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Stable carbon and nitrogen isotope analysis of infant feeding practices and stress in 18th-19th century Pointe-aux-Trembles, Québec

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Abstract

This thesis is a bioarchaeological study of infant feeding practices and early life stress in 18th-19th century Pointe-aux-Trembles, a rural community near Montréal, Québec that was known to practice wet nursing. Stable carbon and nitrogen isotope analyses of 62 incremental dentine samples were used to reconstruct the feeding histories of 10 infants (<3 years of age) interred between 1709-1843. At least 6 of 10 infants display evidence of breastfeeding, with weaning foods (e.g., porridge, bread) typically introduced between ~1.5-5.5 months of age and weaning completion around 10.5-13.5 months. Isotopic and/or dental evidence of stress (e.g., enamel hypoplasia) was identified in 8 of 10 infants and is likely related to disease burden, frequent food shortages, gastrointestinal distress, and/or maternal stress. This study sheds light on the short lives of infants from a wet nursing community and contributes to the growing body of literature on women and children in bioarchaeology.

Keywords

Stable isotope analysis, incremental dentine, deciduous teeth, breastfeeding, weaning, physiological stress, Pointe-aux-Trembles, Montréal

Summary for Lay Audience

This thesis studies breastfeeding and weaning practices and early life nutritional and/or physiological stress in 18th to 19th century Pointe-aux-Trembles, a rural community near Montréal, Québec that was known to practice wet nursing. The foods we consume differ in their isotopic composition and leave signatures in our tissues (e.g., teeth). Breast milk has higher stable carbon and nitrogen isotope compositions than alternative infant foods (e.g., animal milk, pap), and this difference can be used to reconstruct infant feeding practices in past populations. Teeth form incrementally, beginning prior to birth and continuing into early life. Since teeth do not remodel, isotopic analysis of different layers can reveal an infant's feeding history. Periods of nutritional or disease stress during growth can also be identified via altered isotopic signatures, and via dental lesions that result from disruptions to enamel growth (such as enamel hypoplasia).

Stable carbon and nitrogen isotope analyses of 62 incremental dental samples were used to reconstruct the early life diets of ten infants (<3 years of age) buried in Pointe-aux-Trembles (AD 1709-1843). At least 6 of 10 infants display isotopic patterns indicative of breastfeeding, with weaning foods (e.g., porridge, bread) usually introduced between 1.5-5.5 months of age, and weaning completion around 1 year of age. Isotopic and/or dental evidence of stress was also identified in 8 of 10 infants, and may be related to disease burden, frequent food shortages, gastrointestinal distress, and/or maternal stress known to have affected Montréal at the time. This study sheds light on the short lives of infants from a documented wet nursing community and contributes to our understanding of women and children in Canadian history.

Résumé

Cette thèse est une étude bioarchéologique des pratiques d'alimentation des nourrissons et du stress au début de la vie à Pointe-aux-Trembles au 18e-19e siècle, une communauté rurale près de Montréal, au Québec, qui était connue pour pratiquer l'allaitement en nourrice. Les analyses des isotopes stables du carbone et de l'azote de 62 échantillons de dentine incrémentielle ont été utilisées pour reconstituer l'histoire de l'alimentation de 10 nourrissons (<3 ans) inhumés entre 1709 et 1843. Au moins 6 des 10 nourrissons montrent des signes d'allaitement, avec des aliments de sevrage (par exemple, porridge, pain) typiquement introduits entre ~1,5-5,5 mois et la fin du sevrage vers 10,5-13,5 mois. Des preuves isotopiques et/ou dentaires de stress (par exemple, hypoplasie de l'émail) ont été identifiées chez 8 des 10 nourrissons et sont probablement liées à la charge de morbidité, aux pénuries alimentaires fréquentes, à la détresse gastro-intestinale et/ou au stress maternel. Cette étude met en lumière la courte vie des nourrissons d'une communauté d'allaitement humide et contribue au corpus croissant de littérature sur les femmes et les enfants en bioarchéologie.

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Résumé Pour Public Non-Spécialiste

Cette thèse étudie les pratiques d'allaitement et de sevrage ainsi que le stress nutritionnel et/ou physiologique au début de la vie à Pointe-aux-Trembles aux XVIIIe et XIXe siècles, une communauté rurale située près de Montréal, au Québec, qui était connue pour pratiquer l'allaitement maternel. Les aliments que nous consommons diffèrent par leur composition isotopique et laissent des signatures dans nos tissus (par exemple, les dents). Le lait maternel présente des valeurs isotopiques stables de carbone et d'azote plus élevées que les autres aliments pour nourrissons (par exemple, le lait animal, le lait maternisé), et cette différence peut être utilisée pour reconstituer les pratiques d'alimentation des nourrissons dans les populations du passé. Les dents se forment progressivement, avant la naissance et jusqu'au début de la vie. Comme les dents ne se reforment pas, l'analyse isotopique des différentes couches peut révéler l'historique de l'alimentation d'un nourrisson. Les périodes de stress nutritionnel ou de maladie pendant la croissance peuvent également être identifiées par l'altération des signatures isotopiques et par les lésions dentaires résultant de perturbations de la croissance de l'émail (telles que l'hypoplasie de l'émail).

Les analyses des isotopes stables du carbone et de l'azote de 62 échantillons dentaires incrémentaux ont été utilisées pour reconstituer le régime alimentaire de dix nourrissons (<3 ans) enterrés à Pointe-aux-Trembles (AD 1709-1843). Au moins six des dix nourrissons présentent des profils isotopiques indiquant l'allaitement maternel, les aliments de sevrage (p. ex. bouillie, pain) étant généralement introduits entre 1,5 et 5,5 mois, et le sevrage étant terminé vers l'âge d'un an. Des preuves isotopiques et/ou dentaires de stress ont également été identifiées chez 8 des 10 nourrissons, et peuvent être liées à la charge de morbidité, aux pénuries alimentaires fréquentes, à la détresse gastro-intestinale, et/ou au stress maternel dont on sait qu'il a affecté Montréal à l'époque. Cette étude jette un éclairage sur la courte vie des nourrissons d'une communauté d'allaitement humide documentée et contribue à notre compréhension des femmes et des enfants dans l'histoire du Canada.

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Chapter 1

1 Introduction

This thesis studies infant feeding practices and physiological stress in 18th to 19th century Pointe-aux-Trembles using (1) stable carbon and nitrogen isotope analysis of incremental dentine collagen and (2) dental lesions indicative of stress. This chapter will introduce the project by providing some brief background information on bioarchaeological studies of infant feeding and Pointe-aux-Trembles. It will then outline the research questions and theoretical approach that guide this project and describe the remaining chapters found in this thesis.

1.1 Background

Prior to the 1990s, women and children were chronically under-represented in bioarchaeological literature. Consequently, the experiences of these groups have traditionally been overlooked, with women and children often perceived as passive members of society, not active contributors. Since Lillehammer's landmark publication in 1989 calling for greater attention to childhood in archaeology, there has been increasing interest in this research (Lillehammer, 1989, 2015; Lewis, 2007). Likewise, feminist archaeologists have called for greater attention to the perspectives and roles of women in past populations (Gero & Conkey, 1991). The rise in both of these areas has included research on breastfeeding and weaning practices, and such work has been used to understand constructions of childhood, the lived experiences of children, child-rearing practices, population demographics, infant and maternal health, and maternal investment in offspring across a wide range of populations and time periods (e.g., Britton et al., 2018; Gowland & Halcrow, 2020; Halcrow et al., 2017; Katzenberg & Waters-Rist, 2018; Tsutaya & Yoneda, 2015; Waters-Rist et al., 2022). Ultimately, this research offers important insight into the experiences of women and children and contributes to rectifying their under-representation in bioarchaeology.

A variety of methods have been used in bioarchaeological studies of infant feeding practices, but much of this research has been facilitated by stable isotope analysis (e.g.,

Beaumont et al., 2013; Britton et al., 2018; Burt & Garvie-Lok, 2013; Eerkens et al., 2011; Gutierrez et al., 2021; Katzenberg et al., 1996; King et al., 2018; Tsutaya & Yoneda, 2013; Waters-Rist et al., 2022; Wright & Schwarcz, 1998). The isotopic signature of a person's diet is recorded in their bodily tissues during growth and isotopic analysis of human skeletal and dental tissues enables bioarchaeologists to reconstruct the types of foods consumed by past individuals and populations (DeNiro & Epstein, 1978, 1981). Since breast milk has higher stable carbon (δ^{13}C) and nitrogen (δ^{15}N) values than alternative infant foods (e.g., pap, porridge, animal milk), infant δ^{13}C and δ^{15}N values will normally be elevated during breastfeeding and decline with weaning (Fogel et al., 1989; Fuller et al., 2006). As such, by evaluating changes in δ^{13}C and δ^{15}N values in early life, researchers can identify periods of exclusive breastfeeding, weaning, and post-weaning diets (Fuller et al., 2006).

Some bioarchaeological studies of infant feeding practices use bone collagen. These studies take a population-level approach wherein the researchers analyze separate burials and compare each individual's age-at-death to the isotopic composition of recently formed bone collagen (e.g., Britton et al., 2018; Tsutaya & Yoneda, 2013; Waters-Rist et al., 2022). A trend may emerge that shows higher isotopic signatures in infancy (associated with breastfeeding) that lower with increasing age to levels associated with adult diets. The age at which the isotope values start to decline provides an estimated average weaning initiation age within the population. This method may be preferred by some researchers as it can permit evaluation of large samples within a relatively short amount of time. However, it can obscure intra-population variation in breastfeeding practices, and relies on samples of non-survivors who may not accurately represent the larger population (DeWitte & Stojanowski, 2015; Wood et al., 1992). Further, isotopic analyses of bone are complicated by remodeling. The isotope values of adult bone represent an average of the past ~10 or more years of life due to the continuous removal and deposition of bone tissue (Hedges et al., 2007; Matsubayashi & Tayasu, 2019). The time span is less in non-adults who experience both bone modeling (growth) and faster remodeling than adults; however, the exact amount of time encapsulated in different bones is largely unknown. This introduces a degree of uncertainty to the ages represented by samples of bone collagen, suggesting that inferences of weaning practices produced

by bone collagen must be made with caution (Beaumont, 2020). To mitigate some of these issues, researchers have developed methods of studying infant feeding practices using other archaeological tissues, namely teeth (Beaumont et al., 2013; Czermak et al., 2018; Eerkens et al., 2011; Fuller et al, 2003).

Bioarchaeologists may reconstruct infant feeding practices using collagen from tooth dentine. Teeth form incrementally in early life, beginning prior to birth and ending in adolescence. As teeth do not remodel, the isotopic composition of dentine is retained over time and can provide reliable evidence for the types of foods consumed during infancy and childhood (Beaumont, 2020). By analyzing δ^{15}N and δ^{13}C from sequentially formed layers of dentine, researchers can create a longitudinal reconstruction of an individual's dietary history, including periods of exclusive breastfeeding and weaning (Beaumont et al., 2013; Eerkens et al., 2011; Fuller et al., 2003). Rather than taking a population-level approach, this method involves an in-depth consideration of each individual in the study sample (Beaumont, 2020). This allows researchers to consider variation in infant feeding practices within groups, while also permitting them to identify patterns that arise between individuals. Further, researchers can use additional information about the individual (e.g., evidence of pathological lesions) to weigh competing explanations for changes in their δ^{15}N and δ^{13}C values. Thus, by analyzing sequential samples of dentine collagen (also referred to as incremental or serial samples), bioarchaeologists can produce reliable interpretations of infant feeding histories.

In 2014, archaeological excavations by the CRM firm Ethnoscop in Pointe-aux-Trembles, Québec, uncovered a portion of a Catholic cemetery in use between AD 1709-1843 (Ethnoscop, 2016). Pointe-aux-Trembles is located ~20km from the city of Montréal and in the 18th to 19th centuries, it was a rural village of European settlers. Despite the rapid population growth and urbanization experienced in Montréal, Pointe-aux-Trembles retained its rural character until the 1900s (Ethnoscop, 2016). It was primarily an agricultural community and a stopping-point for travelers en route to Montréal or Québec City (Ethnoscop, 2007). Pointe-aux-Trembles was also home to wet nurses who would feed and care for infants born in Montréal (Robert, 2011). This practice, combined with the notion that infant feeding practices contributed to the high rates of infant mortality in

18th to 19th century Montréal (Grenier, 1871; Thornton & Olson, 2011), suggests further exploration of breastfeeding and weaning practices in Pointe-aux-Trembles is important. Bioarchaeological analyses are uniquely positioned to improve our understanding of infant feeding practices in this community by providing direct evidence of what infants consumed (e.g., breast milk, alternative foods) and the ages when dietary shifts occurred.

1.2 Project Aims and Approach

This thesis aims to improve our understanding of infant feeding practices and physiological stress in 18th to 19th century Pointe-aux-Trembles, Québec. To do so, this project uses stable carbon and nitrogen isotope analysis of incremental dentine collagen, dental health analyses, and a biocultural theoretical approach. Deciduous teeth were analyzed to capture the first 2-3 years of life, as well as the third trimester of prenatal development. Bone collagen samples were collected from adult females to contextualize the non-adult isotope results and aid interpretations. The dental remains of non-adults were also analyzed for evidence of pathological lesions that may be indicative of stress (e.g., enamel hypoplasia), and the presence of such lesions was considered when analyzing the isotopic data. This thesis has three research questions:

1. Were infants in this sample breastfed? If so, for how long?
2. What types of supplementary foods were consumed, and when were they introduced?
3. Do infants in this sample show dental or isotopic evidence of nutritional or disease stress?

Along with the isotope and dental health data, the historical context of 18th to 19th century Pointe-aux-Trembles and Montréal are used to answer the research questions.

The biocultural theoretical approach considers breastfeeding as both a social and biological phenomenon (Zuckerman & Martin, 2016). Decisions surrounding infant feeding practices are inextricably linked to sociocultural factors, including socioeconomic status, cultural practices, and religious beliefs. They are also dependent upon biological factors, such as the ability of women to produce and provide breast milk and the ability of

the infant to suckle. These decisions have physiological implications for both the woman breastfeeding (e.g., mother, wet nurse) and the child. As such, studies of breastfeeding practices must consider both social and biological aspects of this process. By interpreting isotopic data within the cultural context of 18th to 19th century Pointe-aux-Trembles, a more comprehensive reconstruction of infant feeding practices will be created. For this thesis, context is gathered from data in archaeological reports, archival records, and historical sources.

Previous research has investigated breastfeeding practices in Pointe-aux-Trembles (Gutierrez, 2019; Gutierrez et al., 2021). This thesis will build upon earlier work by including analyses of δ^{13}C (only δ^{15}N was used previously) and by using more refined incremental sampling methods. Additionally, including dental health analyses will permit clearer interpretations of the isotopic results from each individual.

This thesis is part of a larger interdisciplinary research project that combines paleodietary and paleopathological approaches to explore the relationship between diet and disease in bioarchaeology. The scope of this thesis is limited to isotopic and dental health analyses, and paleopathology analyses of skeletal remains are currently being conducted by collaborators at McMaster University. The results of both approaches will be combined in future work; the skeletal and post-cranial pathology data are not considered here.

1.3 Organization of this Thesis

There are seven chapters in this thesis. This chapter (Introduction) has introduced the project, its central research questions, and theoretical approach. Chapter 2 (Background) is a literature review that covers the methodological information needed to understand dental and isotopic studies of infant feeding and stress. This includes dental development, pathological dental lesions, stable carbon and nitrogen isotopic systems, and incremental sampling approaches. Chapter 3 (The Sample and Historical Context) describes the archaeological and historical background for Pointe-aux-Trembles (1709-1843) and details the sample selection procedure. Lifeways in the city of Montréal and the rural community of Pointe-aux-Trembles are discussed. Chapter 4 (Methods) describes the methods used in this study. Chapter 5 (Results) presents the results of dental health and

isotopic analyses. Chapter 6 (Discussion) interprets the results within the context of 18th to 19th century Pointe-aux-Trembles. The final chapter (Chapter 7) is the conclusion.

Chapter 2

2 Background

This chapter describes the background information necessary to understand (1) how dental pathology can contribute to our understanding of stress, and (2) how isotopic analyses and incremental dentine sampling methods can be used to study diet and physiological stress during infancy. The terms used throughout this thesis are first defined. Then, general background on dental tissues and tooth formation is introduced, followed by a brief description of the dental lesions examined in this thesis. Next is a discussion of stable carbon and nitrogen isotopes and their use in studies of infant feeding practices and stress. The chapter concludes with a review of previous infant feeding studies that have used incremental dentine sampling techniques.

2.1 Terminology

To ensure clarity and consistency with existing literature, it is important to explicitly define frequently used terms. Lactation is the production and secretion of milk. It occurs as a result of hormonal cascades related to pregnancy in female mammals and evolved to feed and promote immunological development of offspring (Quinn, 2018). In humans, lactation is often discussed in the context of breastfeeding, or the act of feeding a child with milk produced by one's body. Complementary or alternative foods are foods given to infants that are not human breast milk and weaning is the gradual cessation of breast milk consumption (Kendall et al., 2021). Breastfeeding practices vary widely within and between populations, both in terms of nursing duration and the types of complementary foods that are introduced during the weaning process. Typically, children are exclusively breastfed following birth, consuming nothing but breast milk. The initiation of weaning is marked by the introduction of complementary foods, and the complete cessation of breastfeeding signals the end of the weaning process (Kendall et al., 2021).

Stress is a physiological disruption to homeostasis in one's body. It can be caused by several different psychological or physiological factors, making it challenging to define in bioarchaeology (Edinborough & Rando, 2020; Temple & Goodman, 2014). Since this

thesis studies human remains, the data and conclusions it produces will only reflect stressors that leave isotopic and/or dental evidence (Temple & Goodman, 2014; Wood et al., 1992). As isotopic and dental indicators of stress are generally caused by illness or malnutrition, this thesis focuses on physiological stress that is derived from nutritional and/or disease factors.

Various terms can also be used to define stages within one's life, and the use of such terms varies across anthropological subdisciplines (Halcrow & Tayles, 2008b). In bioarchaeology, age categories are often based on estimations of biological age (the age of an individual represented by their stage of skeletal or dental development), which can differ from chronological age (time since birth) and social age (a culturally constructed definition of the roles and behaviours associated with age) (Halcrow & Tayles, 2008b). Within this thesis, age groups are defined using biological age. Adults include anyone over 15 years of age, while non-adults include individuals ≤15 years of age. The prenatal period lasts from conception to birth (i.e., <40 weeks *in utero*) and the perinatal period lasts from 24 weeks gestation (~4 months prior to birth) until 7 days after birth (Scheuer & Black, 2000). The neonatal period is the first 28 days after birth and is followed by infancy, which lasts until ~3 years of age (Bogin, 2020). To simplify the terminology used in this thesis, infancy is defined as the period from birth to 3 years of age, unless otherwise specified. Additional terms (e.g., isotope, wet nursing) will be defined as they are discussed throughout this thesis and Appendix A lists abbreviations and acronyms used throughout the text.

