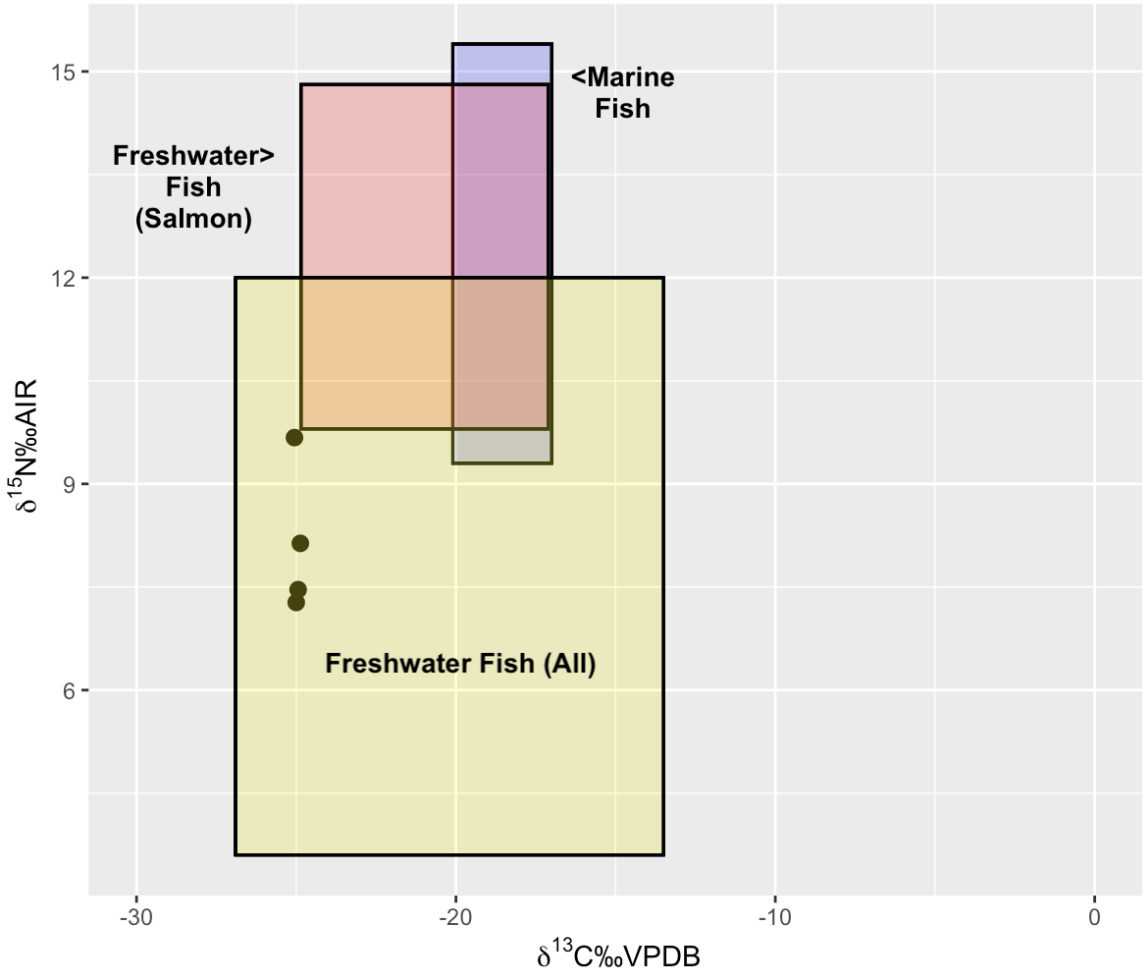

Figure 10: Stable isotope results for four adult females with acceptable C/N ratios plotted against stable isotope data for Atlantic marine fish (blue), freshwater salmon (red), and all freshwater fish (yellow) from the St. Lawrence River and Ontario rivers and lakes (data from Guiry et al., 2016; Hammersley, 2016; Lesage et al., 2001; Morris, 2015). Human $\delta^{13}C_{col}$ was corrected by –5‰ and $\delta^{15}N_{col}$ was corrected by –3‰ (DeNiro & Epstein, 1981). Data for modern marine fish from Lesage et al. (2001) were corrected by +1.6‰ to account for the Suess Effect.

Table 7: Mass spectrometry results for all adult females, including ages-at-death. This table includes those with C/N ratios outside of the accepted range.

Sample	Age-at-death (in years)	$\delta^{13}C_{col}$ (‰)	$\delta^{13}C_{diet}$ (‰)	$\delta^{15}N_{col}$ (‰)	$\delta^{15}N_{diet}$ (‰)	Carbon (%)	Nitrogen (%)	C/N ratio	Within accepted C/N ratio range?
20C-S6	20-29	–19.9	–24.9	+10.5	+7.5	40.64	14.70	3.2	Yes
25B-S2	20-30	–19.9	–24.9	+11.1	+8.1	38.40	13.23	3.4	Yes
20A-S13	16-29	–20.1	–25.1	+12.7	+9.7	38.32	13.30	3.4	Yes
12C-S1	20-29	–19.1	–24.1	+9.5	+6.5	16.95	3.11	6.4	No
20C-S23	20-30	–20.0	–25.0	+10.3	+7.3	39.63	13.81	3.4	Yes
22A-S1	20-29	–28.8	–33.8	–1.68	–4.68	59.98	3.07	23.5	No

5.2.2 Individual Results: 20C-S1

One individual (20C-S1) within the subadult sample yielded 5 sections (out of 9) with acceptable preservation indicators, suggesting that reliable stable carbon and nitrogen isotope compositions were obtained (Table 8; Figure 17). Dentine sections from this individual, who was approximately 15 years old at death, show a 0.5‰ increase in $\delta^{13}C$ between 4.0 to 11.5 years, and while the $\delta^{15}N$ values are somewhat variable, they do not demonstrate the same pattern. This suggests that the increase in $\delta^{13}C$ may be the result of the integration of more C_4 foods into the individual's diet, rather than an increase in the consumption of marine animal protein.

Table 8: Values for subadult individual 20C-S1. Note that this table includes values that are not acceptable, alongside acceptable values.

Sample	Age-of-dentine layer	$\delta^{13}C_{col}$ (‰)	$\delta^{13}C_{diet}$ (‰)	$\delta^{15}N_{col}$ (‰)	$\delta^{15}N_{diet}$ (‰)	Carbon (%)	Nitrogen (%)	C/N ratio	Within accepted C/N ratio range?
20C-S1(A)	1 y	–21.6	–26.6	+11.6	+8.6	39.74	14.10	3.2	Yes
20C-S1(B)	2.5 y	–22.3	–27.3	+11.0	+8.0	44.15	12.05	4.3	Yes
20C-S1(C)	4 y	–19.5	–24.5	+10.8	+7.8	32.85	11.50	3.3	Yes
20C-S1(D)	6.5 y	–28.8	–33.8	–2.9	–5.9	60.44	2.79	25.3	No
20C-S1(E)	8 y	–26.5	–31.5	+7.1	+4.1	54.10	6.59	9.6	No
20C-S1(F)	9.5 y	–19.3	–24.3	+11.8	+8.8	38.98	13.91	3.3	Yes
20C-S1(G)	11.5 y	–20.0	–25.0	+10.3	+7.3	40.50	14.10	3.4	Yes
20C-S1(H)	12 y	–28.5	–33.5	–0.4	–3.4	60.07	3.30	21.2	No
20C-S1(I)	14 y	–23.2	–28.2	+10.1	+7.1	46.46	10.71	5.1	No

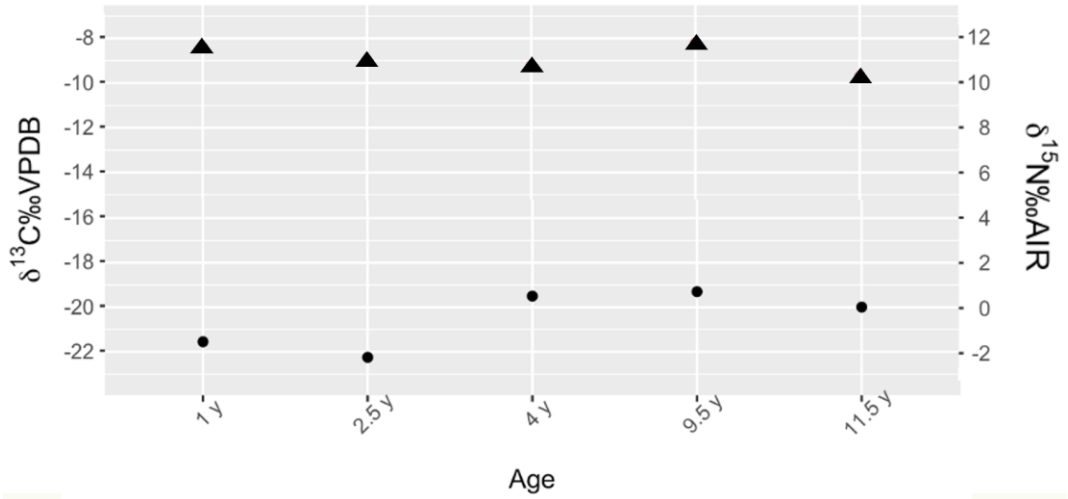

Figure 11: $\delta^{13}C$ (circles) and $\delta^{15}N$ (triangles) values for 20C-S1, lower central incisor. The values plotted here are uncorrected for bone-collagen offset. This graph only includes values that fall within the accepted range of preservation indicators.