2.2 Dental Tissues

Teeth are composed of three dental tissues (enamel, dentine, and cementum) and two main anatomical regions (crown and root; Figure 2.1). Enamel covers the tooth crown and is highly mineralized. Dentine forms the core of the tooth and surrounds the pulp chamber/cavity, which contains nerves, blood vessels, and other soft tissue. Dentine is composed of ~70% inorganic (mineral) and ~30% organic (mainly collagen) components (Dean, 2017). Cementum is a thin layer of tissue that covers the tooth root and attaches to the periodontal ligament. The areas where these tissues meet are the enamel-dentine

junction (EDJ), cement-dentine junction (CDJ), and the cement-enamel junction (CEJ). The CEJ is located at the cervix of the tooth, where the crown meets the root.

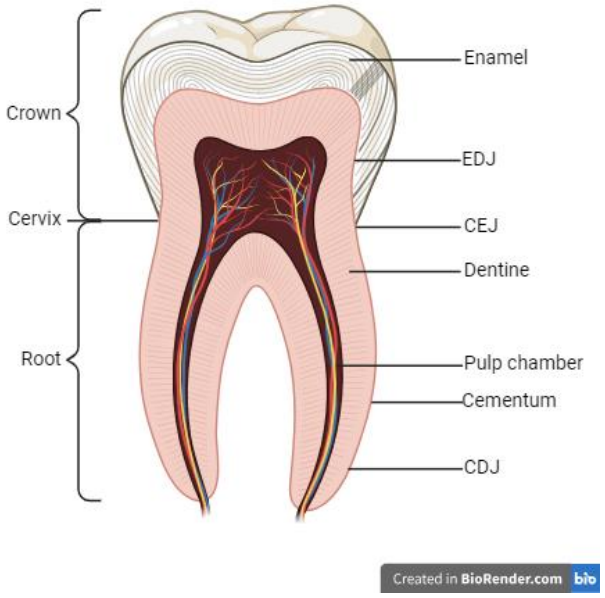

Figure 2.1. Labelled diagram showing cross section of a molar. EDJ: enamel-dentine junction; CEJ: cement-enamel junction; CDJ: cement-dentine junction. Figure created using BioRender (2023).

Humans are diphyodonts, and thus have both deciduous and permanent dentition. Deciduous teeth develop early in life and are generally lost by 12 years of age, while permanent teeth begin forming around birth and continue to develop and erupt throughout adolescence (AlQahtani et al., 2010). Because teeth do not remodel, they provide a record of dietary and health information from their time of formation (Hillson, 2014). Teeth are also more resistant to diagenetic alteration than bone and are thus a good tissue for bioarchaeologists to analyze (Kendall et al., 2018).

2.2.1 Tooth Formation and Eruption

Odontogenesis is the process of tooth formation. In the first three stages (bud stage, cap stage, bell stage; Figure 2.2), the tooth crown begins to take shape. Odontogenesis starts at approximately six weeks *in utero*. At this point, the arch of the jaws has developed from mesenchymal cells and a layer of epithelium (Adserias-Garriga & Visnapuu, 2019;

Hillson, 1996). A primary epithelial band forms from the epithelium and divides into the vestibular lamina and dental lamina (Hillson, 1996; Scheuer & Black, 2000). By the tenth week *in utero*, the process has reached the end of the bud stage and 20 (10 mandibular, 10 maxillary) enamel organs (‘buds’) of the deciduous teeth have developed on the dental lamina (Hillson, 1996). In the cap stage, the enamel bud develops a concavity within which the dental papilla forms (Adserias-Garriga & Visnapuu, 2019; Hillson, 1996). The internal enamel epithelium forms from the enamel organ, and the dental follicle forms from the surrounding mesenchyme (Hillson, 1996). During the bell stage, the tooth germ begins to take the shape of a tooth crown and dentine- and enamel-forming cells (odontoblasts and ameloblasts, respectively) start to differentiate (Hillson, 1996). Odontoblasts form from the dental papilla and begin to produce pre-dentine while ameloblasts form from the internal enamel epithelium and produce enamel matrix (Hillson, 1996; Scheuer & Black, 2000). Layers of enamel are deposited conically with each successive layer increasing the cuspal height and extending further down the crown (Figure 2.3; Hillson, 1996). Simultaneously, layers of dentine are deposited following the internal shape of the developing cusp (Figure 2.4; Hillson, 1996). The processes of enamel and dentine formation are discussed in greater detail below.

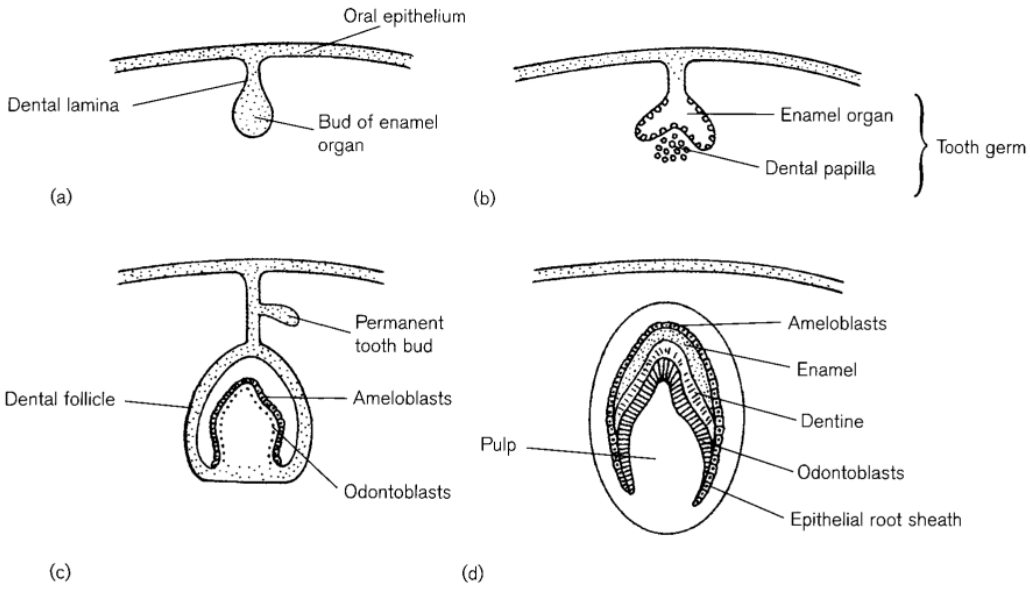

Figure 2.2. Diagram depicting the initial stages of odontogenesis. A) bud stage; B) cap stage; C) bell stage; D) late bell stage when mineralization begins. From Scheuer & Black (2000, p. 154).

2.2.1.1 Enamel

There are two main stages of enamel formation: matrix secretion and mineralization/maturation. During the first stage, ameloblasts secrete a matrix that contains both organic (amelogenins, enamelin, and ameloblastin) and mineral (hydroxyapatite) components. During the maturation/mineralization phase, the ameloblasts remove the organic portion from the matrix, and the mineral crystals grow to replace it (Hillson, 1996; Palmer et al., 2008). New minerals are deposited and the crystals grow in width until they represent approximately ~95-97% of the enamel tissue (Lacruz et al., 2017; Palmer et al., 2008).

Ameloblast activity varies on a regular rhythmic basis and produces incremental microscopic markings. There are two main types of these markings in enamel that reflect different periodicities: cross striations are formed daily, and the striae of Retzius form every 6-12 days (Hillson, 1996; Mahoney, 2011). Where the striae of Retzius reach the outer enamel surface, they are referred to as perikymata. In deciduous teeth, an accentuated striae of Retzius develops around birth and is referred to as the neonatal line

(Adserias-Garriga & Visnapuu, 2019). Counts of cross-striations and striae of Retzius visible on histological sections have been used to estimate enamel formation times for permanent and deciduous teeth (Holt et al., 2012; Mahoney, 2011, 2012; Reid & Dean, 2000, 2006).

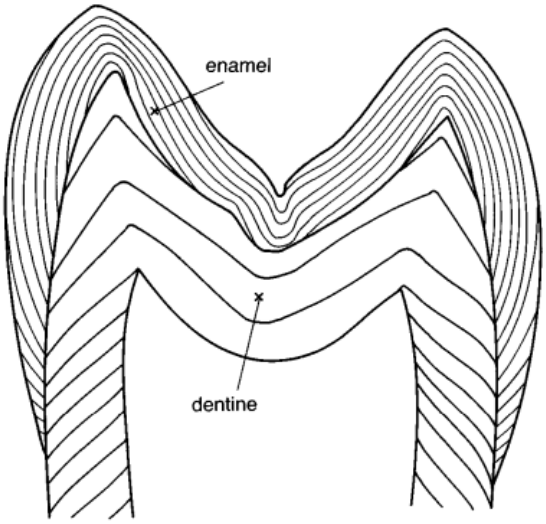

Figure 2.3. Diagram showing orientation of layers (striae of Retzius) in enamel. Dentine growth layers (Andresen bands) are also visible. Modified from Hillson (1996, p. 120).

2.2.1.2 Dentine

Dentine forms simultaneously with enamel. As with enamel, dentine formation occurs in two main stages: the secretion of a pre-dentine matrix, followed by mineralization (Hillson, 1996). Beginning at the EDJ, odontoblasts start to secrete the pre-dentine matrix, which contains collagen fibers embedded in a ground substance (Hillson, 1996). Once this matrix has been established, calcospherites (calcium salts) are deposited within. During the mineralization stage, these calcospherites grow and fuse together (Dean, 2017; D'Ortenzio et al., 2016; Hillson, 1996). Unlike enamel formation, the collagen fibers deposited during matrix secretion remain in the dentine.

Dentine formation proceeds in the direction depicted in Figure 2.4 and also produces incremental structures (e.g., Andresen bands), though these are less clearly defined than the striae of Retzius in enamel (Hillson, 1996). Some studies have used markers (e.g., tetracycline) to track dentine formation and their results suggest that dentine forms at a

relatively constant rate, though there is some minor variation (Dean & Scandrett, 1995). Once dentine is deposited, it does not remodel. Secondary dentine is continuously deposited along the pulp chamber throughout life, but this only occurs after tooth formation is complete (Hillson, 1996).

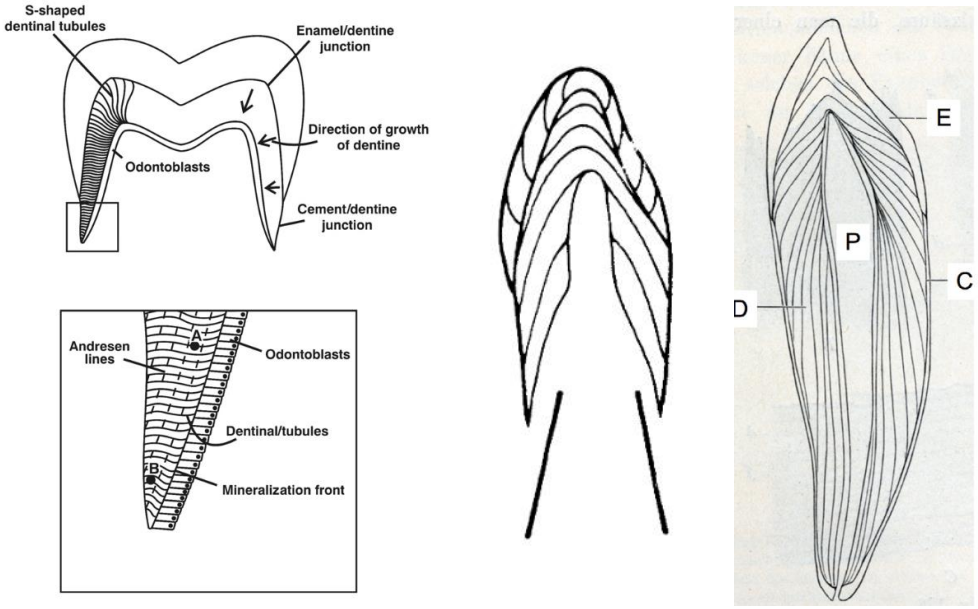

Figure 2.4. Diagrams depicting dentine development. Left images show the direction of dentine growth and the Andresen lines (points A and B lie in the same Andresen band; modified from Beaumont et al., 2013, p. 279). Center and right images show how the angles of incremental dentine lines change throughout the tooth (modified from Dean, 2017, pp. 559, 566). E: enamel; D: dentine incremental lines; P: pulp cavity; C: cementum.

2.2.1.3 Eruption and Age Estimation

Dental eruption is the process by which teeth emerge from the jaws and come to protrude into the mouth (Hillson, 1996). Deciduous teeth are the first to erupt, and while in occlusion, permanent teeth are forming within the jaws. Eruption begins after the crown and part of the root have formed. First, the surrounding alveolar bone begins to resorb and the tooth migrates above the alveolar crest. The tooth then erupts through the gingiva and continues to move until it reaches occlusion (Hillson, 1996). Over time, the roots of deciduous teeth resorb, and permanent teeth start erupting in their place.

Patterns of tooth formation and eruption are commonly used to estimate the age of a developing individual. As dental development is less variable than skeletal growth, it is considered a better indicator of age in non-adults (Hillson, 1996). Several charts have been developed to track sequences of formation and are regularly used by bioarchaeologists (e.g., AlQahtani et al., 2010; Buikstra & Ubelaker, 1994; Gustafson & Koch, 1974; Moorrees et al., 1963a, 1963b; Smith, 1991). More recent work has produced charts to estimate ages of formation for increments within individual teeth (e.g., Beaumont & Montgomery, 2015; Holt et al., 2012; Mahoney, 2011, 2012; Reid & Dean, 2006).

2.3 Dental Pathology

There are a number of different conditions and types of pathological lesions that can appear on teeth. Some arise during tooth formation, while others develop after teeth have erupted. In bioarchaeology, dental lesions are used to study diet, malnutrition, health, behaviour, and a wide range of other topics. In this thesis, teeth are examined for dental defects indicative of physiological stress during the growth period, namely enamel hypoplasia (EH). Caries, periodontitis, dental calculus, and wear are also assessed, as these can often be intertwined with EH and may provide insight into early life diet and behaviour (Hillson, 2018).

2.3.1 Enamel Hypoplasia

Enamel hypoplasia is a visible defect in enamel thickness caused by a disruption to ameloblast activity during the matrix secretion stage (Hillson, 1996, 2018; Lewis, 2018). The mechanisms by which this occurs are poorly understood, but EH has been associated with several conditions including dietary deficiencies, birth trauma, childhood diseases, and more (Hillson, 2005; Lewis, 2018; Salanitri & Seow, 2013). Given the range of associated factors, they are typically used as indicators of non-specific physiological stress in bioarchaeology (Goodman & Rose, 1990; Lewis, 2018).

Hypoplastic defects can take several different forms. As explained by Hillson (2014), there are three general types of defects: furrow-form, pit-form, and plane-form. Furrow-form EH, also commonly referred to as linear enamel hypoplasia, appears as a horizontal

groove in the tooth surface. Plane-form EH is similar to furrow-form EH, but they affect a larger surface area. Depending on when the disruption occurred, these may appear as accentuated deep bands along the crown or as small malformed cusps that look like nodules of enamel (Hillson, 2014; Lewis, 2018). Pit-form EH are discontinuous defects that appear as pits on the crown surface. They may develop individually, in a horizontal row, or scattered across the tooth crown. In addition to these types, some researchers consider localized hypoplasia of the primary canine (LHPC) as its own class of defect. LHPC appear as roughly circular, flat or concave pits on deciduous canines (Halcrow & Tayles, 2008a; Skinner & Hung, 1989). Finally, cuspal EH was proposed by Ogden and colleagues (2007) as another form of defect. Cuspal EH is described as a combination of abnormal cusp development and pit- and plane-form lesions, leading to extensive defects on the tooth surface (Ogden et al., 2007).

Since enamel contains incremental markings that form at regular rhythms/intervals, one can use these markings to estimate the age-at-formation of hypoplastic defects and thus the age when the stress episode was experienced. This can be achieved by using histological sections to count cross-striations and striae of Retzius, or to measure the distance of the accentuated striae from the EDJ (e.g., Birch & Dean, 2014). These methods, however, require destruction of the affected tooth.

Some studies have used counts of incremental markings to develop macroscopic, non-destructive methods of estimating age at EH formation. In 2000, Reid and Dean used histological analyses to generate decile-based charts for use in estimating crown formation times in anterior permanent teeth, and later published such data for permanent molars (Reid & Dean, 2006) and premolars (Holt et al., 2012). Similar techniques have been applied to deciduous teeth by Mahoney (2011, 2012) to reconstruct crown formation times. These charts and distance-based regression equations derived from them have been used to estimate age-at-formation for enamel defects in permanent teeth (e.g., Dąbrowski et al., 2021; Henriquez & Oxenham, 2019), but such work in deciduous dentition is less common (López-Lázaro et al., 2022).

These macroscopic techniques have an important limitation (Hillson, 2014). Because of the appositional nature of enamel growth, the layers visible on the surface obscure previously formed layers beneath (Figure 2.3). When EH is observed on only the outer surface of enamel, it is not clear which layer was affected by the disruption to amelogenesis (Hillson, 2014). For a given defect, the disruption may have occurred while enamel close to the surface was forming, or it may reflect a disruption in the formation of enamel closer to the EDJ. Examination using thin sections is required to determine which layer(s) were disturbed. Methods of estimating age-at-formation must be considered carefully with this limitation in mind, particularly when working with deciduous teeth where distinctions between pre-, peri-, and postnatal EH formation can significantly alter interpretations of the results.

2.3.2 Dental Caries

Carious lesions form through the removal of hydroxyapatite from enamel and dentine. Such lesions range in severity, from small areas of focal demineralization to gross cavities that extend into the pulp chamber. Early caries may appear as areas of discoloration but, given the number of depositional/burial factors that can cause staining, an indentation is typically required to identify caries bioarchaeologically. Caries can develop on the crowns or roots of teeth, and the distribution of carious lesions varies within the mouth (Hillson, 2008). Caries are observed more frequently on molars than incisors and canines, and more often in the maxillary dentition than mandibular teeth (Hillson, 2005). A number of variables have been associated with caries development (e.g., diet, oral hygiene, individual susceptibility) and as such, caries etiology is considered multifactorial.