5.2.3 Subadult Results

For the remaining subadults, all 81 dentine sections yielded unacceptable preservation values. The mean C/N ratio is 26.75 +/- 3.69, with ratios ranging from 21.1 to 47.62. The acceptable range for C/N ratios is between 2.9 and 3.6 (DeNiro, 1985). The average %C is 64.53% +/- 6.3, and the average %N is 2.84% +/- 0.34. According to Ambrose (1990), the acceptable range for %C and %N in well-preserved collagen is >13% and >4.8%, respectively. According to Van Klinken (1999), %C values should not exceed 35 wt %C. The full isotope results for the subadult sample can be found in Table 9.

For the isotope compositions, the mean $\delta^{13}C_{col}$ is –28.7 +/- 0.44‰ and the mean $\delta^{15}N_{col}$ is –2.1 +/- 0.74‰. $\delta^{13}C$ in human bone collagen are not expected to be as low as they are here, as the diet-to-tissue spacing for collagen is +5‰ (Reitsema, 2015). The mean $\delta^{13}C_{col}$ of –28.7‰ in this sample would suggest a diet with an isotopic average of approximately –33.7‰, once corrected for bone-collagen offset. This is near impossible given that most C_3 plants do not have $\delta^{13}C$ values this low ($\delta^{13}C$ values for C_3 plants lie between –35 and –22‰; Muccio & Jackson, 2009) and even those with such low values could not have been consumed in a high enough quantity to result in these collagen $\delta^{13}C$. Meanwhile, $\delta^{15}N$ from human bone collagen would not produce negative values given that no $\delta^{15}N$ plants possess $\delta^{15}N$ values low enough to produce such low collagen $\delta^{15}N$ (Feranec & Hart, 2019). The possible reasons for such results, and their respective likelihood, will be discussed in detail in Chapter 6.

Table 9: Values for subadult dentine sections, excluding one individual (20C-S1) who had acceptable C/N ranges. Note, collagen yield was calculated per tooth (not per section). Per tooth yield results can be found in table 4.

Sample	Age	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Carbon (%)	Nitrogen (%)	C/N ratio
10A-S3(2)(A)	2.5 y	–28.7	–2.8	62.46	2.79	26.07
10A-S3(2)(B)	4 y	–28.7	–2.6	64.87	2.90	26.06
10A-S3(2)(C)	6 y	–28.7	–2.3	63.82	2.83	26.27
17T-S1 (2) (B)	1.5 y	–28.7	–2.8	68.02	3.06	25.92
17T-S1 (2) (C)	3 y	–28.8	–2.8	62.79	2.79	26.22

17T-S1(2) (A)	9 m	–28.8	–2.6	61.86	2.81	25.68
17T-S1(2)(D)	7 y	–28.5	–2.6	62.47	2.81	25.91
17T-S1(2)(E)	9 y	–28.6	–4.2	25.19	1.03	28.51
17Z-S2(2)(A)	9 m	–28.7	–1.3	68.13	3.28	24.24
17Z-S2(2)(B)	1.5 y	–28.4	–2.1	65.23	2.71	28.04
20F-S1(A)	2.5 m	–28.9	–2.0	66.66	3.10	25.09
20F-S1(B, C)	2 y	–28.5	–2.3	65.15	2.96	25.67
20F-S2(E)	4.5 y	–28.4	–2.1	66.69	2.80	27.82
20F-S2(A)	9 m	–28.7	–2.4	64.98	2.94	25.80
20F-S2(B)	1.5 y	–28.6	–2.0	65.34	2.93	25.96
20F-S2(C)	2.5 y	–28.5	–1.7	68.73	3.06	26.21
20F-S2(D)	3.5 y	–27.7	–2.6	64.25	2.62	28.64
20F-S2(F)	5.5 y	–28.5	–1.9	65.30	2.62	29.11
20F-S2(G)	6.5 y	–28.5	–2.4	64.26	2.64	28.40
20F-S31(A)	6 m	–29.7	–1.4	63.96	2.88	25.92
20F-S31(B)	10 m	–29.8	–1.1	63.52	2.83	26.19
20F-S31(C)	1 y	–29.8	–2.2	64.08	2.96	25.23
20F-S31(D)	1.5 y	–28.6	–1.2	63.79	3.00	24.79
20F-S39(A)	1.5 m	–28.7	–2.3	63.06	2.92	25.14
20F-S39(B)	4 m	–28.8	–2.2	62.55	2.97	24.56
20F-S39(C)	6 m	–28.8	–2.2	61.09	2.96	24.04
20F-S6(A)	4.5 m	–28.7	–2.3	64.05	3.02	24.74
20F-S6(B)	10 m	–30.1	–3.1	61.56	2.88	24.96
20F-S6(C)	1.5 y	–28.8	–2.1	61.86	2.98	24.20
20T-S1(A)	3 m	–28.2	–2.4	63.09	2.81	26.18
20T-S1(C)	6 m	–28.6	–1.6	62.45	2.86	25.45
20T-S1(D)	10 m	–28.6	–1.8	62.87	2.82	25.96
20T-S1(E)	1 y	–29.7	–2.2	62.40	2.69	27.08
20T-S1(F)	1.5 y	–28.8	–2.7	62.26	2.68	27.04
20T-S1(G)	2.5 y	–28.6	–1.0	64.50	2.95	25.51
21E-S14	6 y	–28.7	–2.7	59.43	2.80	24.77
21E-S4(A)	9 m	–28.4	–2.5	45.83	2.12	25.16
21E-S4(B)	1.5 y	–28.8	–1.9	52.48	2.50	24.52
21E-S4(C)	3 y	–28.6	+0.4	56.20	2.74	23.89
21E-S8(A)	3.5 m	–28.8	–2.2	68.30	2.95	27.03
21E-S8(B)	6 m	–28.8	–2.2	68.67	2.82	28.37
21E-S8(C)	9 m	–28.9	–2.6	67.19	2.86	27.38

21E-S8(D)	1 y	–28.4	–1.8	66.05	2.97	25.96
21N-11(C)	7.5 m	–29.8	–2.7	61.42	2.83	25.28
21N-S11(A)	3 m	–28.8	–2.5	61.63	2.72	26.41
21N-S11(B)	5 m	–28.8	–3.0	62.96	2.69	27.28
21U-S6(A)	6 m	–28.6	–2.4	64.65	2.94	25.61
21U-S6(B)	10.5 m	–28.5	–2.2	60.46	2.78	25.35
21U-S6(C)	1.5 y	–28.6	–2.3	65.26	2.91	26.20
21U-S6(D)	2.5 y	–28.7	–2.2	62.11	2.86	25.35
21U-S6(E)	3 y	–28.4	–2.0	64.65	2.85	26.46
24H-S2(A)	2 y	–28.3	–1.3	69.97	2.90	28.13
24H-S2(B)	4 y	–28.3	+0.8	66.49	3.49	22.23
24H-S2(E)	8 y	–28.6	–2.2	69.29	2.87	28.19
24H-S2(F)	9 y	–28.6	–2.0	69.30	2.90	27.87
24H-S2(G)	10.5 y	–28.6	–2.1	70.86	2.87	28.80
25C-S19(A)	2.5 m	–28.6	–2.0	69.33	3.23	25.02
25C-S19(B, C)	10 m	–28.5	+0.9	68.81	3.80	21.14
25C-S73(A)	1.5 y	–28.4	–2.6	64.76	2.60	29.05
25C-S73(B)	2.5 y	–28.3	–3.1	64.82	2.54	29.82
25C-S73(C)	4 y	–28.4	–2.2	66.86	2.52	30.99
25C-S73(D)	5.5 y	–28.5	–2.6	73.23	2.62	32.61
25C-S73(E)	6 y	–28.2	–2.5	77.48	2.40	37.57
25C-S73(F)	7 y	–27.8	–2.6	76.01	1.86	47.62
25C-S73(G)	8 y	–28.2	–2.6	72.62	2.06	41.14
25C-S73(H)	8.5 y	–28.4	–2.4	74.80	2.68	32.57
25C-S9(A)	2.5 y	–29.6	–2.5	64.49	3.04	24.71
25C-S9(B)	6.5 y	–28.6	–2.2	64.74	2.91	25.93
25C-S9(C)	8 y	–28.6	–2.4	62.81	2.94	24.89
25C-S9(D)	9 y	–29.7	–2.5	64.23	3.06	24.46
25C-S9(E)	10 y	–29.9	–2.9	61.65	2.84	25.27
25C-S9(F)	12 y	–28.7	–2.7	62.85	2.89	25.38
2FH-S2(D)	5.5 y	–28.7	–2.2	67.08	2.73	28.65
30R-S7(A)	1.5 y	–28.8	–1.9	66.52	3.19	24.31
30R-S7(B)	2.5 y	–28.6	–1.8	67.27	3.09	25.37
30R-S7(C)	3.5 y	–28.9	–1.8	69.29	3.22	25.09
30R-S7(D)	5 y	–28.6	–2.0	69.86	3.22	25.28
30R-S7(E)	7 y	–28.9	–2.1	67.67	3.21	24.62
30R-S7(F)	8 y	–28.9	–1.8	65.53	3.20	23.89
S31(A)	1.5 y	–28.0	–2.0	61.03	2.83	25.18
S31(B)	4.5 y	–28.8	–1.9	66.86	3.30	23.66