There is a strong link between diet and caries development, and some foods promote caries to a greater degree than others. Generally, carbohydrates are more cariogenic than proteins and fats because plaque bacteria produce demineralizing acids by breaking down sugar molecules (Hillson, 2008). Mono- or disaccharides (e.g., sucrose) are used by oral bacteria more readily than starches or other polysaccharides, and high consumption of sugary foods has been linked to caries development (Hillson, 2008, 2018). Since starches can be converted to disaccharides in the oral cavity, diets containing starchy foods can

also be considered cariogenic (Hillson, 2008). Cooked, ground, or otherwise processed starches are more easily broken down, and thus more cariogenic than raw starches (Hillson, 2008).

Caries may also be intertwined with nutritional or disease stress. Malnutrition has been associated with increased risk of caries, particularly in non-adults (Psoter et al., 2005; Singh & Purohit, 2020; Walter et al., 2015). Additionally, caries can form more readily in hypoplastic regions of teeth (Hillson, 2018). As such, individuals who experienced stress during tooth formation may be at a greater risk of caries development.

Dental plaque has an important role in caries production. Plaque deposits develop on tooth surfaces and are composed of fluid, a plaque matrix, and a diverse array of bacteria (Hillson, 2008). Some of these bacteria can metabolize carbohydrates to form acidic products, which can then demineralize nearby dental tissues (Hillson, 2005, 2008). Ideally, the demineralization is balanced by remineralization that occurs when calcium and phosphate ions from saliva are re-incorporated into the tooth mineral (Hillson, 2008; Ortiz et al., 2019; Shaffer et al., 2015; Yousefi et al., 2020). Ultimately, any factor that upsets this balance (resulting in a net loss of hydroxyapatite) can promote caries development (Hillson, 2008; Lukacs & Largaespada, 2006).

2.3.3 Dental Calculus

Dental calculus is mineralized dental plaque. It indicates that plaque deposits were present for an extended period and may appear above or below the gums (supragingival and subgingival calculus, respectively) (Hillson, 2018; Lewis, 2018; Roberts & Manchester, 2005). Calculus can be a useful indicator of diet in bioarchaeology, as it can contain plant matter (e.g., starch granules, phytoliths) that provides direct evidence of food consumption (Forshaw, 2022; Hillson, 2018; Roberts & Manchester, 2005). Subgingival calculus is also associated with periodontal disease (Hillson, 2018; Roberts & Manchester, 2005).

2.3.4 Periodontal Disease

Periodontal disease is the result of infection and inflammation in the tissues of the jaw. Gingivitis occurs first and, if untreated, the infection may spread to bone (periodontitis). This can lead to bone loss that appears as an increased distance between the tooth CEJ and the surrounding alveolar bone (Hillson, 2018; Roberts & Manchester, 2005). Factors such as poor oral hygiene can increase an individual's risk of periodontal disease, and periodontitis has been associated with several nutritional deficiencies (e.g., vitamins C and D) and systemic conditions (e.g., diabetes) (Dommisch et al., 2018; Nazir, 2017).

2.3.5 Dental Wear

Dental wear refers to the gradual loss of enamel (and possibly dentine) that is not caused by caries. It may form through attrition (contact with other teeth), erosion (caused by chemical degradation), or abrasion (contact with foreign objects) (Roberts & Manchester, 2005). In bioarchaeology, it is used to indicate aspects of one's diet (e.g., hardness of foods) or behaviour but, given the range of factors that can lead to dental wear, specific causes can be challenging to identify (Hillson, 2018; Roberts & Manchester, 2005). Dental wear is important to consider as loss of tissue from the tooth surface can remove evidence of other lesions, such as caries or EH. It can also expose new surfaces or tissues (e.g., dentine) to the external environment, possibly increasing the risk of caries development (Hillson, 2005, 2018).

2.4 Stable Isotopes

Isotopes are atoms of the same element that vary in their number of neutrons. This results in differences in atomic mass, which affect the properties of an isotope and its behaviour in chemical reactions. Some isotopes of a particular element are stable (i.e., they do not decay over time), while others may be radioactive. The mass of an isotope can affect the speed at which it reacts in chemical reactions and different reaction pathways may prefer heavier or lighter isotopes. As such, the products of a chemical reaction may have a different isotopic composition than the reactants. This phenomenon is called isotopic fractionation, and it leads to the variation in isotopic signatures that forms the basis of this research (Coplen, 2011).

All molecules and macromolecules (e.g., proteins, carbohydrates) are made of isotopes, and the ratios of isotopes found within a molecule define its isotopic composition (Coplen, 2011). Macromolecules are formed using monomers (e.g., amino acids or monosaccharides) and in humans, these come from digested foods and liquids. The isotopic composition of a macromolecule depends on its degree of fractionation (often called the fractionation factor) and the initial isotopic composition of the reactants. These macromolecules can be extracted from human tissues (such as dentine), and their isotopic composition can be measured. Since macromolecules are formed using monomers obtained from an individual's diet, the macromolecule's isotopic composition reflects the foods and liquids one consumes (DeNiro & Epstein, 1978, 1981).

Before discussing the key isotopes in this research project, it is important to define the terminology and conventions used in isotopic literature. Isotopic compositions are expressed as delta values (δ) in units permil (‰). Delta values relate the isotopic composition of a substance (e.g., a tissue) to the composition of internationally recognized standards (Equation 2.1).

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \text{ where } R = \frac{heavy\ isotope}{light\ isotope}$$

Equation 2.1. Formula for calculating delta (δ) values (Szpak et al., 2017). For carbon, ^{13}C is the heavy isotope, ^{12}C is the light isotope, and VPDB is the standard. For nitrogen, ^{15}N is the heavy isotope, ^{14}N is the light isotope, and AIR is the standard.

The standards used for carbon and nitrogen are Vienna Pee Dee Belemnite (VPDB) and AIR, respectively (Szpak et al., 2017). These standards have a homogeneous isotopic composition and are the agreed-upon zero point that isotope scientists use to compare findings. A sample with a positive delta value has more of the heavy isotope than the standard and is said to be enriched. Negative delta values describe samples that are depleted in the heavy isotope relative to the standard.

2.4.1 Carbon

The first isotope system to be reviewed is carbon. There are three main carbon isotopes: ^{12}C, ^{13}C, and ^{14}C; ^{12}C is the most abundant. ^{14}C is radioactive and is commonly used for radiocarbon dating. In stable isotope analyses of carbon, $\delta^{13}C$ compares the amount of ^{13}C (the heavy isotope) and ^{12}C (the light isotope) relative to VPDB. Bioarchaeologists are interested in the carbon isotopes found in bone or dentine collagen, and bone or enamel bioapatite. The $\delta^{13}C$ values from collagen and bioapatite reflects variation in dietary carbon, which is obtained from carbohydrates, fats, and proteins found in plant and animal food sources.

Plants vary in their carbon isotopic composition due to their photosynthetic pathways and carbon source. Photosynthesis is the process by which plants use light energy to convert carbon dioxide (CO_2) and water into glucose and oxygen. Plants are divided into three main categories based on the pathway that they follow: C_3 (e.g., trees, shrubs, grasses, other temperate plants), C_4 (e.g., maize/corn, sugarcane, tropical grasses), and Crassulacean Acid Metabolism (CAM) plants (e.g., succulents, cacti) (Marshall et al., 2007). C_3 and C_4 pathways involve different enzymes, and this leads to variation in $\delta^{13}C$ values. In modern C_3 plants, $\delta^{13}C$ is around –27‰ on average, while modern C_4 plants have $\delta^{13}C$ values of about –12‰ (Casey & Post, 2011). CAM plants may follow either photosynthetic pathway and their $\delta^{13}C$ values are between those of C_3 and C_4 plants (Marshall et al., 2007). Further, the mean $\delta^{13}C$ values of plants may vary over time due to changes in the $\delta^{13}C$ values of atmospheric CO_2 (Casey & Post, 2011). This is important to consider in paleodietary reconstructions as the increase in fossil fuel emissions after the Industrial Revolution has decreased atmospheric $\delta^{13}C$ (the ‘Suess effect’), thus decreasing modern plant $\delta^{13}C$ signatures as well (Graven et al., 2020; Marshall et al., 2007).

There is a systematic difference between dietary $\delta^{13}C$ and the $\delta^{13}C$ of one’s tissues (called diet-tissue spacing or diet-tissue offset) that varies according to the tissue being analyzed (e.g., bone, blood). Fractionation occurs when dietary components are broken down and used to build collagen and other body tissues, leading to a difference in the $\delta^{13}C$ values of the foods that were consumed and tissue that was formed. As tissue formation involves

different processes and chemical reactions for particular tissue types, different degrees of fractionation occur, leading to variation in diet-tissue spacing. For collagen, $\delta^{13}C$ values are typically between 3.5-5.1‰ higher than dietary $\delta^{13}C$ (DeNiro & Epstein, 1981; Fernandes et al., 2012; Froehle et al., 2010; Keegan & DeNiro, 1988; Moreiras et al., 2020; van der Merwe & Vogel, 1978).

There is a trophic level effect which denotes a consistent increase in isotope values with increasing trophic level. For $\delta^{13}C$, this increase is typically considered to be ~1‰, but some research suggests enrichment values may range from 0 to 2‰ (Bocherens & Drucker, 2003; Fuller et al., 2006).

In dentine and bone, carbon may be found in collagen and hydroxyapatite. By removing the mineral components of these tissues, one can analyze the $\delta^{13}C$ values found in collagen. Collagen is a protein synthesized from amino acids. Some amino acids can be produced by one's body (non-essential), while others must be obtained from one's diet (essential). Essential amino acids will come from consumed protein, while non-essential amino acids can be formed using carbon from other sources (including carbohydrates and lipids). Some models and feeding studies have attempted to characterize the proportion of collagen $\delta^{13}C$ that comes from various dietary sources. Fernandes and colleagues (2012) suggest that ~75% of collagen $\delta^{13}C$ comes from protein, while ~25% comes from carbohydrates and/or lipids. Thus, collagen $\delta^{13}C$ values predominantly reflect dietary protein, but variation in carbohydrates and lipids also contributes to final $\delta^{13}C$ values.

2.4.2 Nitrogen

The second isotope system relevant to this thesis is nitrogen. ^{14}N and ^{15}N are the two nitrogen isotopes, with ^{14}N as the most abundant. $\delta^{15}N$ measures the amount of ^{15}N (the heavy isotope) and ^{14}N (the light isotope) in a substance relative to the internationally recognized standard AIR (Szpak et al., 2017). In bioarchaeology, nitrogen is measured in the collagen of bone or dentine and $\delta^{15}N$ values reflect the trophic level of consumed protein (DeNiro & Epstein, 1981; Schoeninger & DeNiro, 1984).

As with carbon, interpreting nitrogen variation in bioarchaeological materials begins with understanding nitrogen variation in plant food sources. Plant δ^{15}N depends on the δ^{15}N of the surrounding soil, the type of plant, and the processes used to convert atmospheric nitrogen into compounds used by the plant (i.e., ammonia, nitrates, or nitrites) (Casey & Post, 2011; Evans, 2007; Katzenberg & Waters-Rist, 2018). Average temperature, water availability, and the nitrogen cycle also contribute to variation in plant δ^{15}N values (Casey & Post, 2011; Evans, 2007). With respect to bioarchaeological research, an understanding of the range of δ^{15}N values exhibited by regional plants is important for interpreting isotopic results.

Typically, bioarchaeological studies of nitrogen isotopes focus on trophic level distinctions. Trophic level is a significant source of variation in δ^{15}N values, such that animals at higher trophic levels have higher δ^{15}N values than those at lower levels. Whether a δ^{15}N value is considered 'high' depends on the average δ^{15}N values of the local vegetation, as plants form the base of the food chain. Herbivores typically display δ^{15}N values that are ~3-5‰ higher than those of their diet, and carnivore δ^{15}N values increase again by ~3-5‰. With each successive increase in trophic level, there is an additional increase in δ^{15}N values (Bocherens & Drucker, 2003; Schoeninger & DeNiro, 1984). Organisms from marine environments tend to have higher δ^{15}N values than terrestrial organisms because there are a greater number of trophic levels in marine ecosystems (Schoeninger, 2010; Schoeninger & DeNiro, 1984). As with carbon, the degree of diet-tissue spacing in δ^{15}N values varies according to the tissue being analyzed. In collagen, this offset is around +2.5‰ (DeNiro & Epstein, 1981; Keegan & DeNiro 1988).

Another source of variation in δ^{15}N values is nitrogen balance, which refers to the relative amounts of nitrogen input versus output. If an individual is taking in more nitrogen than they are excreting, they are in positive nitrogen balance. Conversely, if nitrogen intake is insufficient, an individual is in negative nitrogen balance. States of positive and negative balance can lead to decreases and increases in δ^{15}N, respectively (Katzenberg & Waters-Rist, 2018). Nutritional stress is one factor that can lead to negative nitrogen balance, and this will be discussed in a subsequent section (2.4.4).

2.4.3 Infant Feeding Practices

The trophic level effect is the basis for interpreting patterns of breastfeeding and weaning from stable carbon and nitrogen isotopic data. When breastfeeding, a child is consuming milk produced by their mother or another lactating female. Exclusively breastfeeding infants are thus at a higher trophic level than the individual providing their milk.

Studies have investigated the effects of breast milk consumption on δ^{15}N and δ^{13}C values in living humans (Dailey-Chwalibóg et al., 2020; Fogel et al., 1989; Fuller et al., 2006; Herrscher et al., 2017). Among the first of these was by Fogel and colleagues (1989), who examined δ^{15}N and δ^{13}C values in fingernail samples from mother-infant pairs. They found that breastfed infants had δ^{15}N values that were 2.4‰ higher than those of their mothers but did not note significant differences between mother and infant δ^{13}C values. In 2006, Fuller and colleagues conducted a longitudinal study that followed living mother-infant pairs throughout breastfeeding and weaning periods. They measured δ^{15}N and δ^{13}C values from fingernails and hair and showed that infant δ^{15}N values were ~2-3‰ higher than maternal δ^{15}N during exclusive breastfeeding periods, and a decrease in breast milk consumption was accompanied by a ~2-3‰ drop in δ^{15}N. Exclusive breastfeeding was also associated with infant δ^{13}C values that were ~1‰ higher than those of their mothers. After the initiation of weaning, δ^{13}C values dropped more rapidly than δ^{15}N. Since δ^{13}C values reflect carbohydrates and lipids as well as protein, the researchers suggested that carbon may be more responsive to dietary changes and the introduction of alternative foods (Fuller et al., 2006). Another longitudinal study of a single mother-infant pair found that infant nail δ^{15}N values were ~2-3‰ higher than those of the mother during breastfeeding; however, the 1‰ difference in mother-infant δ^{13}C values was not observed (Herrscher et al., 2017). This study also examined variation in the isotopic composition of breast milk and noted changes in δ^{13}C values throughout the breastfeeding period (Herrscher et al., 2017). Finally, in 2020, a cross-sectional study of hair samples from over 200 infants showed that δ^{15}N and δ^{13}C decreased with weaning by 3.3‰ and 0.8‰, respectively (Dailey-Chwalibóg et al., 2020). Taken together, these studies suggest that infant δ^{15}N values are ~2-3‰ higher during periods of breastfeeding, and that δ^{13}C values may be up to ~1‰ higher, but factors such as variation in breast

milk δ^{13}C and complementary feeding may mean full trophic shifts in carbon are not always visible. These results from studies of living humans provide the basis for interpreting infant feeding practices of past populations using skeletal and dental samples.

Several bioarchaeological studies have identified elevated δ^{15}N and δ^{13}C values in early life and used declines in these values to infer the age of weaning (e.g., Britton et al., 2018; Eerkens et al., 2011; Fuller et al., 2003; Gutierrez et al., 2021; King et al., 2017; Salahuddin & Prowse, 2023; Waters-Rist et al., 2022). While hair and fingernails are often used in studies of infant feeding in living humans, these tissues are rarely available in archaeological contexts. As such, bioarchaeological approaches to infant feeding generally use samples of bones and/or teeth.

Some early approaches examined collagen samples from multiple teeth that formed at different ages. For example, Dupras and Tocheri (2007) measured bulk samples of δ^{15}N and δ^{13}C from various deciduous and permanent teeth from Kellis, Egypt, and found that δ^{15}N and δ^{13}C values from deciduous teeth were ~2‰ and 0.6‰ greater than those of permanent teeth, respectively. Since these shifts are similar to the weaning-related isotopic changes identified by studies of living humans, they suggested this was related to breast milk consumption in early life (Dupras & Tocheri, 2007). Improvements in sampling techniques and analytical equipment have since allowed researchers to examine multiple samples from within the same tooth and use intra-tooth changes in δ^{15}N and δ^{13}C to infer breastfeeding and weaning practices (e.g., Beaumont et al., 2018; Eerkens et al., 2011; Fuller et al., 2003; King et al., 2017; Salahuddin & Prowse, 2023). These techniques are referred to as ‘incremental dentine sampling’ and will be discussed in Section 2.5.

2.4.4 Stress

Patterns of change in δ^{15}N and δ^{13}C values can also be used to indicate nutritional or physiological stress. In 2005, Fuller and colleagues studied changes in δ^{15}N and δ^{13}C values from hair samples of women experiencing weight loss and/or nutritional stress associated with morning sickness. They found that δ^{15}N values increased by up to 1‰ during periods of nutritional stress, but no consistent changes in δ^{13}C values were

observed. Mekota and colleagues (2006) conducted similar analyses of hair from individuals with anorexia nervosa and noted that δ^{15}N values were higher during periods of starvation. Recovery periods were associated with increases in δ^{13}C and decreases in δ^{15}N (Mekota et al., 2006). Neuberger and colleagues (2013) studied individuals who had experienced nutritional stress prior to death and found δ^{15}N values increased by 0.2-1.9‰ (average 0.5‰) and δ^{13}C values decreased by up to 5.4‰ (average 0.5‰). In some individuals, however, change in δ^{13}C values was not observed. Finally, D'Ortenzio and colleagues (2015) examined hair from two individuals with long-term terminal illnesses and found that δ^{15}N values increased by 1.6-1.9‰ prior to death, while δ^{13}C values showed little change. Taken together, these studies suggest that nutritional and physiological stress can lead to increases in δ^{15}N accompanied by stable or decreasing δ^{13}C values.

These observations can be explained by physiological processes. The increase in nitrogen is essentially the same as the trophic level effect (Fuller et al., 2005; Neuberger et al., 2013). When dietary nitrogen intake is insufficient (such as during periods of protein malnutrition), one's body will begin to break down its own muscle tissue. This leads to the same processes of fractionation that occur with dietary protein, and results in further enrichment in ^{15}N. The changes in carbon are thought to be related to decreased intake of carbohydrates and/or the recycling of body fat stores (Neuberger et al., 2013). If catabolism of body fat does not occur, the changes in δ^{13}C would not be observed.

These patterns of isotopic change (increasing δ^{15}N and decreasing δ^{13}C; sometimes referred to as 'opposing covariance') have been used in bioarchaeology to identify periods of nutritional stress (e.g., Beaumont & Montgomery, 2016; Beaumont et al., 2018; Craig-Atkins et al., 2018; D'Ortenzio et al., 2015; King et al., 2018; O'Donoghue et al., 2021; Walter et al., 2020). Much of this work has been facilitated by incremental dentine sampling, as this method allows researchers to examine changes in δ^{15}N and δ^{13}C values throughout one's life. Some studies have examined burials associated with famines and used incremental dentine collagen to identify patterns of opposing covariance (Beaumont & Montgomery, 2016; Walter et al., 2020). The association of these cases with historically recorded food shortages strengthened the researchers'

interpretations of nutritional stress and demonstrated that it is possible to find isotopic evidence of stress in bioarchaeological contexts (Beaumont & Montgomery, 2016).

2.5 Incremental Sampling

Incremental sampling techniques (also called intra-tooth or serial sampling) have been employed by bioarchaeologists studying infant feeding practices for many years. These techniques are based on the incremental patterns of dentine growth and the absence of remodelling. Dentine from the tooth cusps forms earlier than dentine in the cervical region, which forms before dentine at the apical end of the root (see Figure 2.4). By cutting a tooth into several sections following this pattern, and analyzing each section's isotopic composition, researchers can identify changes in isotope values over the course of tooth development. Depending on the method, each section provides the average isotopic composition from ~2-9 months of growth, which is often preferred over bulk sampling methods that produce isotopic values representing several years (Beaumont & Montgomery, 2015; Curtis et al., 2022). As infant feeding patterns can change in a matter of months, the increased resolution provided by serial samples is better suited to studies of early life diet.

There are several variations of intra-tooth sampling techniques that reflect the development of this method over time. In 2003, Fuller and colleagues divided deciduous and permanent teeth from Wharram Percy into 3-4 horizontal sections representing the tooth crown and halves or thirds of the root. In 2011, Eerkens et al. increased temporal resolution by taking 1-2mm horizontal sections of dentine from first permanent molars. Later, Beaumont and colleagues (2013) compared two different horizontal sectioning techniques: Method 1 sectioned teeth prior to demineralization using a slow-speed saw, while Method 2 used a scalpel to section teeth after demineralization. Method 1 was more accurate, but resulted in a greater loss of tissue, and as such, they recommended using Method 2. They also suggested that 1mm sections produce the minimum amount of tissue for isotopic analysis (Beaumont et al., 2013). Since their work, 1mm horizontal sections have been applied in several studies of early life diet across a range of time periods and regions (e.g., Beaumont et al., 2013, 2014; Craig-Atkins et al., 2018; King et al., 2017; O'Donoghue et al., 2021).

While horizontal sectioning methods are straightforward and easy to apply, they cut across the Andresen lines which can result in significant blurring or time-averaging between sections (Figure 2.5) (Tsutaya, 2020). To address this limitation, some studies have attempted to track dentine growth lines by removing oblique sections (e.g., Avery et al., 2021; Czermak et al., 2018; Lee et al., 2020). Other work has tested the use of a biopsy punch for collecting 0.75-1mm diameter microsamples of dentine (Burt & Garvie-Lok, 2013; Czermak et al., 2020). A pilot study demonstrated that this technique reduced time-averaging and improved precision of the isotopic measurements while minimizing destruction of the dental samples (Burt & Garvie-Lok, 2013), and additional research in this area has attempted to standardize this microsampling technique (Cheung et al., 2022; Czermak et al., 2020). More recently, a study by Curtis et al. (2022) used a MicroMill to take 0.35mm sequential samples of dentine from permanent molars and reduced the age per section to ~2-4 months.

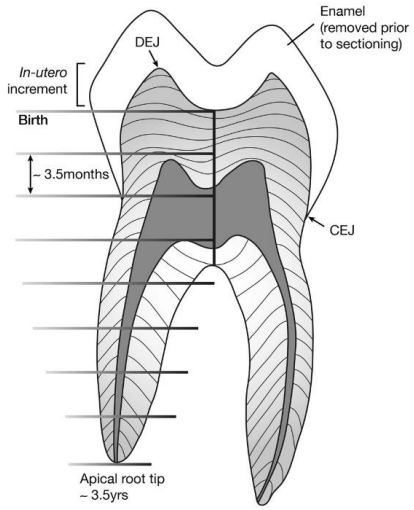

Figure 2.5. Diagram showing horizontal serial sections relative to the dentine growth lines in a deciduous molar. From King et al. (2017, p. 128).

Some adaptations of serial sampling techniques have been developed to target dentine that forms before birth (Beaumont et al., 2018; Burt & Garvie-Lok, 2013; Burt & Amin, 2014). Burt and Garvie-Lok (2013) prepared thin sections of teeth to measure the location of the neonatal line and took microsamples on either side of its position. These thus

represented dentine formed before and after birth. Additionally, Beaumont and colleagues (2018) used micro-CT scans of deciduous teeth from individuals who had died around birth to estimate the amount of dentine formed *in utero*. They found that dentine present at birth was a minimum of 0.5mm thick, but this increased according to tooth type. Other methods have employed regular horizontal or oblique sectioning procedures and used the ages represented by each dentine slice to identify prenatal dentine sections (Craig-Atkins et al., 2018; King et al., 2017).

2.6 Conclusion

This chapter has reviewed the concepts and research relevant to identifying infant feeding practices and stress in bioarchaeology. Enamel and dentine grow incrementally, and as such, analysis of different sections can permit evaluation of stress and dietary shifts during their formation. Dental defects (i.e., EH) can be used as a general indicator of stress and are often intertwined with other dental lesions (e.g., caries). Stable isotope fractionation forms the basis of variation in δ^{15}N and δ^{13}C values, and the isotopic composition of our tissues reflects a combination of (1) the foods we consume and (2) fractionation processes that occur within our bodies. In collagen, nitrogen comes from dietary protein while carbon sources include protein, carbohydrates, and lipids (Fernandes et al., 2012). δ^{15}N and δ^{13}C values are ~2-3‰ and up to ~1‰ higher, respectively, during periods of breast milk consumption (Fogel et al., 1989; Fuller et al., 2006). Increases in δ^{15}N that are associated with decreasing or stable δ^{13}C may indicate periods of nutritional or physiological stress (Mekota et al., 2006; Neuberger et al., 2013). Improvements in incremental dentine sampling techniques have allowed bioarchaeologists to identify these shifts and infer infant feeding practices and stress in past populations.

Chapter 3

3 The Sample and Historical Context

This chapter describes the individuals included in the study sample, the historical context in which they lived, and the archaeological context in which they were found. The infants being studied were interred in a Catholic cemetery in Pointe-aux-Trembles that was in use from AD 1709-1843 (Ethnoscop, 2016). This chapter will first situate the site within Pointe-aux-Trembles and Montréal more broadly and describe the structure of the village during this time. The following section will then draw upon historical sources to describe life in 18th to 19th century Montréal and Pointe-aux-Trembles. This will include discussion of infant feeding practices and wet nursing, as well as infant mortality. Archival records associated with the cemetery will then be used to better understand the individuals who were buried in Pointe-aux-Trembles. Next, the archaeological context of the site and burials will be discussed, and the chapter will conclude by outlining the sample selection procedures used in this study.

3.1 Location and Site

Pointe-aux-Trembles is located on the northeast shore of the Island of Montréal (Figures 3.1-3.2) on the traditional lands of the Kanien'kehá꞉ka (Mohawk) Peoples, members of the Haudenosaunee Confederacy (Fougères & MacLoed, 2017; Native Land Digital, 2023). Following the French settlement of Ville Marie (later known as Montréal) in 1642, Pointe-aux-Trembles was established, making it one of the oldest settler villages in the Montréal area (Ethnoscop, 2007; Fougères & MacLoed, 2017). Around 1690, the village contained a windmill, chapel, school, and convent (Figure 3.3; Ethnoscop, 2007, 2016). Due to conflicts between the settler population and local Indigenous Peoples, a palisade was built around the village for defense (Ethnoscop, 2007, 2016). Slowly, more settler families began to move into the area, and in 1705, a new church was built to accommodate the rising population (Ethnoscop, 2007, 2016). This church replaced the previous chapel and was built near the school in the northeast corner of the village (Figure 3.4; Ethnoscop, 2016). It remained in place until a fire in 1937 (Ethnoscop, 2016).

With the church built in 1705 came the cemetery in which the study sample was buried. It was established in 1709 and used until 1843 (Ethnoscop, 2016). It is the second of four cemeteries that have been used in Pointe-aux-Trembles: the first from 1677 to 1709; the second from 1709 to 1843; the third from 1843 to 1919; and the fourth from 1919 to present (Ethnoscop, 2007, 2013, 2016). Today, they are all considered part of the Saint-Enfant-Jésus Cemetery, which was established in its current location in 1919 (Figure 3.2; Ethnoscop, 2016). Throughout this thesis, all references made to the cemetery will refer to the second one unless otherwise specified. The cemetery's use from 1709 to 1843 includes parts of the French and British regimes, with the latter beginning in 1760 (Ethnoscop, 2007; Fougères & MacLoed, 2017). Its use also spanned periods of population growth, increases in tourism, expansion of the village, and epidemics, which will be discussed in more detail throughout this chapter.

Figure 3.1. Map showing the location of Pointe-aux-Trembles relative to Montréal. Pointe-aux-Trembles is ~20km from the city core. Figure created using ArcGIS Online (2023).

Figure 3.2. Map of present-day Pointe-aux-Trembles showing shaded area indicated on Figure 3.1. A) Current location of the Saint-Enfant-Jésus cemetery. B) Approximate location of archaeological site BjFi-17. See also Figure 3.7. Figure created using ArcGIS Online (2023).

Figure 3.3. Model of Pointe-aux-Trembles circa 1693 including the windmill (1), school (3), convent (4), and palisade surrounding the village. Label 2 shows the location of the original chapel and cemetery used from 1677-1709. From Ethnoscop (2016, p. 13).

Figure 3.4. Model of Pointe-aux-Trembles circa 1912 demonstrating the location of the church built in 1705 (1), a presbytery built in 1881 (2), and the convent built in 1879 (3). The cemetery in use from 1709-1843 was located by the church (1). From Ethnoscop (2016, p. 13).

3.2 Historical Context: Life and Death in Urban and Rural 18th-19th Century Montréal

In the 18th to 19th centuries, urban and rural areas on the island of Montréal were integrated and interdependent (Fougères & MacLoed, 2017; Robert 2011). Residents of rural communities needed goods from the urban markets, while rural farmers supplied materials such as firewood, grain, and other food or animal products to the city (Fougères & MacLoed, 2017; Robert, 2011). As urban areas grew, the effects of population growth and increased travel were felt in rural communities. Given their interconnectedness, both urban Montréal and rural Pointe-aux-Trembles will be discussed in this section to provide a more complete picture of life during this time. Population growth and its effects will first be considered, followed by aspects of daily life such as farming, travel, and women's roles in Montréal society. Infant feeding practices and attitudes towards them will be described, and infant mortality will be discussed.

3.2.1 Population Growth

Throughout the 18th to 19th centuries, Montréal experienced rapid population growth and urbanization. From 1707 to 1741, the population of Montréal increased from ~1300 to ~3500, to ~6000 in 1782, and ~37,000 in 1831 (Robert, 2011). The city saw many waves of immigration and it was an important center for the fur trade (Fougères & MacLoed, 2017). Population growth was also fueled by high rates of fertility, which were necessary to counter the similarly high mortality rates (Amorevieta-Gentil, 2010; Henripin, 1954). Members of all levels of socioeconomic status resided in the city, but there was considerable segregation according to social class and factors such as language and religion (e.g., French Catholic, Irish Catholic, Protestant) (Thornton & Olson, 1991).

Growth was also seen in Pointe-aux-Trembles and other rural areas, but not to the same extent. Pointe-aux-Trembles grew from 34 families in 1690, to ~850 residents at the end of the 1700s, and ~1000 people in 1825 (Ethnoscop, 2007, 2016). The rapid population growth experienced in Montréal was not seen in Pointe-aux-Trembles until the 20th century, when urbanization took over the rural village and the population reached ~8200 after World War II (Ethnoscop, 2016). Farmers, craftsmen (e.g., a shoemaker, blacksmiths), a surgeon, and a midwife were among those who owned land in Pointe-aux-Trembles circa 1731, and the village was also home to innkeepers, carpenters, and day labourers (Ethnoscop, 2007). As the population of Pointe-aux-Trembles grew, the village expanded beyond the palisade and families began to reside outside of its borders (Ethnoscop, 2016).

With an increase in population came an increase in unhygienic practices and a deterioration of living conditions. City streets were often covered in manure, garbage, and other human and non-human waste, and odours from slaughterhouses, cemeteries, and latrines filled the air (Fougères & MacLoed, 2017). Water sources, such as the St. Lawrence River, were also frequent dumping grounds for waste, including animal carcasses, manure, and refuse (Amorevieta-Gentil, 2010; Fougères & MacLoed, 2017). This meant that drinking water from rivers and public wells was often contaminated, leading to fevers and gastrointestinal diseases (Fougères & MacLoed, 2017). Conditions are thought to have been better in rural communities with lower population densities and

fresh “country air” (Amorevieta-Gentil, 2010; Pelletier et al., 1997). Studies of mortality in 18th to 19th century Montréal often credit some deaths to poor living conditions and water contamination, especially in infants and children (Pelletier et al., 1997; Thornton & Olson, 2011).

The population density and unhygienic living conditions meant that Montréal was a common site of epidemics. In their review of historical accounts, Amorevieta-Gentil (2010) identified several epidemics in Montréal between 1621-1779, including measles in 1714-1715, and typhus in 1742 and 1748-1750. Several smallpox epidemics were also recorded, including in 1732-1733, 1769, and 1775-1776 (Amorevieta-Gentil, 2010; Bruckner et al., 2018). There was also a devastating cholera outbreak in 1832 that was linked to contaminated drinking water and poor sanitation (Noel, 1995; Pelletier et al., 1997).

3.2.2 Life in Montréal and Pointe-aux-Trembles

Extensive descriptions covering all aspects of life in 18th to 19th century Montréal and Pointe-aux-Trembles can fill entire books and are undoubtedly beyond the scope of a Master’s thesis. To balance this limitation with the desire to describe daily activities of the time, this section will focus on topics most relevant to Pointe-aux-Trembles and the individuals under study. Three topics were selected: agriculture, travel, and the roles of women in Montréal. Infant feeding practices and infant mortality are described in subsequent sections.

3.2.2.1 Agriculture

Agriculture was an important sector in Montréal and, until the 1900s, Pointe-aux-Trembles and the surrounding area were primarily agricultural regions (Ethnoscop, 2016; Fougères & MacLoed, 2017). In Montréal more broadly, some farms were owned by members of the upper and middle class (e.g., elites, merchants, artisans) and leased to agricultural workers, while others were owned by farmers who worked their own land (Waywell, 1989). Crops such as wheat, barley, rye, corn, peas, potatoes, oats, and vegetables were grown on the island, and orchards with apples and other fruits were common in the city (Fougères & MacLoed, 2017). Animals such as cattle, horses, oxen,

pigs, sheep, and poultry could be found on farms, and they formed an important part of the industry by providing food products (e.g., dairy, eggs, meat), farm work (e.g., plowing fields), and fertilizer (i.e., manure) (Waywell, 1989).

The island of Montréal had fertile soil and good agricultural potential, but farmers were often critiqued for using inefficient practices that led to soil depletion and crop failures (Fougères & MacLoed, 2017; Waywell, 1989). A growing population combined with poor crop production and a decrease in farmland (due to expansion of the city) led to frequent food shortages (Amorevieta-Gentil, 2010; Fougères & MacLoed, 2017). In Pointe-aux-Trembles, the land was suitable for hay production, which was important for supporting livestock and dairy farms (Fougères & MacLoed, 2017). As an agricultural region, farming in Pointe-aux-Trembles would have been an important means of feeding local families, and a way of life for many individuals of the time.

3.2.2.2 Travel

Travel became an important part of the local economy in Pointe-aux-Trembles throughout the 1700s (Ethnoscop, 2007). By the end of the 1730s, the Chemin du Roi, a road connecting Montréal to Québec City, had been built. Pointe-aux-Trembles was situated along this road and was the closest village to the ferries crossing the St. Lawrence River (Ethnoscop, 2007). As a result, the construction of the Chemin du Roi brought an influx of travelers to the community and it became a frequent stopping point along the route (Ethnoscop, 2007, 2016). Inns and hotels were built in the region, and business increased for local craftsmen, farmers, and other workers (Ethnoscop, 2007). Travel through the area remained common until the latter half of the 1800s (Ethnoscop, 2007). While this allowed the local community to prosper, it also meant that it was not isolated from urban centers and, as a result, was not safe from the infectious diseases and epidemics experienced in Montréal.

3.2.2.3 Women

Throughout the 18th and early 19th centuries, women in Montréal held important roles in society. Their contributions were not limited to household tasks and child-rearing; rather, they included integral roles in farm maintenance, craft production, philanthropy,

education, and health care (Noel, 1995). Some women owned farms and leased them to labourers, and others would garden, poultry-keep, and participate in dairy farming (Noel, 1995; Waywell, 1989). Women also produced and sold artisanal goods such as textiles, soap, candles, and clothes, and worked in taverns and boarding houses (Fougères & MacLoed, 2017; Noel, 1995). Charities and philanthropic organizations, such as the Ladies Benevolent Society established in Montréal in 1815, were founded and run by women who wished to help the poor, sick, orphaned, and less fortunate (Noel, 1995). The Grey Nuns of Montréal provided care and shelter for the sick, unhoused, and elderly, and received a number of orphans and foundlings (abandoned infants) (Noel, 1995; Young, 2013). They would often send the foundlings to wet nurses and find homes for them upon their return (Noel, 1995; Robert, 2011). Wet nursing itself was a profession and, in many cases, the practice appears to have been passed down between generations of women (Robert, 2011). Other occupations such as midwifery and nursing were common, particularly among women who were widowed and from the working class (Amorevieta-Gentil, 2010; Young, 2013). Ultimately, women in Montréal and its surrounding areas contributed to family life and the local economy, and provided important care for those in need, adults and non-adults alike.