5.3 Standards

The standards used to calibrate isotopic results in this study included keratin, UGSG-41a, USGS-40, and Szpak SRM-14. The results for the standards included in each tray, along with their locations within each tray, are recorded in Table 10. All standards except one keratin standard in tray 2 yielded isotopic results consistent with their expected $\delta^{13}C$ and $\delta^{15}N$ values, which are noted in the table below. The discordant value in tray 2 differed in $\delta^{13}C$ by 1.8‰ (with no discrepancy in $\delta^{15}N$) and is highlighted in Table 10 below. It is unclear why there is a discrepancy between the $\delta^{13}C$ yielded and the expected value of this one standard.

Given that all standards but one yielded $\delta^{13}C$ and $\delta^{15}N$ values consistent with what would be expected, it can be determined that the cause of the problematic values among subadults in this sample is not a result of the mass spectrometer. Rather, the problem must lie elsewhere, either in laboratory procedures or in the preservation of samples. These possibilities will be explored in chapter 6.

Table 10: Results for standards, alongside expected isotopic values.

Standard	Tray	Location	$\delta^{13}C$ (‰)	Expected Value $\delta^{13}C$	C (%)	$\delta^{15}N$ (‰)	Expected Value $\delta^{15}N$	N (%)	C/N Ratio
Keratin	2	A2	–24.1	–24.0	45.38	+6.4	+6.4	14.19	3.7
Keratin	2	A3	–24.1	–24.0	46.28	+6.4	+6.4	14.39	3.8
UGSG-41a	2	A5	+36.5	+36.6	40.73	+47.7	+47.6	9.50	5.0
USGS-40	2	A6	–27.4	–26.4	39.43	–4.6	–4.5	9.17	5.0
Szpak SRM-14	2	A7	–13.8	–13.7	38.66	+21.6	+21.6	13.88	3.3
Keratin	2	B1	–24.1	–24.0	45.14	+6.5	+6.4	14.15	3.7
UGSG-41a	2	B8	+36.7	+36.6	40.58	+47.6	+47.6	9.46	5.0
Keratin	2	C2	–24.0	–24.0	46.72	+6.3	+6.4	14.71	3.7
USGS-40	2	C9	–26.4	–26.4	40.25	–4.5	–4.5	9.43	5.0
Keratin	2	D3	–24.0	–24.0	46.58	+6.2	+6.4	14.70	3.7
USGS-41a	2	D10	+36.4	+36.6	40.78	+47.3	+47.6	9.59	5.0
Keratin	2	E4	–25.9	–24.0	40.70	+6.4	+6.4	12.76	3.7
USGS-40	2	E5	–27.3	–26.4	40.22	–4.5	–4.5	9.45	5.0

Szpak SRM-14	2	E6	–13.7	–13.7	38.60	+21.6	+21.6	13.94	3.2
Keratin	3	A2	–24.1	–24.0	50.76	+6.5	+6.4	15.98	3.7
Keratin	3	A3	–24.2	–24.0	50.23	+6.4	+6.4	15.67	3.7
UGSG-41a	3	A5	+36.4	+36.6	43.94	+48.1	+47.6	10.29	5.0
USGS-40	3	A6	–26.3	–26.4	43.32	–4.5	–4.5	10.13	5.0
Szpak SRM-14	3	A7	–13.7	–13.7	40.92	+21.5	+21.6	14.75	3.2
Keratin	3	B1	–24.2	–24.0	46.72	+6.3	+6.4	14.64	3.7
UGSG-41a	3	B8	+36.7	+36.6	34.82	+47.1	+47.6	8.12	5.0
Keratin	3	C2	–24.0	–24.0	50.04	+6.4	+6.4	15.78	3.7
USGS-40	3	C9	–26.5	–26.4	43.62	–4.6	–4.5	10.20	5.0
Keratin	3	D3	–24.2	–24.0	51.01	+6.4	+6.4	16.08	3.7
USGS-41a	3	D10	+36.6	+36.6	43.47	+47.5	+47.6	10.19	5.0
Szpak SRM-14	3	E2	–13.9	–13.7	39.65	+21.3	+21.6	14.19	3.3
Keratin	4	A2	–24.1	–24.0	46.16	+6.6	+6.4	15.09	3.7
Keratin	4	A3	–24.2	–24.0	47.68	+6.5	+6.4	15.45	3.7
UGSG-41a	4	A5	+36.5	+36.6	40.62	+47.6	+47.6	9.83	5.0
USGS-40	4	A6	–26.4	–26.4	39.93	–4.6	–4.5	9.65	5.0
Szpak SRM-14	4	A7	–13.7	–13.7	38.74	+21.6	+21.6	14.41	3.2
Keratin	4	B1	–24.1	–24.0	46.19	+6.4	+6.4	15.12	3.7
UGSG-41a	4	B8	+36.6	36.6	40.78	+47.4	+47.6	9.85	5.0
Keratin	4	C1	–24.1	–24.0	49.26	+6.3	+6.4	16.09	3.7
USGS-40	4	C2	–26.4	–26.4	62.17	–4.4	–4.5	15.07	5.0
Szpak SRM-14	4	C3	–13.7	–13.7	21.63	+21.1	+21.6	8.06	3.2
Keratin	1	A2	–23.7	–24.0	-	+6.2	+6.4	15.29	-
Keratin	1	A3	–24.1	–24.0	47.49	+6.4	+6.4	14.85	3.7
UGSG-41a	1	A5	+35.7	+36.6	40.65	+47.6	+47.6	9.46	5.0
USGS-40	1	A6	–26.4	–26.4	39.95	–4.6	–4.5	9.32	5.0
Szpak SRM-14	1	A7	–13.8	–13.7	38.54	+21.6	+21.3	13.84	3.3
Keratin	1	B1	–24.2	–24.0	46.73	+6.5	+6.4	14.68	3.7
UGSG-41a	1	B8	+36.5	+36.6	40.83	+47.9	+47.6	9.59	5.0
Keratin	1	C2	–24.1	–24.0	46.43	+6.5	+6.4	14.68	3.7
USGS-40	1	C9	–26.4	–26.4	40.42	–4.5	–4.5	9.50	5.0
Keratin	1	D3	–24.1	–24.0	46.13	+6.4	+6.4	14.59	3.7

USGS-41a	1	D10	+36.6	+36.6	40.61	+47.2	+47.6	9.50	5.0
Keratin	1	E4	–25.1	–24.0	46.68	+6.4	+6.4	14.77	3.7
USGS-40	1	E5	–27.2	–26.4	41.01	–4.5	–4.5	9.63	5.0
Szpak SRM-14	1	E6	–13.8	–13.7	39.10	+21.6	+21.3	14.18	3.2

Chapter 6

6 Discussion

This chapter discusses the low prevalence of enamel defects among this sample, moderate prevalence of dental caries, as well as provides insight into the adult female diet and the diet of subadult 20C-S1 based on their isotopic results. It will then discuss possible diagenetic changes negatively impacting isotopic values, challenges associated with poor results and the constraints of conducting graduate level research, before finally detailing limitations and future research.