3.2.3 Infant Feeding Practices

Throughout history, there has been great diversity in approaches to and attitudes toward infant feeding practices. Beliefs and recommendations surrounding what to feed infants, when (i.e., at what age) to begin feeding them, how much they should be fed, and who should be responsible for feeding them (e.g., mother, wet nurse) have varied both within and across cultures over time (Wickes, 1953). Since this study focuses on an early settler-colonial population, and since Montréal experienced several waves of immigration during the 18th and 19th centuries, it is likely that infant feeding practices in Montréal and Pointe-aux-Trembles were influenced by the dominant practices in Europe at the time (Thulier, 2009). As such, this section will first briefly consider sources focused on Europe to preface the discussion of infant feeding in Montréal. Evidence for practices such as wet nursing will then be reviewed.

3.2.3.1 Europe

Much has been written on infant feeding recommendations and customs in 18th to 19th century Europe. Several historical recommendations favoured maternal breastfeeding, with some suggesting that breast milk was the best and most natural food for infants (Fildes, 1986; Wickes, 1953). Others argued that suckling would strengthen the bond between mothers and their infants, or that mortality was higher among children who were not breastfed (Fildes, 1986; Grenier, 1871; Wickes, 1953). Certain religious views also encouraged breastfeeding by mothers (Fildes, 1986; Thulier, 2009). However, customs of the time suggest that it was not common, particularly among members of the upper class, for mothers to breastfeed their infants (Fildes, 1986). Arguments against maternal breastfeeding included cosmetic concerns (e.g., sagging breasts), demands on one's time, social pressures, and interference with sexual intercourse and the fulfillment of one's "marital duties" (Fildes, 1986). Additionally, the contraceptive effects of breastfeeding opposed parental desires for large families with many children, and physical challenges, such as poor milk production or difficulty suckling, also decreased the incidence of maternal breastfeeding (Fildes, 1986; Wickes, 1953). Mothers who did not breastfeed (whether by choice or by necessity) would follow two main alternative practices: some opted to feed infants foods such as animal milks, pap (bread or flour cooked in water), panada (bread or grains cooked in broth), and gruel (porridge made from cereals boiled in water or milk), while others would employ wet nurses (Obladen, 2014; Wickes, 1953).

A wet nurse is a female individual who breastfeeds children born to another mother. Wet nursing was a common alternative to maternal breastfeeding prior to the widespread use of feeding bottles and formula in the 19th century and was often considered the best alternative when mothers could not breastfeed themselves (Stevens et al., 2009; Wickes, 1953). In some countries (e.g., France), wet nursing was an organized practice managed by religious and/or legal authorities (Fildes, 1986; Siles-González et al., 2020; Stevens et al., 2009; Thulier, 2009). Given the social attitudes surrounding breastfeeding and the funds necessary to employ wet nurses, wet nursing was more common among upper class families, though members of lower classes began to partake towards the end of the 18th century as the increased cost of living placed higher demands on women (Stevens et al.,

2009). Wet nurses were employed not only to breastfeed, but also to provide general care to infants. Most often, wet nurses were from rural communities, and infants would be sent to them from their families in towns and cities (Fildes, 1986).

Just as there were many societal opinions surrounding breastfeeding, there were opinions on wet nursing. A common belief throughout the 18th and 19th centuries was that a woman's qualities, ideals, and intellect were transmitted to infants through breast milk (Fildes, 1986; Thulier, 2009). As such, women of particular appearances, ages, and personal qualities (e.g., cheerful, well-mannered) were thought to be better suited for the profession and were preferred over others (Fildes, 1986). Additionally, despite it being a common practice, wet nursing was considered deadly by some (Golden, 1996). Wet nurses were often subject to blame for ill health or death of infants, with accusations ranging from carelessness to infanticide (Fildes, 1986; Golden, 1996; Hill et al., 1987; Thulier, 2009). Nonetheless, wet nursing was a widespread practice throughout 18th to 19th century Europe and was continued in settler colonial populations in North America and beyond (Gauvreau, 1987; Golden, 1996; Obladen, 2012; Thulier, 2009; Thorley, 2021).

3.2.3.2 Québec

There is evidence that wet nursing was practiced in Montréal and other areas of Québec throughout the 17th to 19th centuries (Amorevieta-Gentil, 2010; Gauvreau 1987; Grenier, 1871; Noel, 1995; Robert, 2011). Gauvreau (1987) examined parish records from Québec City between 1680-1730 to identify wet nursing during the early French Régime. They looked for infants (<2 years of age) who had been born to families in Québec City but had died in another parish and suggested that these infants had been sent to wet nurses. Some records noted that the infant had been in the care of a nurse at the time of their death, though specific mention of this in the registers was rare (Gauvreau, 1987). They suggest that the infants were more commonly from families of military and civilian officers, merchants, and craftsmen, and they estimated that between 1700-1730, ~15% of infants in Québec City were cared for by wet nurses (an increase from ~4% of infants between 1680-1700) (Gauvreau, 1987).

A similar study by Robert (2011) focused on Montréal between 1680-1768 (Robert, 2011). Robert (2011) used archival records of women and children to identify wet nurses and the infants for whom they cared (n = 245 and 438, respectively). The wet nurses were women between 18-68 years of age (average = 35.5 years) and were often married or widowed. Almost all the wet nurses had their own children (only two of the 245 wet nurses they had identified did not), and the average number of births per nurse was between 10 to 11 (range: 1-20; Robert, 2011). Sometimes they would accept infants within a few months of giving birth, while other times they would accept infants after their own children died or had been weaned. The majority of the infants sent to wet nurses had been baptized in the urban parish of Notre-Dame-de-Montréal, but only 5% were nursed there (Robert, 2011). Most infants were placed with wet nurses in rural communities close to their family's home (Robert, 2011). In total, 60% of the infants they identified were foundlings, while the other 40% were from known families (Robert, 2011). Those from known families were typically born to merchants, civil officers, craftsmen, high commissioners, and members of nobility (Robert, 2011).

The analysis conducted by Robert (2011) not only provides evidence of wet nursing in 17th to 18th century Montréal, but also paints a picture of what wet nursing looked like in Pointe-aux-Trembles. Of the wet nurses identified by Robert (2011), 32 were from this community. Pointe-aux-Trembles was the third most common parish to accept infants (behind St-Laurent and Sault-au-Recollet), receiving 14% (62/438) of the children identified by Robert (2011). Most of these infants (40/62, 65%) were known and 35% were foundlings (22/62).

3.2.4 Infant Mortality

Montréal had exceptionally high rates of infant mortality in the 18th to 19th centuries and has been regarded by some as one of the deadliest cities in North America (Pelletier et al., 1997; Thornton & Olson, 1991). In the 17th century, infant mortality rates were similar in cities and rural communities, but they diverged as urbanization intensified (Amorevieta-Gentil, 2010). Urban cities saw infant mortality rates almost twice as high as the surrounding rural areas, with some estimates suggesting nearly one in two infants from the city died before their first birthday (Amorevieta-Gentil, 2010; Pelletier et al., 1997).

Several factors were responsible for the death of infants in Montréal. Poor hygiene and living conditions of the time undoubtedly played a role (Fougères & MacLoed, 2017). Infants were often swaddled and not cleaned regularly, as some individuals believed that dirt could provide a protective barrier for the infant (Amorevieta-Gentil, 2010). Alongside poor hygiene, poor sanitation favoured the spread of disease, particularly in the summer months (Pelletier et al., 1997). Some researchers have identified seasonal patterns in which mortality in Montréal was higher in the warmer months (Thornton & Olson, 1991, 2011), and others have identified increases in infant mortality throughout Québec in years with warm temperatures and droughts (Bruckner et al., 2018). These may be related to an increase in contaminated water sources when the water table was low and temperatures favoured the proliferation of bacteria and insects or other carriers of disease (Bruckner et al., 2018; Thornton & Olson, 1991). When diseases such as smallpox or measles spread through the city, infants who had not yet been exposed to them were susceptible, leading to spikes in infant mortality during epidemics (Bruckner et al., 2018). Increases in infant mortality have also been noted in years when food prices were high, suggesting poor food availability affected infants in Montréal (Bruckner et al., 2018). Finally, some sources suggest infant feeding practices, such as early complementary feeding and short to absent breastfeeding, were responsible for a large portion of infant deaths (Grenier, 1871; Thornton & Olson, 1991, 2011).

Based on historical accounts, some researchers suggest that wet nursing played a role in the high infant mortality rates during the 1700s (Amorevieta-Gentil, 2010; Fildes, 1986). However, the relationship between wet nursing and infant death is not straightforward. It is possible that factors associated with wet nursing increased mortality risk. Infants were often transported to wet nurses very soon (hours to days) after birth, and many did not survive the journey (Amorevieta-Gentil, 2010). Those that did survive likely would not have received their mother's colostrum, losing some of its protective effects while being exposed to several novel pathogens during travel (Fildes, 1986). Abandoned infants from foundling hospitals often died after being sent to wet nurses, as was the case for 70% of foundlings received by the Hôpital Général between 1800-1823 (Noel, 1995). However, these infants were generally in a state of poor health upon arrival at the hospital, thus decreasing their chances of survival before being sent for care (Noel, 1995). These

factors may have increased morbidity and/or mortality and contributed to perceptions of wet nursing as a deadly practice. However, wet nursing was popular at a time when germ theory and the importance of personal hygiene and public health were not well understood, making it challenging to untangle the effects of wet nursing from other factors now known to increase morbidity and mortality. Additionally, by providing breast milk to infants who may not have otherwise been breastfed (e.g., due to death of the mother or difficulty producing breast milk), wet nurses may have actually improved the chances of survival among some infants (Siles-Gonzáles et al., 2020). Thus, despite the negative perception of the practice and claims of its association with infant deaths, the relationship between wet nursing and high infant mortality rates is not entirely clear.

3.3 Archival Records from Pointe-aux-Trembles, 1709-1843

While the available studies of infant mortality in 18th to 19th century Montréal provide a useful picture of infant death during this time, they tend to focus on urban areas or Québec more broadly (e.g., Amorevieta-Gentil, 2010; Bruckner et al., 2018; Thornton & Olson 1991, 2011). Settler-colonial populations that took residence in Québec in the 1600s kept a wealth of historical records regarding baptisms, births, deaths, marriages, and burials, and these records have been compiled into an online database by the *Programme de Recherche en Démographie Historique* (PRDH, 2018; Dillon et al., 2018). By accessing records associated with the Saint-Enfant-Jésus cemetery in Pointe-aux-Trembles, one can gain insight into patterns of mortality directly relevant to the time and region being studied.

Using this database, burial records from the parish of Pointe-aux-Trembles between 1709-1843 were accessed to provide background information on the cemetery in which the study sample was interred. These records provide demographic information for the individuals buried in the Saint-Enfant-Jésus cemetery (discussed in this section) and they permit consideration of factors such as the impact of seasonality and epidemics on infant deaths (to be discussed in Chapter 6). The data gathered from PRDH include the number of total burials per year, but in order to capture the age group of the study sample (i.e., infants), collection of additional data (e.g., age, sex, month of burial) was limited to

individuals ≤3 years of age at death. Three years was chosen as the cut-off age to ensure that all infants selected for analysis would be included. Since this analysis is not directly related to the research questions posed in this thesis, the methods used to search for and analyze the burial records are described in more detail in Appendix B. Additional tables and figures can also be found in Appendix C.

From 1709 to 1843, 3113 burials were recorded in the parish of Pointe-aux-Trembles, and 1934 (62%) were individuals ≤3 years of age at death (PRDH, 2018). Figure 3.5 compares the number of infant burials to the total number of burials each year. The cemetery spans a period of 134 years, and in 112 of those years (84%), over half of the recorded burials were of infants. On average, 60% of yearly burials were of infants ≤3 years of age, but this varies from 23% in 1723 to 90% in 1716. While this is not a complete assessment of infant mortality (i.e., deaths have not been compared to yearly births), these data demonstrate that a substantial number of infants died in Pointe-aux-Trembles during the 18th and 19th centuries. Thus, while studies suggest lower infant mortality in rural communities (Amorevieta-Gentil, 2010; Pelletier et al., 1997), it is clear that life in Pointe-aux-Trembles still posed challenges for infant survival.

When considering burials by sex, the records show a greater number of male infants than female infants (52% versus 44%, respectively; Appendix C), which is consistent with sources that note higher mortality in boys than in girls during this time (Amorevieta-Gentil, 2010). Figure 3.6 shows a trend in age-at-death for the infants buried in Pointe-aux-Trembles. There is a higher concentration of burials in younger age groups compared to older age groups, and 68% of infant burials (42% of the total burials) were ≤6 months of age at death. Several of the infants (41%) died within one month of birth, and 12% within one week.

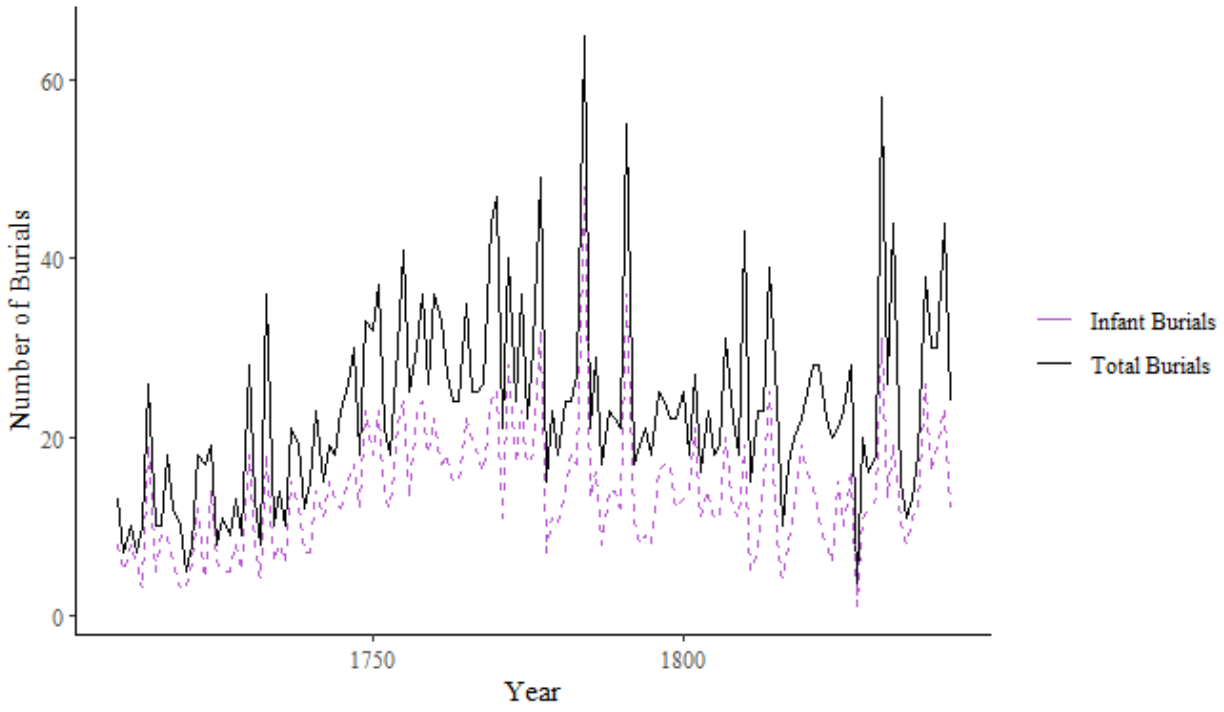

Figure 3.5. Total number of burials (black solid line) compared to the number of infant (≤3 years of age) burials per year (purple dashed line) in Pointe-aux-Trembles (1709-1843; PRDH, 2018).

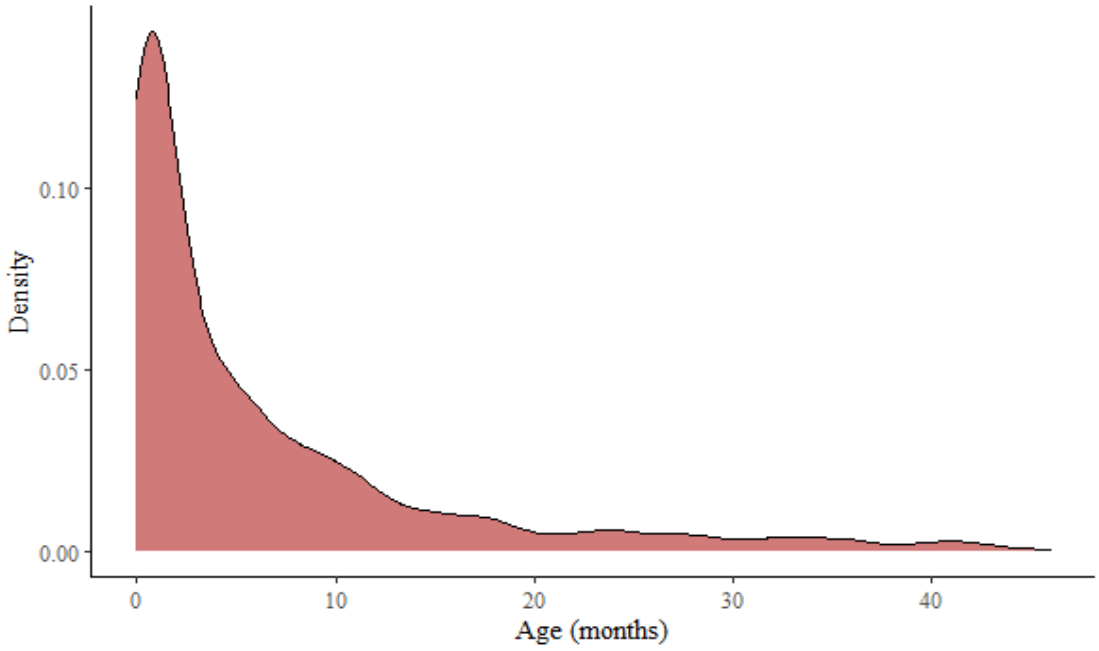

Figure 3.6. Density plot showing a trend in age-at-death of the infants (≤3 years of age) buried in Pointe-aux-Trembles (1709-1843; PRDH, 2018). The area under the curve indicates the percentage of burials within a given age range.