6.1 Low Prevalence of Enamel Defects and Linear Enamel Hypoplasia

LEH is a non-specific phenomenon caused by an array of stressors including malnutrition, disease, genetics, or other factors such as trauma that influence enamel crystal elongation and thus influence or determine the thickness of enamel (Kreshover, 1960). Many bioarchaeological studies have hypothesized that LEH is associated with the onset of weaning, meaning the first introduction of solid foods to an infant's diet, on the basis that weaning has the potential to be a nutritionally stressful event for the infant (Cook & Buikstra, 1979; Crowder et al., 2019; Henderson et al., 2014). However, individuals within this sample have a relatively low prevalence of LEH, with only 3 individuals demonstrating evidence of any enamel defects, and only 2 of those having LEH. In deciduous tooth enamel that forms *in utero*, the absence of LEH indicates an absence of major fetal stress. This could be due to a lack of maternal stress or fetal buffering. The placenta buffers the fetus from many of the effects of physiological stress in the mother (Vuppaladhadiam et al., 2021). Of course, there is a limit to placental buffering, as pronounced maternal malnutrition and some illnesses will affect the fetus, but at the very least the lack of prenatal enamel defects suggests the mothers did not experience severe stress. In tooth enamel formed after birth, the low prevalence of enamel defects is likely in part due to the young age-at-death for many individuals in this

sample, as many died in infancy or early childhood, meaning their teeth reflect a relatively short amount of life.

The individuals in this sample that do have enamel defects ranged in age-at-death from approximately 3 years to 5.5 years, with enamel defects resolving between 2.5 and 4.6 years of age. Given that the earliest enamel defect formed around 2.5 years of age, it is highly unlikely that this is associated with the weaning process directly, which would have likely occurred between 6 months and 2 years of age (Guttirez et al., 2021; Thornton & Olson, 2011). Rather, it is more likely that these enamel defects are the result of stress events occurring after the completion of the weaning process.

Moggi-Cecchi et al. (1994), Wood (1996), and Kreshover (1960) have demonstrated that LEH is strongly associated with stressors such as fever, some types of viruses, and bacterial infections. Given that weaning is a gradual process, occurring over the course of several months and sometimes years, it is expected that there may be a delay in the effects of reduced nutrition expressing itself as skeletal lesions and enamel defects (Moggi-Cecchi et al., 1994). Blakey et al. (1994) proposes that post-weaning stress could explain why some LEH form between 6-9 months after a historically documented weaning age, as the post-weaning period is associated with an increase in an infant's motor and language skills, which in turn exposes them to more frequent contact with a higher number of individuals and more environmental substances. This results in an increased chance of developing disease (Blakey et al., 1994).

Based on the age-at-resolution of enamel defects in this sample (2.5 to 4.5 years), only some could be associated with post-weaning stress. Weaning commonly begins around 6 months of age and, in this population, was likely completed by 2.0 years of age (Gutirrez et al., 2021; Thornton & Olson, 2001). If weaning ceased around 2.0 years, the 6-to-9-month delay proposed by Blakey et al. (1994) means we would see LEH forming around 2.5 to 3.25 years. Two individuals, 20Z-S5 and 21R-S5, exhibit enamel defects that resolved at 2.5 and 2.7 years, respectively. The remaining enamel defect in 21R-S5 resolved at 4.6 years of age which is too late to be attributed to weaning with any confidence, even when considering a potential delay in the appearance of LEH. Thus,

weaning itself is not a cause of enamel defects in this sample, post-weaning stress may be the cause of some of the defects, while at least one is likely to have been caused by stressors other than weaning, such as malnutrition, illness and/or infection. These stressors may be related to the numerous cholera and typhus epidemics in the nineteenth century, in addition to other illnesses common to the period like tuberculosis and other respiratory infections (Bellhouse & Genest, 2005; Thornton & Olson, 2011).

The prevalence of LEH may be additionally affected by the 'threshold effect'. This frames the appearance of LEH as the result of a certain threshold of ameloblast disruption being met as the result of a stress event (Goodman & Rose, 1990). For example, an individual may experience several stress events during periods of enamel formation, but without meeting or surpassing the threshold for ameloblast disruption these stress events may have no effect on enamel, and thus not result in the appearance of LEH. Therefore, it is possible that the individuals within the Saint Antoine sample did not reach the threshold for ameloblast disruption when experiencing stress events such as illness and/or malnutrition, resulting in a low prevalence of LEH.

Reconstruction of breastfeeding and weaning practices using stable isotope analysis could allow for added interpretation of the timing of LEH, allowing changes in diet to be pinpointed and even connected with the timing of LEH. This project had hoped to use isotopic evidence of physiological stress to shed light on the causes of LEH, however, with the poor isotope results this is no longer possible, and it is not possible to suggest anything more specific about the causes of enamel defects in Saint Antoine.

6.2 Dental Caries

There is a moderate prevalence of caries within this population, as 26% of individuals assessed exhibit caries of some type. Many bioarchaeological studies of caries use adult samples and are thus focused solely on permanent teeth. Consequently, there is less data available regarding caries and dental disease in infants and children, and therefore deciduous teeth. Still, some studies that have compared subadult caries rates to that of adults note that subadults demonstrate a lower prevalence than adults (e.g., Giuffra et al., 2020; Karsten et al., 2015). In an adult sample, a moderate prevalence of caries, as had

been observed here, might be attributed to a diet low to medium in carbohydrates, or a high rate of dental wear that wore away pits where bacteria could accumulate before caries could form or become large (Giuffra et al., 2020). However, in a sample consisting of subadults, low to moderate caries prevalence is likely, at least in part, to be the result of the young age of individuals in the sample, and the loss of deciduous teeth (which may have been carious). While the Saint Antoine sample exhibited a mix of deciduous and permanent teeth, the permanent teeth that were assessed may have been recently erupted, and thus not have been exposed to the oral environment long enough for caries to form. Like the interpretation presented here, Prowse et al. (2008) also attributed a low prevalence of caries at and before two years of age to the short period of time that teeth were exposed to the oral environment. Hence, due to the Saint Antoine sample consisting of many young subadults, and consequently having many deciduous or recently erupted permanent teeth, it is not appropriate to attribute the prevalence of caries to a low carbohydrate diet.

6.3 Isotopic Results

This section discusses isotopic results for the adult female sample that yielded acceptable results, and results from subadult 20C-S1, and will compare historical records and documents with isotopic data to reconstruct the likely dietary staples consumed by these individuals.

6.3.1 Adult Female Diet

Stable isotopic data resulting from the adult females indicate a diet consisting of predominantly C_3 terrestrial foods, with variation in sources of dietary protein likely including a range of terrestrial animals and freshwater or marine fish (Pfieffer et al., 2016). Such variety in the consumption of dietary proteins is consistent with available foods at the time. Given Montreal's role as an important center of trade in North America, a wide array of food was available for purchase and consumption. Foods such as grain, butter, cheese, salted pork and beef were available locally or brought from other parts of the province, while overseas imports consisted of molasses, coffee and tea, alcohol, and salt (Fyson, 1989). Frederick William Ermatinger, a businessman in

Montreal, recorded his food purchases between 1805 and 1814, and particularly commented on the variety of meat and poultry available for purchase in Montreal's markets (Fyson, 1989), which supports the possibility that the adult females in this study had somewhat variable animal protein consumption. However, it should be stipulated that what foods were available is not necessarily what was consumed, as factors such as the affordability of foods, household size, cultural norms, personal preference, accessibility of markets and shops, as well as the ability to access the tools necessary to prepare foods, were important considerations. Thus, what was purchased by Ermatinger, who was of high socioeconomic, likely does not reflect what was purchased and consumed the French-Canadian women of Saint Antoine, as they occupied a lower SES and had different cultural norms.

As mentioned in previous sections, it was increasingly common for women and children to participate in the workforce in nineteenth century Montreal, given their status as low-cost workers (Bradbury, 2007; Thornton & Olson, 2011; Ward & Ward, 1984). Fyson (1989) analyzed purchasing records across classes from the nineteenth century in order to gain insight into dietary variation. The discussion of Lachine Canal worker's purchases could serve as a proxy for understanding what the adult females might have consumed, especially when considering the likelihood of them working in industries like cotton mills (Thornton & Olson, 2011). Fyson (1989) found that the Lachine Canal worker's diet consisted of bread, salted pork, and alcohol (rum), with bread being the largest item in terms of both caloric value and financial expenditure. Rum is made from sugarcane, a C_4 plant, which would contribute to elevated $\delta^{13}C$ values. Based on historical records, it is unclear whether women within the workforce were consuming rum and meat, and if they were whether they were consuming them at the same rate as male workers. However, based on the isotopic results presented here, it appears that there was less emphasis on C_4 foods within the adult female diet, and so it may be that rum was not consumed by women in great quantity, if at all. Moreover, there was an emphasis on peas, a C_3 plant, with peas being consumed eight times more among Francophone workers when compared to their Anglophone counterparts (Fyson, 1989).

Nitrogen isotope results suggest that the adult females of Saint Antoine were consuming a diet with somewhat variable sources of dietary protein. As mentioned above, this is consistent with the wide range of foods available in Montreal during the nineteenth century. The emphasis on pork in the Lachine Canal workers diet, which women may have been consuming if participating in the workforce, may contribute to the observed variability in δ^{15}N. In an analysis of nineteenth century urban and rural pigs in Upper Canada (present-day Southern Ontario), Guiry et al. (2017) found rural pigs δ^{15}N values had a lower standard deviation of 0.9‰, with urban pigs demonstrating a higher standard deviation of 2.9‰, likely the result of urban pigs being fed a more variable diet consisting of household scraps. If women were consuming salted pork within the workforce, it likely came from urban pigs which then contributed to the range of δ^{15}N compositions observed here.

Interestingly, purchasing records indicate an absence of fish from the diet of Lachine Canal workers, despite the abundance of fish available in the canals and markets (Fyson, 1989). However, this population consisted of Catholic individuals, and although religiously imposed restrictions on diet were loosening during industrialization, fish would still likely have been an important stable in a Catholic diet, particularly during the Lenten season (Fyson, 1989). Thus, while not as commonly consumed as terrestrial animals, consumption of freshwater or marine foods is expected, and can be suggested to be evident in the stable isotopic compositions of the adult female sample.

While women were more likely to be working during this period, it should not be assumed that all women were participating in the workforce and hence eating outside of the household. Eating within the home provides more dietary flexibility, as foods were not required to keep throughout the day like foods packed by or for workers, and those within the home had the means, and perhaps the time, to prepare their food using tools available within their kitchens (i.e., pots, pans, fuel). In the home, animal proteins likely included the occasional consumption of fish, and common consumption of beef, pork, and poultry (including eggs). Thus, the diet of a woman who did not participate in the workforce and remained within the home may differ from those in the workforce. *La Cuisinière Canadienne* (1840) reveals what foods might have been prepared and

consumed within the home, and includes recipes for soups, animal meats (beef, calf, poultry, lamb, game, fish), baked goods (pastries, biscuits, bread), jam, salads and vegetables, beverages, and macarons. However, the record of recipes within this cookbook, similarly to the variety of foods available within the city, does not necessarily mean these foods were being prepared. Historical documents describe that the Ladies Benevolent Society, a charitable organization, considered bread an essential component to donate to poor families, as well as barley, soup, and rice (Fyson, 1989). These foods provided by charitable organizations may have occasionally factored into the home diet of the sample represented here, meaning that C_3 foods like rice, and foods made with C_3 plants like bread, would have been dietary staples within the home, in addition to the staples of alcohol (rum), bread, and salted pork outside of the home.

6.3.2 Subadult 20C-S1

The dentine sections from 20C-S1 that produced acceptable isotopic results suggest that the weaning process was completed between 1 and 2.5 years of age, with $\delta^{13}C_{diet}$ values decreasing from –26.6‰ to –27.3‰ between those ages. This likely indicates a diet initially consisting of weaning foods, such as pap, gruel, or animal milk, with more solid and tougher foods likely being consumed as they got older. Gruel is a liquefied porridge, sometimes with meat added, and pap is made of wheat, rye, barley, or oats mixed with water, unpasteurized milk and occasionally raw meat juice (Radbill, 1981; Stevens et al., 2009; Thulier, 2009; Fildes, 1986). Fuller et al. (2006) demonstrated that exclusively breastfed infants demonstrate $\delta^{13}C_{diet}$ values that are enriched by approximately 1‰. This trophic shift is not seen here because the earliest dentine section formed at 1 year of age, which is too late to represent the period of exclusive breastfeeding (weaning can be expected to begin between 6 months and 1 year of age, if not earlier). The comparatively low $\delta^{13}C_{diet}$ values of the 1- to 2.5-year-old dentine samples of individual 20C-S1 suggest they were weaned onto a diet consisting mostly of C_3 plants.

Nitrogen isotope diet values decrease between 1 and 2.5 years from +8.6‰ to +8.0‰, which supports the suggestion that this was the period of weaning. The $\delta^{15}N_{diet}$ value from dentine formed around 1 year of age is slightly higher than the adult female $\delta^{15}N_{diet}$ mean (+8.1 +/- 1.08‰), which suggests breastfeeding was continuing at this age, in

addition to consumption of weaning foods. By 2.5 years, $\delta^{15}N_{diet}$ values are like those of the adult females, indicating the completion of the weaning process at or before this age.

There is a 1.9‰ difference in $\delta^{13}C_{diet}$ from the earliest dentine section (1 year) and the dentine section formed around 4 years of age (from −26.6‰ to −24.5‰), while the $\delta^{15}N_{diet}$ values between these ages differ less (shifting from +8.6‰ to +7.7‰, a 0.9‰ decrease). This suggests that this individual's diet shifted to include more C_4 foods, perhaps because of a shift away from gruels and paps made with C_3 plants. The lowering of $\delta^{15}N_{diet}$ values suggests the dietary change probably did not involve higher consumption of fish. When comparing these isotopic values with the adult female mean, it further indicates that, at 4 years of age, this individual was consuming a diet that was quite similar to that of adult females. These isotopic values remain consistent throughout the remaining dentine sections, with the final section being formed around 11.5 years of age. This suggests that this individual's diet remained relatively stable between 4 and 11.5 years.

6.4 Diagenetic Changes

Several diagenetic factors could have contributed to the alteration of isotopic results, as degradation during inhumation may structurally alter bone tissue or result in molecular loss, leading samples to produce diagenetic signals rather than their original biological signals (Harbeck & Grupe, 2009; Hedges, 2002). Diagenetic alteration can be caused by humic contaminants, fulvic contaminants, chemical degradation from the burial environment, laboratory procedures, and/or microorganisms in the burial environment (Dobberstein et al., 2009; Grupe et al., 2000; Grupe & Turban-Just, 1998; Harbeck & Grupe, 2009; Hedges, 2002; Kendall et al., 2018;).

Microorganisms can cause changes to the amino acid profile of bone collagen and are the most predominant cause of diagenetic change in archaeological bone, and so must be considered here (Grupe et al., 2000; Grupe & Turban-Just, 1998; Hedges, 2002). Using experimental degradation techniques, Balzer et al. (1997) found that isotopic ratios shifted in modern bone exposed to soil bacteria, with $\delta^{13}C$ values generally decreasing and $\delta^{15}N$ values generally increasing when compared to the control. Thus, if samples

were diagenetically affected by microorganisms, low $\delta^{13}C$ and high $\delta^{15}N$ values would be expected. This scenario does not match the samples analyzed herein, as while the $\delta^{13}C$ values are very low the $\delta^{15}N$ values are not enriched, in fact being markedly lower than expected. It is thus unlikely that microorganisms affected isotopic ratios within this sample.

Harbeck and Grupe's (2009) study on chemical degradation and natural diagenetic changes to collagen suggested that a combination of microbial diagenesis, which decreases C/N ratios, and chemical diagenesis or contamination, which increases C/N ratios, could result in an ideal C/N ratio. Given that these samples produced C/N ratios well outside of the accepted range, and the previously discussed unlikelihood of microbial diagenesis in the burial environment, it is unlikely that a combination of microbial and chemical factors affected this sample's collagen.

Given that factors like hydrolysis can cause a shift in C/N ratios, it is possible this is the cause here, although also unlikely. Hydrolysis causes a breakdown of peptide bonds in collagen, resulting in collagen loss (Kendall et al., 2018). Moreover, hydrolysis and groundwater uptake can contribute to chemical uptake of fluoride, uranium, and other ions, which can cause diagenetic alterations, as well as overshadowing already existing trace element content of bone (Hedges, 2002; Hedges & Millard, 1995). The overshadowing of trace element content is not a primary concern here, as trace elements were not measured, but diagenetic changes resulting from hydrolysis and chemical uptake should still be considered. In their study of experimental degradation of modern bone (which would not be affected by microbial attack) via abiotic collagen hydrolysis, Harbeck and Grupe (2009) demonstrated a decrease in $\delta^{15}N$ along with a simultaneous increase in $\delta^{13}C$ values. In the samples from Saint Antoine, while $\delta^{15}N$ values are lower than expected, consistent with Harbeck and Grupe's (2009) findings, the $\delta^{13}C$ values do not follow the same pattern as they are also lower than expected. Thus, it is unlikely that hydrolysis caused diagenetic changes in this sample. Additionally, humic contaminants can alter C/N ratios and $\delta^{13}C$ values. Given that humic acids are rich in carbon, humic contaminants would be expected to increase $\delta^{13}C$ values, which was not the case here, with $\delta^{13}C$ values being lower than anticipated (Guiry & Szpak, 2021).