3.4 Archaeological Context

Archaeological work in Pointe-aux-Trembles has identified several sites in the area, but this thesis focuses on the individuals excavated from archaeological site BjFi-17 (sub-operation 7A; Figures 3.7-3.8). The excavation was conducted by the CRM firm Ethnoscop in 2014 to prevent damage and destruction from nearby building renovations and expansions (Ethnoscop, 2016). As previously mentioned, this site includes part of the cemetery in use from 1709-1843. Sixty-three burials were identified, which accounts for ~2% of the total individuals (3113) interred in the cemetery (Ethnoscop, 2016; PRDH, 2018). These individuals had been buried in the northern-most portion of the cemetery in a total area of approximately 24 m^2 (Ethnoscop, 2016). Initial age estimates provided in Ethnoscop (2016) show a high proportion of non-adults (63%). This could indicate that this area of the cemetery was used to bury non-adults; however, the proportion of non-adult burials that were excavated (63%) is remarkably similar to the proportion of infant burials identified in the parish records (62%) (PRDH, 2018). This suggests that the age

profile of the excavated individuals reflects the high rates of infant mortality during this time, rather than a pattern of cemetery use. Twenty-three adults were excavated, and sex could be estimated for 12 of them (Ethnoscop, 2016). Most (9/12) adults were estimated to be female; sex was not estimated for the non-adults (Ethnoscop, 2016). Coffins were generally poorly preserved, but nails were frequently recovered (Ethnoscop, 2016). Artifacts such as a pipe bowl, cufflinks, beads, and pins were also found amongst the burials (Ethnoscop, 2016).

Figure 3.7. Map showing the location of archaeological site BjFi-17 in Pointe-aux-Trembles. The large purple shape depicts Old Pointe-aux-Trembles, and the small red box shows the area where the site is located. From Ethnoscop (2016, p. 3).

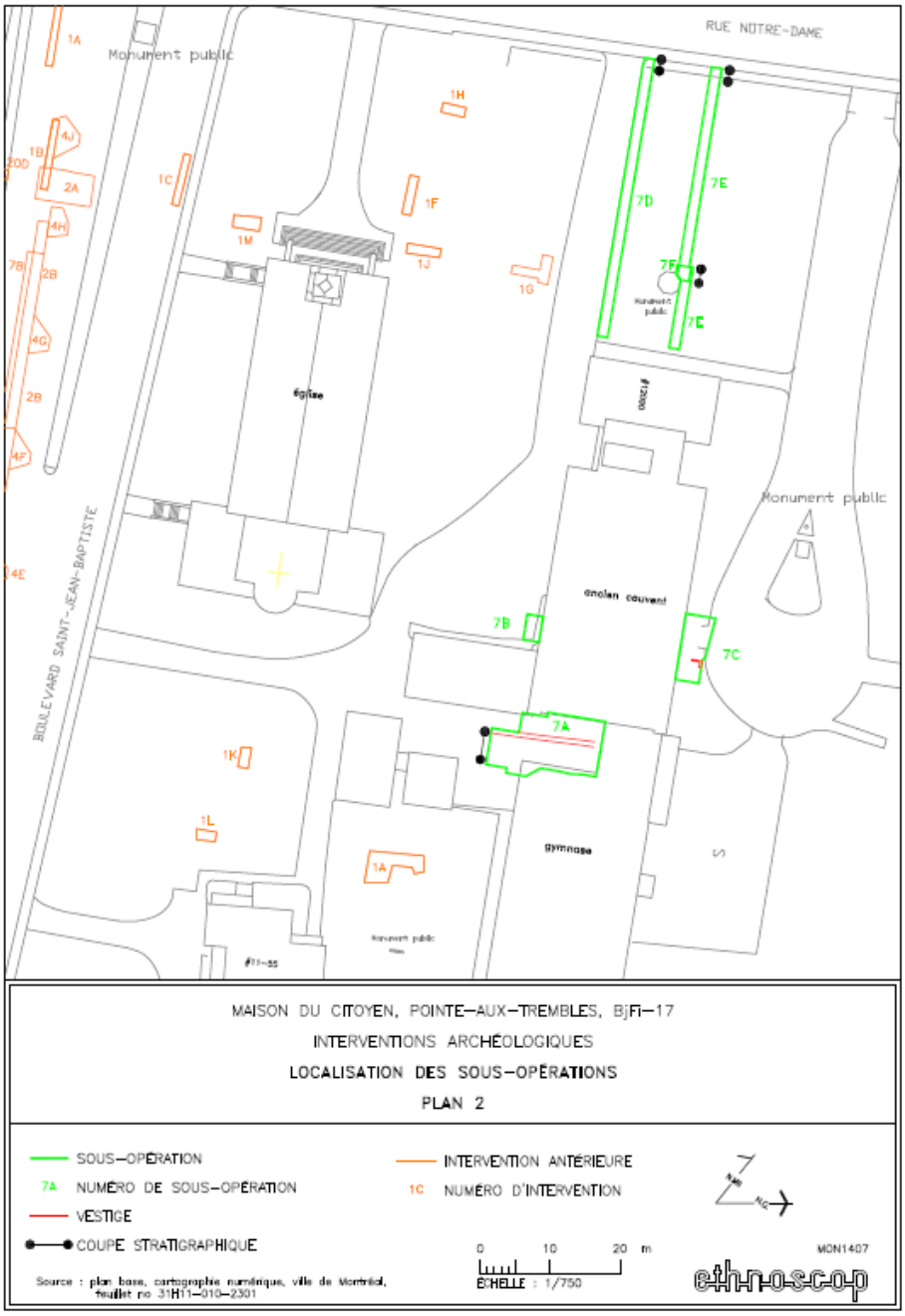

Figure 3.8. Plan showing the locations of sub-operations excavated from archaeological site BjFi-17. Sub-operation 7A is the area in which the burials were found. Modified from Ethnoscop (2016, p. 4).

Figure 3.9 shows where the burials were located within the site. They each fall into one of three stratigraphic layers (7A11, 7A9, 7A2) that correspond to different periods of cemetery use (Figure 3.10). In 18th to 19th century Québec, it was common to raise

cemeteries to provide more burial space as populations increased (Ethnoscop, 2016). This involved depositing new soil to allow individuals to be buried on top of others. Burials from 7A11 represent the cemetery's earliest use, beginning in 1709 (Ethnoscop, 2016). The first addition likely occurred in the early to mid-1700s and is represented by the middle layer (7A9; Ethnoscop, 2016). The final layer, 7A2, represents the second addition, and was in use from the early 1800s until 1843; this was the last level of use for this cemetery (Ethnoscop, 2016). Fourteen burials were excavated from 7A11, 29 from 7A9, and 20 from 7A2 (Ethnoscop, 2016).

Ethnoscop (2016) also note that the burials cluster into four sectors within the site: northern, north-central, south-central, and southern. These clusters could be random, or they may reflect some aspect of cemetery use (e.g., family plots); however, more evidence is necessary to draw such conclusions (Ethnoscop, 2016). Most adults (76%) were buried facing east, while non-adult burials were most commonly positioned with their heads directed north (44%) (Ethnoscop, 2016). All individuals were laid on their backs and positioning of their forearms varied (Ethnoscop, 2016).

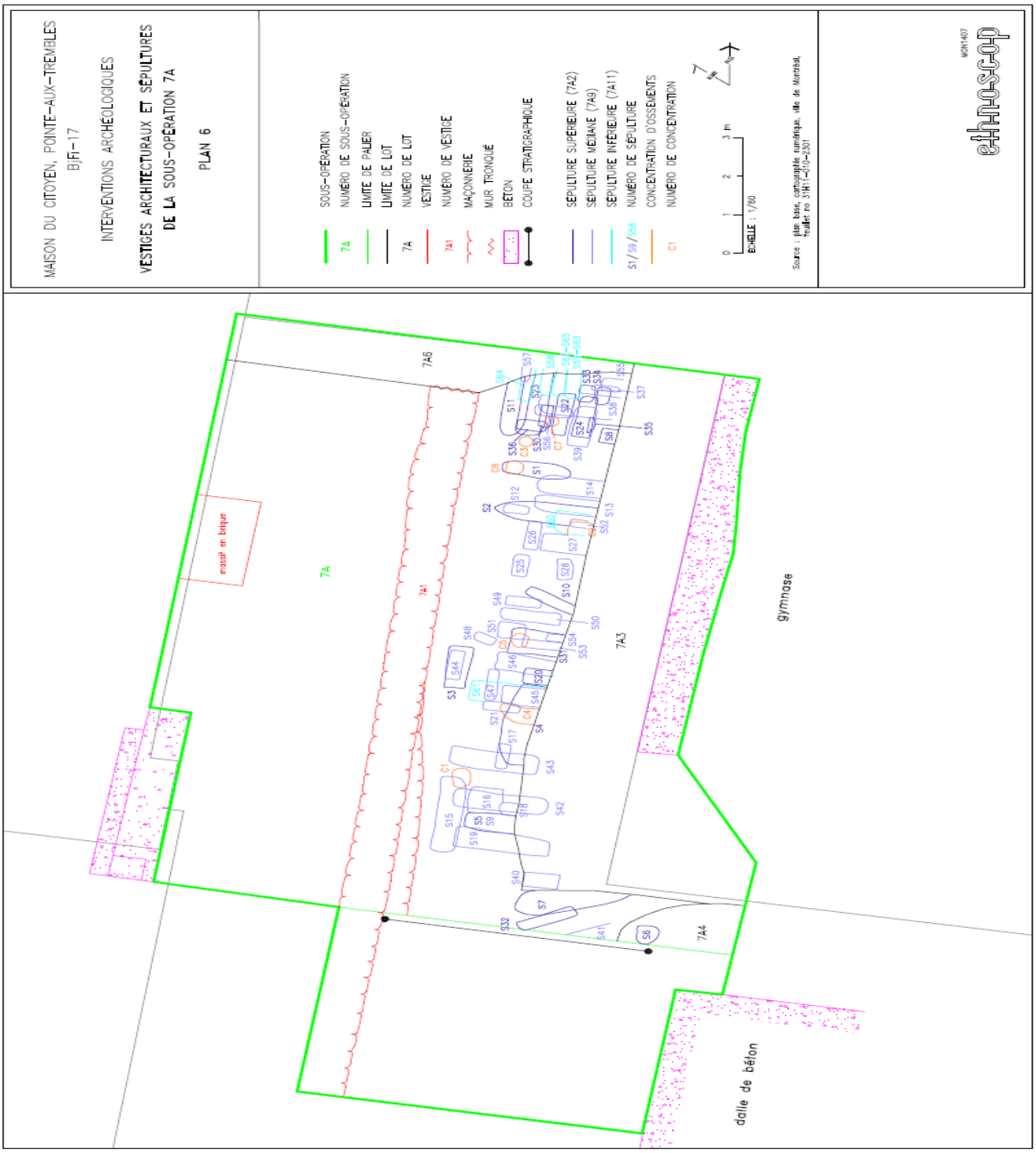

Figure 3.9. Locations of the burials within the site. The green border shows the outline of sub-operation 7A and the blue and orange shapes represent burials. From Ethnoscop (2016, p. 23).

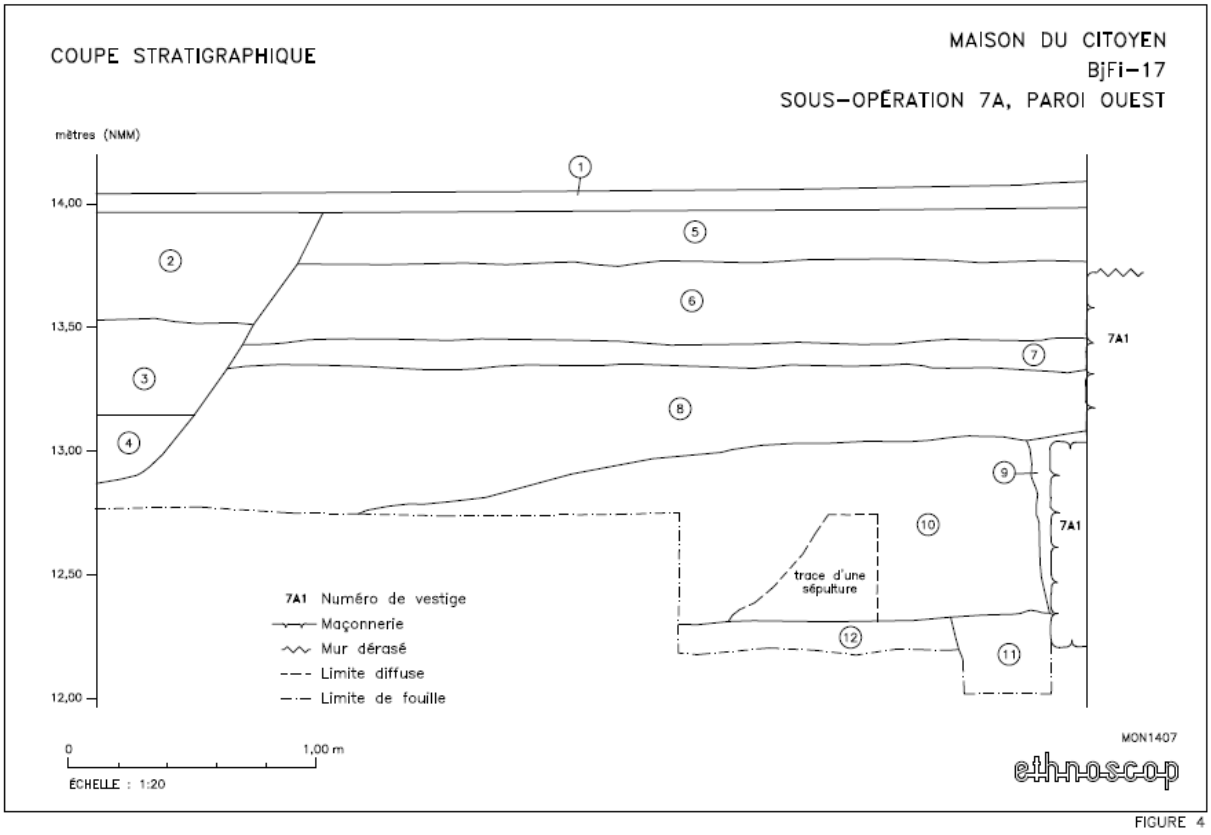

Figure 3.10. Stratigraphy of archaeological site BjFi-17, sub-operation 7A. From Ethnoscop (2016, p. 27).

3.5 Sample Selection

This section outlines the selection procedure followed to collect non-adult dental samples and adult female bone samples for isotopic analysis.

3.5.1 Ethics Approval

This project was approved by Western University's Non-Medical Research Ethics Board on May 11, 2022 (Project ID #120770; Appendix D) and abides by all policies outlined in the most recent Tri-Council Policy Statement (Government of Canada, 2022). Due to the precious nature of bioarchaeological materials, it is of the utmost importance that samples are treated with respect and care. Where destructive analyses are involved, it is particularly important for researchers to limit the loss of material as much as possible. This work has been developed with this in mind. For more on ethics surrounding

bioarchaeology and destructive analyses, refer to Buikstra et al. (2022), Squires et al. (2019), and Turner et al. (2018).

3.5.2 Non-Adult Dental Samples

For this research project, one deciduous tooth was to be sampled from each non-adult individual. Given that the non-adults excavated from Pointe-aux-Trembles all died before 7 years of age and that preliminary age estimates showed all but one non-adult (7A9-S39) was <3 years of age, most would have been forming their deciduous dentition at their time of death (AlQahtani et al., 2010; Gustafson & Koch, 1974; Ethnoscop, 2016). Deciduous teeth are valuable for studies of early life diet because they can offer insight into the prenatal, perinatal, and postnatal environments (Beaumont et al., 2018; Brickley et al., 2020; Burt & Garvie-Lok, 2013; King et al., 2018). While permanent first molars begin developing prior to birth, there is not enough prenatal tissue present to allow isotopic analysis of this period. Further, when sampled incrementally, deciduous teeth can permit bioarchaeologists to capture periods of 2-4 months of life – a much higher resolution than can typically be achieved using permanent teeth (Beaumont & Montgomery, 2015). Given these benefits and the age profile of the non-adults, this analysis focused exclusively on deciduous teeth.

To be included in the sample, teeth had to meet the following criteria: (1) did not come from a commingled burial (designated as “C” instead of “S” in the burial ID; Ethnoscop, 2016); (2) did not show signs of decay, taphonomic alteration, or pathological lesions; (3) was not been damaged from previous analyses; and (4) had reached a developmental stage suitable for isotopic sampling (i.e., a fully formed crown with some evidence of root formation). Deciduous canines were preferred as they were most likely to capture the longest period of development (Appendix E). If deciduous canines were unavailable or did not meet the above criteria, a different tooth was selected following Figure 3.11 (AlQahtani et al., 2010; Beaumont & Montgomery, 2015). No preference was given to left or right teeth, but maxillary teeth were selected over mandibular unless the latter was in better condition. Teeth that had previously been micro-CT scanned were given preference over those that had not in an effort to minimize the information lost through destructive isotopic analyses.

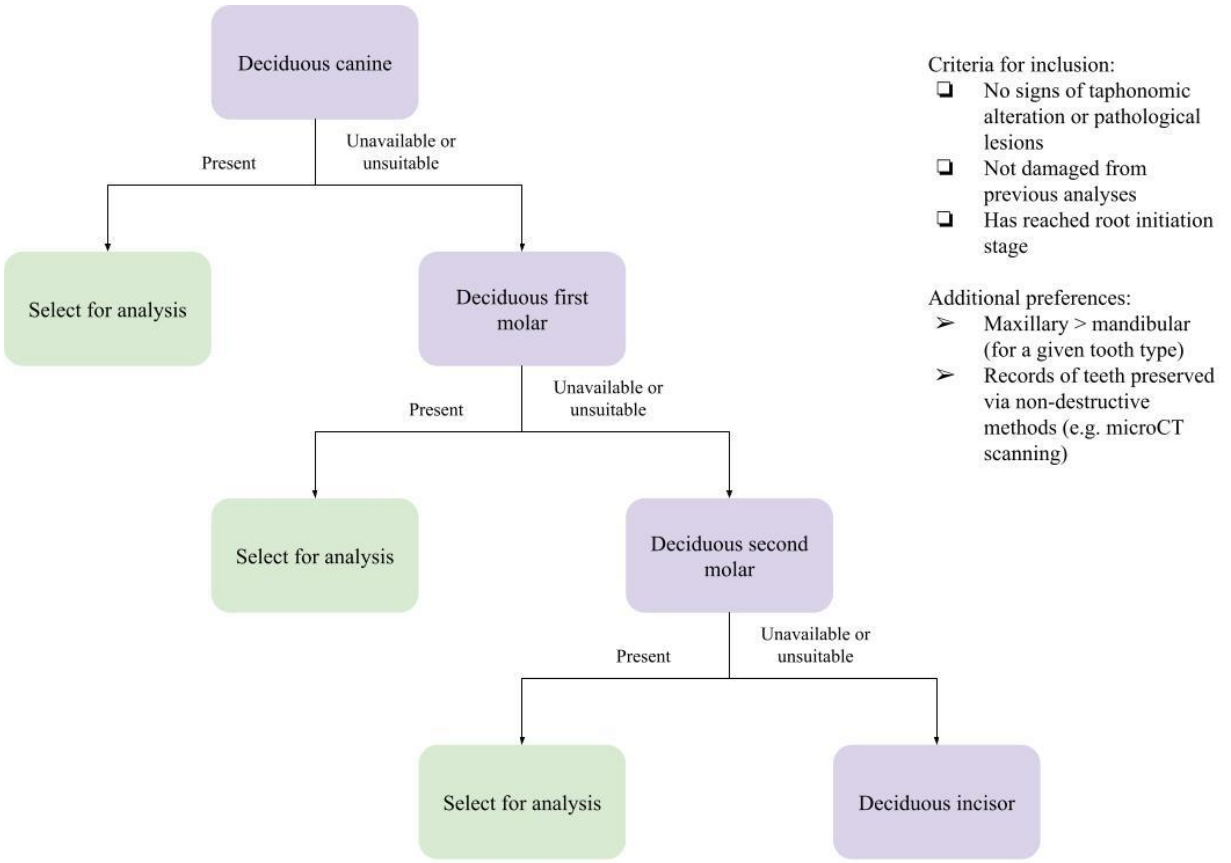

Figure 3.11. Flow chart demonstrating the order of preference for selection of non-adult dental elements.