In considering diagenetic alteration, it is important to consider how these factors may affect teeth specifically, as dentition is typically considered to be more resistant to changes from the burial environment. Dobberstein et al. (2009) found that collagen in teeth is generally resistant to physio-chemical degradation, while also noting that longer post-mortem periods with an unfavourable environment could contribute to an increase in degradation. Here the post-mortem period was approximately 200 years, a relatively short post-mortem period when compared to the post-mortem periods of 400 to 1700 years considered in Dobberstein and colleagues' (2009) study. Thus, when considering the low porosity of teeth, as well as cuspal dentine's encapsulation in enamel, which helps protect it from exogenous factors, it is unlikely that diagenetic changes resulted from the burial environment. Additionally, one would expect the adult female samples to also have been affected by these diagenetic changes, as they were exposed to the same burial environment as the subadult samples. Yet, four out of six adult female samples produced isotopic ratios that do not indicate the presence diagenetic change (with 12C-S1 not being altered to same degree as the subadult samples).

Thus, attention is turned to laboratory methods as a potential issue. As mentioned in the previous chapter, laboratory methods involved use of distilled water, epoxy resin, acetone, sodium hydroxide (NaOH), and hydrochloric acid (HCl) to prepare and demineralize samples. Van Klinken and Hedges (1995) state that a strong base such as NaOH could result in the hydrolysis of peptide and collagen-humic linkages. Indeed, that is why a dilute NaOH solution is often applied to archaeological collagen samples, to remove any potential humic contaminants. Studies have found that immersion of collagen in dilute NaOH can lower the collagen yield because of hydrolysis, however the loss is minor in well-preserved samples so worth it in favour of removing humic substances (Liden et al., 1995).

The duration with which chemical solutions are applied is an additional consideration, given that prolonged chemical treatment, even in a weak concentration, could result in isotopic shifts (Skippington et al., 2019). Studies utilizing microsampling techniques such as Eerkens (Eerkens et al., 2011, 2016; Eerkens & Bartelink, 2013) and Greenwald et al. (2016) utilized NaOH pre-treatment for a period of 24 hours, and Burt (2015) used the

pre-treatment for 20 hours with success. Van der Haas and colleagues (2018) demonstrate the efficacy of comparatively shorter NaOH soaks, with their samples soaking for 6 hours with no effect on isotopic values. This study followed a method previously established by Czermak et al. (2020) wherein a 0.125M NaOH solution was applied to dentine sections for only 30 minutes, a short immersion period. It is highly unlikely that such a short period of time would cause high amounts of hydrolysis. Studies have found that immersion in dilute NaOH had no significant effect on isotopic ratios and that it removed humic contaminants more effectively than other methods like ultrafiltration (Jørkov et al., 2007; Sealy et al., 2014).

Acetone was additionally used during this study in order to remove resin from the samples after they were sectioned into mesial and distal halves via slow-speed saw. The use of acetone on bone samples has also been tested, indicating that there was no significant effect on isotopic values (France et al., 2011; France et al., 2015). While Moreiras and colleagues (2022) did find acetone caused some isotopic change, it is not to the degree that is observed here, and so it can be concluded that acetone is not the cause of isotopic alteration within this sample.

The studies on which the protocol used herein was based used HCl treatments of the same concentration, for similar periods of time, with no significant effect on collagen or isotopic values. Additionally, other studies have used the same number of rinses (minimum three; usually at least five) with distilled water following HCl treatment and found no effect on stable isotope values (i.e., Czermak et al., 2014; Sealy et al., 2014; Vaiglova et al., 2014). This indicates that a minimum of three rinses should be sufficient for expelling all HCl solution from samples. Here, samples were rinsed anywhere from three to five times following treatment with HCl and again following treatment with NaOH. Additionally, the demineralization process for this population yielded pseudomorphs, a strong indicator that collagen chains are still linked and that a certain amount of structural integrity of the sample has been retained (Czermak et al., 2020; Sealy et al., 2014). However, the results produced within this thesis are consistent with isotopic compositions for C_3 plants, and it is possible that the HCl solution was, indeed,

too strong, or applied for too long, resulting in the loss of collagen and leaving behind plant material embedded within the tooth, particularly plant matter from C_3 plants.

Due to the wide range of $\delta^{13}C$ averages for C_3 plants (–22‰ to –38‰, average –26‰), it is important to focus on data from relevant geographic regions (Tieszen et al., 1991; Katzenberg et al., 1995). Based on unpublished data from Pinery Provincial Park in London, Ontario, C_3 plants average $\delta^{13}C$ is –28.3 +/- 2.0‰ and average $\delta^{15}N$ is –4.1 +/- 2.0‰ (these averages have already been corrected by +1.65‰ to account for the Suess Effect; Longstaffe, unpublished data cited in Morris, 2015). These isotopic compositions align well with the data presented here, as the average $\delta^{13}C_{col}$ for the subadults is –28.7 +/- 0.44‰ and the mean $\delta^{15}N_{col}$ is –2.1 +/- 0.74‰, with the $\delta^{13}C_{col}$ matching C_3 plants almost perfectly. Meanwhile, due to little fractionation of N_2 from atmospheric nitrogen (with has a nitrogen isotopic composition of 0‰; Mariotti, 1983), the average legume $\delta^{15}N$ is typically ~0‰ (Kohl & Shearer, 1980; Szpak et al., 2014; Yoneyama et al., 1986). When the average subadult $\delta^{15}N_{col}$ is corrected by +2‰ to account for the effect of the acid, the average $\delta^{15}N_{col}$ becomes 0.1 +/- 0.74‰, aligning with legume $\delta^{15}N$. Therefore, the subadult data is consistent with measurement of C_3 plant materials in the absence of human collagen.

If laboratory methods did, in fact, cause diagenetic changes, one would expect all samples to be affected. This does not explain why 20C-S1, which underwent the same demineralization and preparation protocols as the other individuals, yielded some acceptable results. It should additionally be noted that most individuals (14/21=66%) demonstrated a collagen yield greater than 1%, and 10 individuals demonstrated a collagen yield greater than 2%, which usually indicates good preservation (Ambrose, 1990; Van Klinken, 1999). Despite the successful use of these protocols elsewhere, and good preservation indicators, it is possible that laboratory procedures resulted in the loss of collagen, and the mass spectrometer measured the remaining plant material, particularly plant material from C_3 plants such as legumes. Future investigation in laboratory procedures may be warranted.

6.5 Problematic Data and Lack of Results in Graduate Research

It is evident that this course of research produced a batch of data that were not able to be used to reach any conclusions regarding breastfeeding and weaning practices in the Saint Antoine population, the original purpose of this study. While the reasons for such results are unclear, it provides an opportunity to reflect on problematic data, a lack of results in graduate research, and more broadly, the limitations of conducting research in a graduate program.

Scientific knowledge is produced from failure, as failed experiments are an integral part of the scientific process of ruling out certain possibilities and explanations in favor of others. However, the "arcs of discovery" narrative in which the path toward crucial scientific discoveries is one seemingly free of obstacles, and leads directly toward new scientific knowledge, disregards failure as a key step in the scientific process (Barwich, 2019). Moreover, academia's "publish or perish" mentality, which stipulates that an academic's position is a function of their success in publishing their work, has further contributed to a narrative in which poor results are not productive results, as they will not be able to provide a researcher with a publishable article (De Rond & Miller, 2005). In short, amassing several publications is essential to success within academia. Timmermans (2011) discusses how the reward system that is built into academic institutions causes negative results or failed experiments to harm scientific careers. This is due to the social organization of science, which relies on citations, conference presentations, research and professional awards, and institutional and professional appointments as crucial to having one's work recognized and leads to the accumulation of material rewards and the curation of a reputation (Merton, 1973). Scientific failure exists in direct opposition to this social organization, as failed experiments are often unpublishable and thus remain unrecognized.

Problematic data and lack of results are increasingly complicated by the constrictions of conducting research at the graduate level, particularly at the masters level. Such research is constrained by factors such as time (anthropology masters programs in Canada are typically two years in duration) and funding limits. In the context of this course of

research, compounding factors like the time constraints of a masters program as well as funding mean that the unsuccessful lab work and analyses cannot be redone. In addition to the above-mentioned constraints of graduate research, this study was affected by the COVID-19 pandemic. With lockdowns and pandemic restrictions imposed by both institutions and the federal and provincial governments, the ability to conduct fieldwork and collect samples was delayed by several months, with fieldwork in Montreal occurring in September 2021, rather than earlier in the summer of 2021 as originally intended. Additionally, access to the Bioarchaeology Chemistry Lab was partially restricted throughout 2021 and the beginning of 2022. This study was thus doubly affected by the unfortunate circumstances of the COVID-19 pandemic, and the inherent limitations of graduate research.

While the results of this course of study are unpublishable, I would argue that the desired outcomes of my graduate program have been met. A full thesis has been produced, from the initial conception of the project, through to the analysis and compiling of results into a final, completed thesis, even though the desired stable isotope results were not produced. Hence, this course of study has value, despite the unfortunate fact that publication is not possible, and results are unusable. It is important to acknowledge that good science can produce poor results, and that such work still merits recognition (Timmermans, 2011).

6.6 Limitations and Future Actions

6.6.1 Implicit Assumptions in Stable Isotope Studies of Breastfeeding and Weaning

There are several assumptions that are implicit to stable isotope studies of breastfeeding and weaning practices, some of which may limit interpretations of the data presented here. One such assumption is that the population being studied is an appropriate representation of the diet and physiology of the whole population (Beaumont et al., 2015). This assumption ignores the osteological paradox, which refers to the fact that individuals who survived long enough with illness to manifest skeletal lesions were perhaps healthier than their peers who died prior to the manifestation of skeletal lesions

(Wood et al., 1992). It is essential to acknowledge that the individuals being studied, both in this study and in all bioarchaeological research, did not survive. This is particularly a concern in studies of breastfeeding and weaning that focus on samples derived from subadults. While they may appear healthy in the absence of skeletal lesions, they died prematurely, likely from a severe illness and/or injury. Thus, research is biased toward those who did not survive, rather than those who did survive. While this course of study utilized serial dentine sectioning, a method that allows dietary changes to be tracked across and individual's lifespan, including periods well before their death, the adult females did not undergo dentine sectioning. As such, the adult females consist of individuals who died early in life (individuals were between 16 and 30 years old at the time of death), and the diet of these individuals may have differed from those who survived to later life.

Representativeness of the sample becomes an additional concern when considering whether non-baptized infants were interred at Saint Antoine cemetery. If an infant died before baptismal rites could be performed, then it is possible that they would have been buried elsewhere, and so that group of individuals would not be represented here. This is the case for other nineteenth century Canadian cemeteries (Herring et al., 1998). Records from nineteenth century Montreal as well as plans for Saint Antoine were consulted in the completion of this thesis, and there is indication that infants who died without being baptized were still buried in cemeteries, though they were buried separately from those who died "in possession of their religious state" (Ethnoscop, 2004, p. 25). The plans from Saint Antoine indicate a plot of land set aside for this purpose, and therefore, it appears that infants who died before baptism were included within this sample, as they were excavated alongside others interred at Saint Antoine (Ethnoscop, 2004).

A second implicit assumption is that the δ^{15}N values derived from the adult females is like that of adult females who were breastfeeding (Reynard & Tuross, 2015). It is important to note this assumption as a caveat to conclusions, as it is entirely possible that the adult females in this study were not, in fact, breastfeeding, or that they ever breastfed. Although, given their age at time of death (16-30 years), they are more likely to have been breastfeeding at the time of their death, or the years immediately preceding their

death, compared to older adult females. They thus remain a useful proxy for females who were breastfeeding and, given that it not possible to distinguish breastfeeding females from non-breastfeeding females in an archaeological population, this is a necessary assumption to make.

6.6.2 Lack of Isotopic Results

Perhaps most obviously, the lack of viable isotopic results has significantly impacted the amount of information that can be extracted from this sample. This is a significant limitation of this study and has resulted in a shift in focus from population-level analyses, to focusing on the one individual (20C-S1) who yielded acceptable values, alongside a consideration of adult diet. While everything possible has been done to A) find the cause of the problem and B) find a means to repair the problem, I have unfortunately been able to do neither. Thus, attention must be focused on future research.

As mentioned in previous sections, teeth were sectioned into mesial and distal halves prior to demineralization, and only one half of the tooth was used for this course of study, with the other being retained for future analyses. This study highlights the importance of limiting the destruction of archaeological materials, as the retention of one half of each tooth allows for this population to be revisited in the future. Any such future analyses should use protocols designed for poorly-preserved samples. One such method, used by the Max Planck Institute for Evolutionary Anthropology in Leipzig, involves steps of gelatinization, which is the process of denaturing collagen in a warm dilute acid, followed by filtration and ultra-filtration (Brown et al., 1988; Longin, 1971). While the addition of these steps is more labour-intensive and expensive, it has been used with success on samples with poor collagen preservation, including Neanderthal remains (Richards & Schmitz, 2008). If another study is done using such a technique, it may perhaps show that the error herein lies within the preparation protocol (if a future study produces acceptable isotopic values), or it may show that the issue arose from the burial environment or poor preservation (if a future study does not produce acceptable isotopic values).

6.7 Conclusion

There was a low prevalence of LEH in this sample, likely due to the young age-at-death in this sample, as LEH may not have had time to form in response to a stress event, or the individual may not have survived that stress event. LEH that do occur in this sample resolved between 2.5 and 4.6 years, and so are not directly linked to the weaning process, which would have occurred between 6 months and 2.0 years of age. Rather, the earlier forming LEHs in this sample could be attributed to post-weaning stress, with the other LEH likely being linked to common stress events like infection and disease (Bereczki et al., 2019; Blakey et al., 1994; Kreshover, 1960; Moggi-Cecchi et al., 1994). There was additionally a moderate prevalence of dental caries observed in this sample. While such a prevalence in an adult sample might be attributed to a low to moderate carbohydrate diet, or high rates of dental wear eliminating pits before caries could form or become large, a young subadult sample includes deciduous and recently erupted permanent teeth. Thus, it may not be that subadults were consuming a low carbohydrate diet, but rather that teeth had not been exposed to the oral environment long enough for caries to form.

The adult female diet at Saint Antoine seems to have consisted of a variable terrestrial and aquatic dietary protein and predominantly C_3 foods. Such variation is consistent with the types of foods that would be available in Montreal, though these foods may not necessarily have been purchased or consumed by the individuals within this sample (Fyson, 1989). Purchasing records, as well as historical records from charitable organizations, indicate that dietary staples included bread, pork, barley, and rice (Fyson, 1989). Considering that this is a Catholic population, it is also likely that fish was a staple food, particularly during the Lenten season. Individual 20C-S1 demonstrated $\delta^{13}C$ values consistent with a mixed weaning diet by 1 year of age, with weaning foods being C_3 plants. Between 1 and 4 years, $\delta^{13}C$ values increase by 1.9‰, and $\delta^{15}N$ values decrease by nearly 1.0‰, which indicates the introduction of more C_4 foods into their diet during this time.

Diagenetic changes may have altered the stable isotope values for the majority of this sample, resulting in the loss of collagen and measurement of isotopic compositions from C_3 plants embedded within the teeth. Future studies could be conducted using the half of

each tooth that was retained. If and when such investigations occur, a protocol developed for poorly-preserved samples should be used (Richards & Schmitz, 2008). While poor results were unfortunate, and prove to be a significant limitation, failure is an integral part of the scientific process, and good science may still yield poor results. With the time and financial constraints associated with graduate research, as well as delays in fieldwork arising from the COVID-19 pandemic, research protocols could not be revised and redone. Thus, graduate research, and this particular course of research, must cope with such outcomes, however disappointing.

Chapter 7

7 Conclusion

During the nineteenth century, Montreal experienced numerous changes, including industrialization and urbanization, increased stratification of social classes, and rapid population growth and immigration (Bradbury, 2007; Bradbury & Myers, 2005; Denison, 1955; Gilliland & Olson, 2010; Sweeny, 2015; Thornton & Olson, 2011). These changes cumulated in exacerbation of already-existing health problems and may have contributed to high rates of infant morbidity and mortality, particularly among those from low SES families (Bradbury, 2007; Carpenter, 1869; Gilliland & Olson, 1998; Perrot, 1975; Thornton & Olson, 1991;).The intent of this thesis was to use stable isotope analysis of serial dentine sections of teeth from a nineteenth century French-Canadian population, Saint Antoine, in Montreal to investigate the relationship between infant feeding and weaning practices and A) infant morbidity and mortality and B) cultural norms and practices. Due to problematic isotopic values, these questions were unable to be investigated, and thus the scope of this project shifted. This thesis was able to draw conclusions regarding Saint Antoine adult female diet, as well as assess the diet of one subadult individual (20C-S1) who yielded good isotope results. This study was also able to assess the prevalence of dental caries and enamel defects in a sample of Saint Antoine subadults.