Forty of the 63 individuals (63%) excavated from the Pointe-aux-Trembles cemetery were non-adults (0-15 years of age) (Ethnoscop, 2016). Of these, 27 had associated dental remains, and 10 individuals had teeth that met the sample inclusion criteria. Nine deciduous canines and one upper second deciduous molar were selected (Table 3.1). The formation stages of these teeth ranged from root initiation (Ri) to three quarters of root development (R3/4); none had fully formed roots (AlQahtani et al., 2010; Buikstra & Ubelaker, 1994; Moorrees et al., 1963a). The sample includes individuals from all three layers of the cemetery, with 7A2 (the shallowest/most recent layer) most commonly represented (5/10 infants) (Table 3.1).

Table 3.1. Summary of non-adult dental samples and burial contexts (Ethnoscop, 2016).

Burial ID	Stratigraphic Layer	Sector[1]	Tooth Sampled	Developmental Stage of Tooth[2]	Estimated Age-at-Death (months)[3]
7A2-S1	Shallowest	Central-northern	urdm2	R1/4	15.5 (14-18)
7A2-S3	Shallowest	South-central	uldc	R1/4	11.5 (8-13.5)
7A2-S22	Shallowest	Northern	lrdc	R1/2	14 (11.5-16)
7A2-S24	Shallowest	Northern	lldc	R1/4	13 (10.5-15.5)
7A2-S32	Shallowest	N/A	uldc	R3/4	19 (16-21.5)
7A9-S18	Middle	N/A	urdc	R1/4	18 (12-19.5)
7A9-S53	Middle	South-central	uldc	R3/4	21.5 (17.5-24)
7A9-S55	Middle	Northern	uldc	R1/2	19.5 (13-21.5)
7A11-S57	Deepest	N/A	uldc	Ri	9.5 (7.5-11)
7A11-S63	Deepest	Northern	lrdc	R1/4	9 (7.5-11)

[1]N/A: was not listed as part of a burial cluster by Ethnoscop (2016).
[2]Following Moorrees et al. (1963a) and AlQahtani et al. (2010).
[3]Mean age-at-death estimate; range (1 standard deviation) noted in parentheses.

3.5.3 Adult Female Bone Samples

Interpretations of infant feeding practices are based on trophic level differences between the breastfeeding infant and lactating female (Fuller et al., 2005). However, it is not possible to identify mother-infant pairs in this archaeological sample. Since adult females are most likely to represent the childbearing and/or breastfeeding population, they can thus provide the most relevant information for interpreting infant feeding practices.

Based on sex estimations available in Christenson (2023), there were nine adult females excavated from BjFi-17 (Table 3.2) (Buikstra & Ubelaker, 1994). One bone sample was collected from each individual. Samples of alveolar bone from around the maxillary or mandibular permanent third molars were preferred as these regions remodel during adulthood to permit dental eruption. Alternatively, rib samples were collected as their high rates of bone turnover suggest ribs should contain tissue formed recently prior to

death (Fahy et al., 2017). Four individuals had alveolar bone available, and samples were collected from areas of antemortem tooth loss using a Dremel® 4000 Rotary Tool (Table 3.2). Rib fragments with evidence of recent bone formation were selected from the remaining five individuals (Table 3.2).

Table 3.2. Bone samples selected from adult females and the burial context of each individual (Ethnoscop, 2016).

Burial ID	Stratigraphic Layer	Sector[1]	Location of Bone Sample	Initial Sample Weight (g)
7A2-S2	Shallowest	Central-northern	Rib	0.45
7A2-S11	Shallowest	Northern	Rib	0.40
7A2-S20	Shallowest	South-central	Mandibular alveolar bone from area of LLM3	0.23
7A2(9)-S23	Shallowest	Northern	Rib	0.44
7A9-S27	Middle	Central-northern	Rib	0.39
7A9-S45	Middle	South-central	Rib	0.38
7A9-S9	Middle	Southern	Mandibular alveolar bone from area of LLM3	0.37
7A11-S42	Deepest	Southern	Mandibular alveolar bone from area of LRM2-M3	0.63
7A11-S61	Deepest	N/A	Maxillary alveolar bone from area of URM3	0.07

[1]N/A: was not listed as part of a burial cluster by Ethnoscop (2016).

3.6 Conclusion

This chapter introduced the sample of individuals selected for isotopic analysis and described life during the time they lived, as well as the archaeological and archival context of their burials.

In the 18th and 19th centuries, Montréal experienced rapid population growth, a deterioration of living conditions, and high infant mortality rates. While conditions were said to be better in rural communities like Pointe-aux-Trembles, residents were likely still impacted by contaminated water, infectious diseases, and other challenges facing infant survival (Amorevieta-Gentil, 2010). Agriculture and hospitality/travel were important

parts of life in the community. Women contributed much to society, with roles that included infant care and wet nursing. Taken together, these aspects of life help improve our understanding of infant feeding practices and potential sources of stress in Montréal and Pointe-aux-Trembles.

A large proportion (62%) of burials in Pointe-aux-Trembles were infants (≤3 years of age) with a bias towards younger age groups (≤1 year of age) (PRDH, 2018), and this was echoed in the age profile of individuals excavated by Ethnoscop (2016). Ten infants (~9-21.5 months of age at death) and nine adult females were selected for isotopic analysis, and this sample represents all three periods of cemetery use (Ethnoscop, 2016).

Chapter 4

4 Methods

This chapter will outline the laboratory and analytical methods used in this study. First, procedures for the dental health analyses are described. Then, the methods used to prepare non-adult incremental dentine collagen samples are discussed, including the procedure used to estimate the ages represented by each increment. This is followed by the methods used to prepare bone collagen samples from the adult females. The isotopic analytical methods and measures of quality control are then discussed, followed by a description of statistical analyses and data visualization methods.

4.1 Dental Health Analyses

All available teeth and jaws from the sampled individuals were examined and scored following Buikstra and Ubelaker (1994). Dental development, caries, abscesses, calculus, periodontitis, wear, and enamel defects were evaluated and measurements of the mesiodistal diameter, buccolingual diameter, and crown height were taken from each tooth. Observations were recorded using a modified Human Remains Documentation Packet from the Arizona State Museum (Appendix F; University of Arizona, 2018).

Enamel defects were classified as grooves (horizontal or vertical), pits (single, linear horizontal, or nonlinear array), planar, LHPC, or lesions (Buikstra & Ubelaker, 1994; Halcrow & Tayles, 2008a; Hillson, 2014; Skinner & Hung, 1989). ‘Lesions’ included any enamel defects that were neither caries nor hypoplasia. Shallow, roughly circular pits on the deciduous canines were considered as LHPC (Halcrow & Tayles, 2008a). For single pits and linear horizontal grooves/pits, the distance from the center of the defect to the CEJ was measured and recorded. For vertical grooves, arrays of pits, localized hypoplastic lesions, and other lesions, measurements were taken from the top (most occlusal) and bottom (most cervical) of the defect to the CEJ. The horizontal width of localized hypoplasias was also recorded. Measurements were taken to the nearest 0.01mm using Mitutoyo Absolute Digimatic calipers.

As the most accurate age estimation methods for deciduous teeth rely on destructive histological analyses (e.g., Birch & Dean, 2014; see Hillson, 2014), they have not been applied here. Instead, age-at-formation for deciduous enamel defects was estimated following Mahoney (2011, 2012). For permanent teeth with a completed CEJ, age-at-formation for enamel defects was estimated following Dąbrowski et al. (2021), Henriquez and Oxenham (2019), and Reid and Dean (2006).

4.2 Sample Preparation

This section will describe the methods used to prepare dental and bone samples for isotopic analysis. Samples were prepared in the Bioarchaeology Chemistry Lab in the Anthropology Department at Western University.

4.2.1 Non-Adult Dental Samples

All teeth were first prepared for longitudinal sectioning into mesial and distal halves. Each tooth was cleaned manually to remove surface debris and mounted to a glass sample slide using Crystalbond 509. The teeth were positioned such that the median buccolingual plane was parallel to the slide and above the level of Crystalbond (Figure 4.1). This position ensured that the tooth would be cut along the correct plane and angle and that the Crystalbond would only come in contact with the embedded half of the tooth.

The next step was to cut the teeth in half. The glass slides were attached to a vacuum chuck using vacuum grease and the teeth were cut in half longitudinally along the buccolingual axis using a Buehler IsoMet® Low Speed Saw (Figure 4.1). This produced mesial and distal halves, one of which remained attached to the slide, while the other was ‘free’ (Figure 4.1). The free half was prepared for incremental dentine sampling and the mounted half was retained for future analyses of enamel carbonate. Equipment was rinsed with distilled water (dH_2O) between teeth to prevent potential cross-contamination between samples.

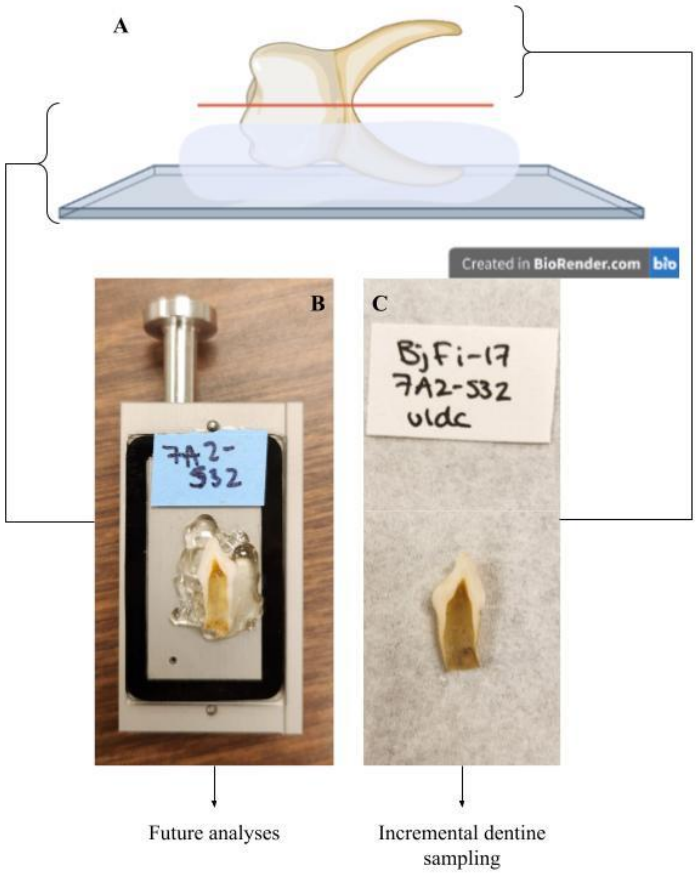

Figure 4.1. Longitudinal sectioning procedure for non-adult dental samples. (A) Demonstrates how teeth were positioned on the glass slides using a deciduous molar. Created using BioRender (2023). The light blue shaded area represents Crystalbond, and the red horizontal line demonstrates the median buccolingual sectioning plane. Teeth were cut into mesial and distal halves. One half remained embedded on the slide (B) while the other was free (C). (B) Shows the embedded half of a canine (7A2-S32) and the glass slide attached to a vacuum chuck. (C) Shows the free half of the upper left deciduous canine from 7A2-S32 to be used for incremental dentine sampling.

Dentine was prepared for serial sectioning following modified procedures from Beaumont et al. (2013, "Method 2") and Sealy et al. (2014, the "chunk" method). Each tooth half was demineralized in 0.1M HCl at 4°C until the tooth no longer visibly reacted with HCl and became flexible with translucent edges (a 'pseudomorph') (Czermak et al., 2020; Eerkens et al. 2011; Pestle, 2010; Sealy et al. 2014; Trayler et al., 2023). The HCl

solution was changed every 24-36 hours until demineralization was completed (~4-6 days). The teeth were then rinsed with dH_2O until a neutral pH was reached and left to soak in dH_2O at 4°C for 48 hours. This was followed by treatment with 0.1M NaOH for 25 minutes at room temperature to remove potential humic acid contaminants (Cheung et al., 2022; Czermak et al., 2020), and subsequent rinsing with dH_2O until neutral. Teeth were soaked in dH_2O at 4°C until sectioned (at least 72 hours). The demineralization process removed almost all tooth enamel, and any remaining pieces were manually removed with a scalpel. All teeth had retained their original shapes, suggesting good collagen preservation (Czermak et al., 2019; Czermak et al., 2020; Sealy et al., 2014).

Each demineralized tooth half was sectioned following modified procedures from Czermak et al. (2018) and Beaumont et al. (2013). They were each cut in half again along the median mesiodistal axis with a scalpel, resulting in two samples that were both approximately one quarter of the original tooth size. One quarter was used for incremental sampling, while the other was stored in dH_2O at 4°C for potential future work. Each quarter-tooth was cut into 1-2mm oblique sections from crown to root using a scalpel. The sectioning angle was approximately horizontal at the crown, and gradually increased over the length of the tooth (Figure 4.2) (Czermak et al., 2018; Lee et al., 2020). This procedure allows one to cut in the direction of dentine growth layers (Andresen lines), thus decreasing the overlap between sections and offering a more precise representation of age periods than horizontal sectioning methods (Figure 4.2) (Avery et al., 2021; Czermak et al., 2018). Sections were labelled alphabetically from crown to root such that ‘A’ represents the earliest-formed dentine, and the final letter represents the dentine formed most recently prior to death.

The oblique sections were then prepared for isotopic analysis. Each section was placed in a test tube, frozen overnight, and freeze-dried for 24 hours. The samples were then weighed to 0.36mg (± 0.01mg) and packed in tin capsules (5mm x 3.5mm, OEA Labs) for isotopic analysis of $\delta^{15}N$ and $\delta^{13}C$. In some cases, consecutive sections (e.g., A+B, D+E) were combined to ensure an adequate sample weight for analysis.

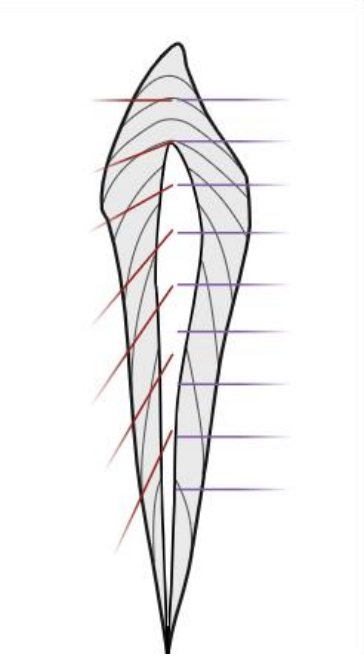

Figure 4.2. Diagram showing the incremental sectioning method of a deciduous canine. The image represents dentine after enamel removal and shows the approximate direction of incremental growth lines (based on Dean, 2017). Red lines on the left demonstrate the oblique sectioning method employed in this study, while purple lines on the right show horizontal sectioning methods. Figure created using BioRender (2023).

Many isotopic studies of dentine collagen include a solubilization step in which the samples are heated in weakly acidic water (pH 3) to denature the collagen. This is suggested to be beneficial because it can remove any impurities that remain in the collagen samples. However, some studies have suggested that the isotopic composition of non-solubilized collagen is not significantly different than that of solubilized collagen in well-preserved samples (Beaumont et al., 2014; Sealy et al., 2014). Further, Cheung et al. (2022) note that the solubilization process can cause substantial collagen loss (up to 56%), particularly in small samples. Current recommendations suggest that the nature of the sample should be factored into decisions surrounding solubilization (Cheung et al., 2022; Czermak et al., 2020). Since many of the sections taken from the developing deciduous roots were already extremely thin, solubilizing them would likely have resulted in a detrimental loss of tissue, and as such, this step was omitted from the procedure. Since the collagen samples being compared in this study were all prepared

using the same pretreatment method, the intra- and interindividual comparisons remain valid, and the lack of solubilization should not greatly influence interpretations (Beaumont et al., 2014; Cheung et al., 2022).

4.2.1.1 Age Estimation for Dentine Sections

An age range was estimated for each dentine section following the general procedure outlined by Beaumont and Montgomery (2015), modified for use on deciduous teeth without fully formed roots. Age-at-death was estimated following Moorrees et al. (1963a, 1963b; Smith, 1991) and confirmed using AlQahtani et al. (2010), Gustafson and Koch (1974), and Liversidge and Molleson (2004) (see Table 3.1). Since deciduous teeth begin forming *in utero* and continue after birth, the total amount of time each tooth took to form will be a sum of the prenatal and postnatal development times (Table 4.1). As all individuals died while their teeth were still forming, age-at-death represents the postnatal formation time. If the sampled tooth root was chipped, the age associated with the tooth's developmental stage was used instead (Moorrees et al., 1963a). The prenatal formation times were calculated with Equation 4.1, using gestational ages of tooth initiation and assuming a 40-week gestation period (Appendix E; Lunt & Law, 1974). The total formation time of the tooth was divided by the number of sections taken to get the approximate amount of time represented by each section (Equation 4.2), and the associated age range was calculated following Equation 4.3. Ages are reported to the nearest 0.5 months.