Low prevalence of LEH may be the result of early age-at-death for individuals within this sample, meaning that LEH and other enamel defects did not have much time to form. The lack of LEH in deciduous teeth (that form *in utero*) suggest the absence of major fetal stress, which could be to due adequate maternal health and/or fetal buffering. For the small number of LEH that were observed, they all occurred in the post-natal period but at an older age than would be indicative of weaning stress. Rather, LEH are more likely to have been caused by post-weaning stress including malnutrition, viral or bacterial infection, trauma, or congenital conditions (Bereczki et al., 2019; Blakey et al., 1994; Kreshover, 1960; Moggi-Checci et al., 1994; Wood, 1996). Meanwhile, there was a moderate prevalence of dental caries among this population. While, in an adult sample,

this may be attributed to the consumption of a diet low to moderate in carbohydrates, the same cannot be said for a sample consisting of subadults like the one from Saint Antoine, as prevalence may be influenced by the loss of deciduous teeth (which may have been carious) and the presence of recently erupted permanent teeth (which may have not been exposed to the oral environment long enough to form caries) (Karsten et al., 2015; Prowse et al., 2008).

The adult female diet at Saint Antoine appears to have consisted of predominantly C_3 foods, alongside variable terrestrial and aquatic dietary protein. This variation in diet is consistent with foods available during the nineteenth century in Montreal, as many food products were available locally and regionally and others were imported from overseas (Fyson, 1989). However, simply because these foods were available, does not necessarily mean they were consumed, especially at the socioeconomic position that French-Canadians occupied. As women and children were increasingly participating in the workforce during this period, it is possible to consult purchasing records of Lachine Canal workers as a proxy for women who worked outside the home in places like cotton mills. These purchasing records suggest a diet consisting of bread, salted pork, and alcohol, as well as indicate a heavy reliance on peas by Francophone workers (Fyson, 1989). Pork can have a wide range of $\delta^{13}C$ values, especially in urban contexts, as pigs kept by individual households are likely to have been fed a diet consisting of variable household scraps, including plant and animal parts that cannot be digested by humans (Guiry et al., 2017). However, $\delta^{13}C$ values for adult females are quite similar, with a low SD of +/- 0.07‰, and as such are not consistent with the consumption of urban pork that was raised on a variety of leftover food scraps. Rather, if pork played a significant part in adult female diet, it appears it came from rural settings (where a more homogeneous diet is expected) or the urban pigs had a less diverse diet than expected.

While women may have worked outside of the home, it should not be assumed that is the case for all women of this period or socioeconomic status. Thus, foods consumed within the home should be considered. While cookbooks from the period can provide an indication of foods that might have been consumed within the home, they are not necessarily representative of what was consumed. Historical records from charitable

organizations emphasized bread, soup, barley, and rice as essential components to distribute to Montreal's less fortunate. These records may, indeed, provide a better indication of foods consumed within the home.

While many isotope results are unusable, 20C-S1 produced some results with acceptable values that can be used to make inferences regarding their diet. $\delta^{13}C$ values indicate that by 1 year of age, 20C-S1 was no longer exclusively breastfeeding, and was likely being weaned onto a diet consisting of C_3 foods. Between 1 and 4 years of age, $\delta^{13}C$ values increase by 1.9‰, while $\delta^{15}N$ values decrease by nearly 1.0‰. This indicates a shift towards a diet containing more C_4 foods or perhaps low trophic level aquatic foods.

Diagenetic changes may have caused alteration of the stable isotope compositions of the tooth dentine samples used in this study. However, the changes in isotopic values observed here are not consistent with changes occurring from the burial environment, like hydrolysis or microbial attack (Balzer et al., 1997; Guiry & Szpak, 2021; Harbeck & Grupe, 2009; Kendall et al., 2018; Hedges, 2002; Grupe et al., 2000; Grupe & Turban-Just, 1998). While laboratory procedures may have caused collagen loss, resulting in the measurement of C_3 plant material instead of collagen, the protocol used here has been replicated elsewhere with success (Czermak et al., 2020; Jørkov et al., 2007; Sealy et al., 2014). Moreover, if laboratory procedures were, indeed, the cause of altered isotopic values, one would expect all samples, including 20C-S1, to yield poor results. Future investigation may be justified. This study is clearly and severely limited by the lack of usable isotope data. This study further highlights the importance of limiting sample destruction in archaeological research, as the retention of the remaining portion of each tooth makes it possible to revisit this sample and conduct future analyses. If such analyses occur, then a method designed for poorly preserved samples should be utilized (e.g., Richards & Schmitz, 2008).

While poor results impact whether this study can be published, it should not negate the quality of the course of study itself. Good science may produce poor results (Timmermans, 2011). Poor results occur in the process of scientific inquiry, and failure is a key part of the scientific process, allowing researchers to return to their protocols,

reassess and determine the problem, and conduct their experiment once more with appropriate changes (Barwich, 2019). Given the constraints of conducting research at the graduate-level, including program duration (which was further exacerbated by COVID-19 delays in this case) and funding limitations, it is not possible to initiate a second round of sample processing and analysis, nor is it possible to go back and redo unsuccessful lab work and analyses. While the failure to produce acceptable isotope results exists in direct opposition to the traditional structure of academia, wherein one must publish and get funding and awards to obtain academic and professional appointments in order to gain full recognition for one's work (De Rond & Miller, 2005; Timmermans, 2011), the work produced here still fulfills the aims of my master's program, and should be recognized as scientifically sound research in spite of the limited results.

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Appendices

Appendix 1: Approval letter from Western Non-Medical Research Ethics Board.

Western Research

Date: 14 September 2021

To: Dr Andrea Waters

Project ID: 118570

Study Title: Stable Isotope Analysis of Breastfeeding and Weaning Practices in 19th Century Montreal

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: 01/Oct/2021

Date Approval Issued: 14/Sep/2021 09:42

REB Approval Expiry Date: 14/Sep/2022

Dear Dr Andrea Waters

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study.**

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Sadlowski MA Proposal Final	Protocol		

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
Order of preference for dental elements	Supplementary Tables/Figures		
Prets 2019_2022 dec Pte_aux_Trembles_St Antoine_	Sponsor Correspondence	23/Jun/2021	
CERSC-2020-045-D(1)Ribot	Sponsor Correspondence	23/Jun/2021	
CSERC (translated)	Sponsor Correspondence	30/Aug/2021	
Prets 2019_2022 dec Pte_aux_Trembles_St Antoine (Translated)	Sponsor Correspondence	30/Aug/2021	
For_J_Sadlowski_I_Ribot_UdeM	Sponsor Correspondence	03/Sep/2021	

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

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

Appendix 2: Full dental scoring records.

The full dental scoring details for subadults, as recorded in Microsoft Excel, can be found in Additional Files.

Curriculum Vitae

Name: Jessica Sadlowski

Post-secondary Education and Degrees:

McMaster University
Hamilton, Ontario, Canada
2015-2019 B.A.

The University of Western Ontario
London, Ontario, Canada
2020-2022 M.A.

Honours and Awards:

Dean's Honour List
McMaster University
2017-2019

Summa Cum Laude
McMaster University
2019

Graduate Research Award Fund ($750)
The University of Western Ontario
2021-2022

Social Science and Humanities Research Council ($19,500)
Canadian Graduate Scholarship-Masters
2021-2022

Related Work Experience

Graduate Teaching Assistant
The University of Western Ontario
2020-2022

Marker (contract)
The University of Western Ontario
2021

Graduate Research Assistant
The University of Western Ontario
2022

Conference Presentations:

Sadlowski, J., Brickley, M.B., Ribot, I. & Waters-Rist, A. (2022, October 26-28). Stable Isotope Analysis of Infant Feeding and Weaning Practices in nineteenth century Montreal [Conference Presentation]. CABA-ACAB 2022, Saskatoon, SK, Canada.

Sadlowski, J. (2022, March 16). Stable Isotope Analysis of Infant Feeding and Weaning Practices in nineteenth century Montreal [Keynote Presentation]. Western Research Forum, London, ON, Canada.