It is important to acknowledge that this method assumes all dentine increments from a tooth formed over the same amount of time (Beaumont & Montgomery, 2015). As there is some variation in spacing between dentine growth lines throughout the tooth, this can be challenging to guarantee. Thus, the calculated ages must be considered as estimates rather than absolute values. Any deviations from the estimated ages are not expected to substantially alter interpretations of the isotopic data.

Table 4.1. Total formation times for the teeth selected for isotopic analysis.

Burial ID	Tooth Type[1]	Prenatal Formation Time	Postnatal Formation Time	Total Formation

		Crown Initiation (weeks)[2]	Development Remaining *in utero* (weeks)[3]	Mean Time Remaining (months)[4]	Developmental Stage[5]	Age-at-Death (months)[6]	**Time (months)[7]**
7A2-S1	udm2	16.0-23.5	16.5-24.0	4.8	R1/4	15.5	20.5
7A2-S3	udc	15.0-18.0	22.0-25.0	5.3	R1/4	11.5	16.5
7A2-S22	ldc	16.0	24.0	5.5	R1/2	14	19.5
7A2-S24	ldc	16.0	24.0	5.5	R1/4	13	18.5
7A2-S32	udc	15.0-18.0	22.0-25.0	5.3	R3/4	19	24.0
7A9-S18[8]	udc	15.0-18.0	22.0-25.0	5.3	R1/4	18	17.5
7A9-S53	udc	15.0-18.0	22.0-25.0	5.3	R3/4	21.5	26.5
7A9-S55	udc	15.0-18.0	22.0-25.0	5.3	R1/2	19.5	24.5
7A11-S57	udc	15.0-18.0	22.0-25.0	5.3	Ri	9.5	14.5
7A11-S63	ldc	16.0	24.0	5.5	R1/4	9	14.5

[1]udm2 = upper deciduous second molar; udc = upper deciduous canine; ldc = lower deciduous canine
[2]From Lunt & Law (1974) as reported in Hillson (1996) and Birch & Dean (2014). Mean values were used in calculations.
[3]Assuming 40 weeks gestation.
[4]Mean developmental time remaining *in utero*. Divided by 4.345 to convert weeks to months.
[5]Following Moorrees et al. (1963a), Buikstra & Ubelaker (1994).
[6]Mean age at death estimate based on Moorrees et al. (1963a). Rounded to nearest 0.5 months.
[7]Sum of prenatal formation time (midpoint) and postnatal formation time. Rounded to nearest 0.5 months. Apparent discrepancies are due to rounding.
[8]Due to chipping on the edge of the tooth root, the age associated with the apparent developmental stage of the tooth was used instead of the age-at-death estimate for this infant.

$$\frac{(40 - C_i)\ weeks}{4.345\ weeks/month} = prenatal\ formation\ time\ (months)$$

Equation 4.1. Formula used to calculate the prenatal formation time in months for a given tooth type. C_i is the gestational age at which crown initiation typically begins. See also Table 4.1.

$$\frac{total\ formation\ time\ (months)}{number\ of\ sections} = time\ per\ section\ (months)$$

Equation 4.2. Formula for the average amount of time represented by each dentine section, assuming sections of equal width. Based on Beaumont and Montgomery (2015).

$$t_n + time\ per\ section = t_{n+1}$$

Equation 4.3. Formula used to calculate the age range represented for each tooth section, where t_n is the lower estimate of the age range and t_{n+1} is the upper estimate. The starting

value (t_0) is the prenatal initiation time for the corresponding tooth (e.g., –5.5 months for a lower deciduous canine; see Table 4.1). This gives an age in months relative to birth where $t < 0$ = prenatal and $t > 0$ = postnatal. Based on Beaumont and Montgomery (2015).

4.2.2 Adult Female Bone Samples

Adult female bone samples (n = 9; see Table 3.2) were prepared for isotopic analysis of collagen following Sealy et al. (2014, the "chunk" method). All samples were cleaned in an Ultrasonic Cleaner (Model CD-4800) using dH_2O and left to dry at room temperature for 10 days. The bones were then demineralized in 0.5M HCl at room temperature with the solution changed every 24-48 hours. Once demineralized (~3 days), the samples were rinsed with dH_2O until neutral and soaked in 0.1M NaOH for 20 hours at room temperature. Samples were rinsed and soaked in dH_2O again until neutral, frozen overnight, and freeze-dried for 24 hours. The solubilization step was omitted to permit comparisons with the non-adult dentine collagen samples. The freeze-dried collagen was then weighed into 0.36mg (± 0.01mg) samples in tin capsules (5mm x 3.5mm, OEA Labs) for isotopic analysis of δ^{15}N and δ^{13}C. Three samples (7A11-S61, 7A2(9)-S23, 7A9-S27) had insufficient sample weights or collagen yields (≤0.5%) and were not included in further analysis.

4.3 Isotopic Analysis and Quality Control Indicators

Samples were processed using a Costech 4010 Elemental Analyzer coupled to a Thermo Scientific^{TM} Delta V Plus continuous flow isotope ratio mass spectrometer at the Western University Laboratory for Stable Isotope Sciences in London, Ontario, Canada. All stable carbon and nitrogen isotope results are reported relative to international standards (VPDB and AIR, respectively) in ‰ using the δ notation. To calibrate results and monitor mass spectrometer performance, collagen samples were analyzed in series with international and internal laboratory standards of known isotopic composition (USGS-40, USGS-41a, Keratin, Szpak SRM-14). These reference materials were analyzed at the beginning and end of each analytical session and at regular intervals throughout (every five samples). USGS-40 (δ^{13}C: –26.39 ± 0.04‰; δ^{15}N: –4.52 ± 0.06‰; USGS, 2019a) and USGS-41a

(δ^{13}C: +36.55 ± 0.08‰; δ^{15}N: +47.55 ± 0.15‰; USGS, 2019b) were used for calibration (n = 2-3 per session). Keratin (MP Biomedicals Inc., Catalogue No. 90211, Lot No. 9966H; δ^{13}C: –24.05 ± 0.10‰; δ^{15}N: +6.37 ± 0.15‰) was used to monitor drift, and Szpak SRM-14 is an internal laboratory standard similar to collagen (δ^{13}C: –13.68 ± 0.09‰; δ^{15}N: +21.62 ± 0.16‰). Duplicate collagen samples were run every 10 samples. Duplicates and standard reference materials were used to calculate accuracy, precision, and total analytical uncertainty following Szpak et al. (2017) and Magnusson et al. (2012).

C:N ratios, carbon and nitrogen content by weight, and correlation analyses (C:N ratios vs δ^{13}C and δ^{15}N) were used to assess collagen quality and the preservation of original δ^{13}C and δ^{15}N values (Table 4.2) (Ambrose, 1990; Cheung et al., 2022; DeNiro, 1985; Guiry & Szpak, 2021; Harbeck & Grupe, 2009; Roberts et al., 2018; Vaiglova et al., 2023; van Klinken, 1999). Collagen yields were also calculated for bone samples (Equation 4.4); however, the method of sample preparation used for dentine collagen did not permit these calculations as the initial sample weights included enamel and additional dentine that was not sampled.

Table 4.2. Measures of quality control used for bone and dentine collagen (Vaiglova et al., 2023).

Measure	Criteria	References
Collagen yield[1]	>1%	Van Klinken, 1999
C:N ratio	3.1-3.5	Van Klinken, 1999
Weight % C	>13%	Ambrose, 1990
Weight % N	>4.8%	Ambrose, 1990
δ^{13}C vs C:N ratio correlation	No correlation (p > 0.05)	Guiry & Szpak, 2021
δ^{15}N vs C:N ratio correlation	No correlation (p > 0.05)	Guiry & Szpak, 2021

[1]Only calculated for bone collagen.

$$collagen\ yield\ (\%) = \frac{final\ collagen\ weight\ (g)}{initial\ sample\ weight\ (g)} \times 100\%$$

Equation 4.4. Calculation of collagen yield for bone samples. Final weights (mg) were taken after the samples were freeze-dried and converted to grams. Initial weights were

taken after samples had been cleaned and dried, but before any chemical treatments had been performed.

4.4 Statistical Analysis

Data analysis and visualization were performed using R Version 4.0.2 in RStudio (Fox, 2020; Pedersen, 2023; Posit Team, 2023; R Core Team, 2020; Wickham et al., 2019). Pearson's correlation was used to test for a relationship between C:N ratios and isotope values (δ^{13}C, δ^{15}N) in non-adult dentine samples. Spearman's correlation was used for adult female bone collagen due to the small sample size. Wilcoxon rank sum, Levene's, and t-tests were used to identify differences between groups (e.g., adults vs non-adults) where appropriate.

Chapter 5

5 Results

This chapter will present the results of dental analyses for non-adults, as well as stable isotopic analyses of bone collagen from adult females and incremental dentine collagen from non-adults. Notable dental lesions, including enamel hypoplasia and caries, are first presented. Then, isotopic analytical error is considered, followed by δ^{15}N and δ^{13}C results for the adult females. Next, non-adult collagen δ^{15}N and δ^{13}C values are compared to the adult female means and the results are discussed for each individual. The co-occurrence of isotopic changes and hypoplastic defects, especially those potentially indicative of nutritional stress, are highlighted. Finally, patterns of variation and age-related trends are assessed.

5.1 Dental Health Analyses

The complete results of dental scoring and measurements for the sampled non-adults can be found in Appendix G.

EH was observed in the majority of non-adults within this sample (Table 5.1). Eight of 10 individuals had EH on at least one deciduous tooth. Most (6/8) displayed pit-form hypoplasia, with planar hypoplasia in one individual (7A2-S3), linear EH in two individuals (7A2-S1, 7A9-S18), and LHPC in one individual (7A2-S22) (Figures 5.1-5.2). Three infants (7A2-S24, 7A9-S18, 7A9-S55) had hypoplastic defects on their developing permanent teeth. Measurements and age-at-formation estimates for each defect are shown in Table 5.1. Since all of the permanent teeth in this sample were still developing at death, and thus did not have a completed CEJ, ages-at-formation were only calculated for defects on deciduous tooth crowns. This information is considered alongside the isotopic results for each individual.

Table 5.1. Enamel defects in the non-adult individuals.

Burial ID	Tooth	Type of Defect	Ages of Formation (months)[1]	Distance from CEJ (mm)
7A2-S1	uldi2	Linear horizontal groove	-1 to 1	3.36-3.86
	urdi2	Linear horizontal groove	-1 to 1	3.34-3.88

Burial ID	Tooth	Type of Defect	Ages of Formation (months)[1]	Distance from CEJ (mm)
7A2-S3	lldi2	Planar	-3 to 0	3.36-top
7A2-S22	lrdc	Single pit	5.5-8.5	2.32
	lrdc	LHPC	2.5-5.5	2.61-3.63
	uldc	Linear horizontal pits	9-12.5	1.28
	urdc	Linear horizontal pits	9-12.5	1.36
	uldm2	Nonlinear array of pits	3.5-8	1.63-4.05
	urdm2	Nonlinear array of pits	3.5-8	2.15-4.33
	urdm2	Single pit	8-10.5	1.20
7A2-S24	lldc	Linear horizontal pits	8.5-11.5	0.34
	lrdm1	Single pits (2)	7-9	0.48
	lrdm2	Nonlinear array of pits	3.5-8	1.79-3.87
	URM1	Single pits (5)	birth-death	N/A
7A9-S18	lldi2	Single pits (2)	3.5-6	1.30
	lldc	Linear horizontal groove	5.5-8.5	3.50
	lrdc	Linear horizontal groove	5.5-8.5	3.50
	urdc	Linear horizontal pits	6-9	2.44-3.95
	lldm1	Single pit	4.5-7	3.47
	uldm1	Single pit	7-9	1.27
	lrdm2	Nonlinear array of pits	3.5-6	2.84-4.54
	lrdm2	Linear horizontal groove	6-8	1.91
	lrdm2	Linear horizontal pits	3.5-6	3.65
	uldm2	Linear horizontal pits	6-8	2.81
	uldm2	Nonlinear array of pits	3.5-6	4.50
	urdm2	Linear horizontal pits	N/A	N/A
	ULM1	Nonlinear array of pits	birth-death	N/A
	URM1	Linear horizontal groove	birth-death	N/A
	URM1	Nonlinear array of pits	birth-death	N/A
7A9-S55	lldm2	Single pit	8-10.5	0.60
	lrdm2	Single pit	6-8	2.74
	lrdm2	Single pit	8-10.5	1.28
	ULM1	Single pit	birth-death	N/A
7A11-S57	urdi2	Single pits (3)	3.5-6	0.03-0.79
	urdc	Single pit	N/A	N/A
7A11-S63	uldi2	Single pit	3.5-6	1.43
	uldc	Nonlinear array of pits	6-9	1.93
	lldc	Linear horizontal pits	2.5-5.5	4.62

[1]Negative values indicate months before birth. Ages estimated following Mahoney (2011, 2012).

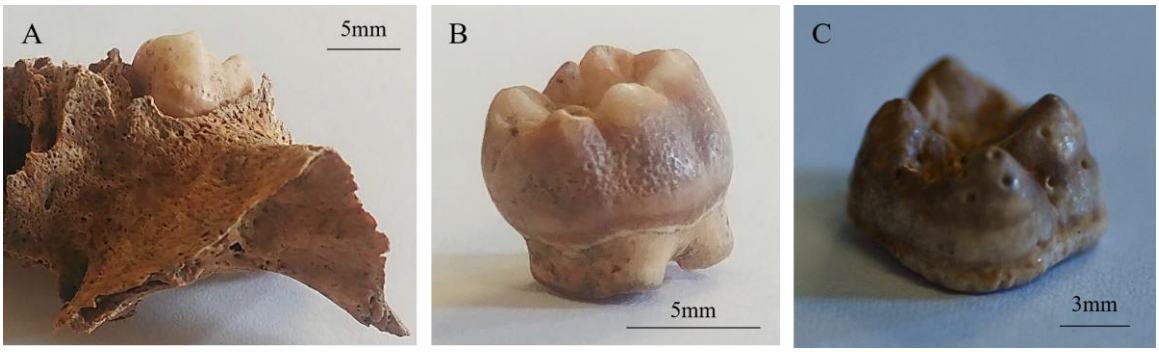

Figure 5.1. A) Example of linear horizontal pit-form enamel hypoplasia on the buccal surface of an upper right deciduous second molar from 7A9-S18. Scale bar shows 5mm. B) Example of a nonlinear array of pit-form enamel hypoplasia on the buccal surface of an upper left deciduous second molar from 7A2-S22. Scale bar shows 5mm. C) Example of pit-form and linear enamel hypoplasia in the developing upper right permanent first molar of 7A9-S18. Scale bar shows 3mm.

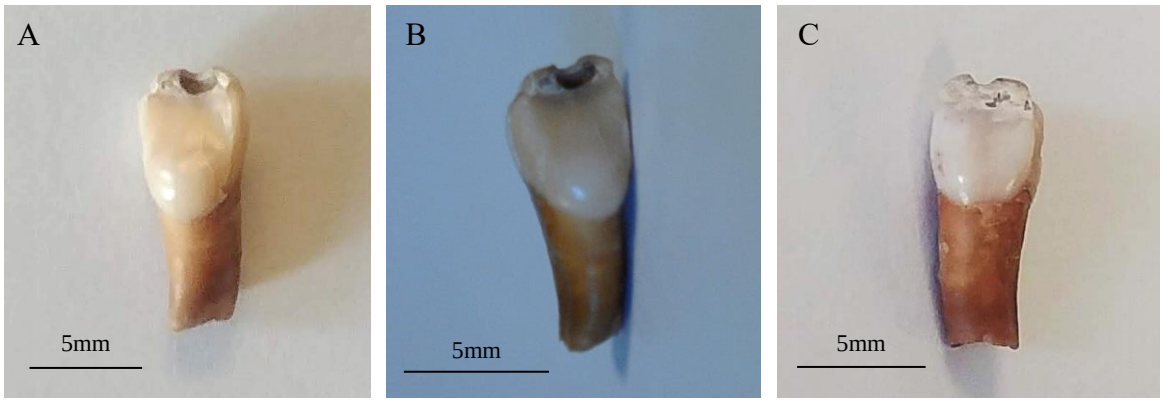

Figure 5.2. Lingual (A and B) and labial (C) views of lower left deciduous second incisor of 7A2-S3. Enamel is missing from the entire lingual surface, exposing the underlying dentine. Caries and planar enamel hypoplasia are visible on the incisal edge. Scale bars show 5mm.

Of the 10 individuals evaluated, eight had pathological dental lesions besides EH (Table 5.2). Dental wear was minimal, if present; calculus and abscesses were not observed, and vertical bone loss associated with periodontitis was observed in one individual (7A9-S53). Caries was the most commonly observed pathological condition, present in eight of 10 individuals and observed in 25 teeth; 22 of these were anterior deciduous teeth. No

permanent teeth were affected as they had not erupted. Two individuals (7A2-S3, 7A2-S32) displayed bilateral carious lesions on the inner (lingual) surface of their incisors (Figure 5.3). In 7A2-S3, all incisors that were present (i.e., recovered/preserved) were affected, whereas only the upper second deciduous incisors were affected in 7A2-S32. Root and/or cervical caries were also commonly observed on the anterior teeth, namely those of 7A2-S1, 7A9-S53, 7A9-S55, and 7A2-S32. Enamel was missing from the lingual surface of one molar (lower left first deciduous molar) and all incisors present for 7A2-S3 (Figures 5.2-5.3). Additional detail can be found in Table 5.2. Due to the extent of the lesions exhibited on 7A2-S1, this individual is discussed separately below.

Table 5.2. Caries and other dental lesions observed in the non-adult individuals.

Burial ID	Tooth	Lesion Description[1]
7A2-S1	urdi1	Grey flaky lesion covering bottom half of labial surface; brown discolouration along edge of lesion; minor groove apparent on lingual surface
	urdi2	Grey flaky lesion covering almost entire labial surface; large areas where tissue has chipped/flaked away; dark linear groove along lingual surface
	uldi2	Grey flaky lesion covering almost entire labial surface; pitted groove on lingual surface
	urdc	Grey flaky lesion covering almost entire buccal surface, across cusp, and down the lingual surface; brown band visible at the borders of the lesion
	urdm1	Grey flaky lesion covers entire occlusal surface and part of the buccal and lingual surfaces
	uldm1	Grey flaky lesion across occlusal, buccal, and lingual surfaces
	lrdi1	Root caries beginning at labial CEJ; white discolouration that covers the upper two-thirds of the lingual surface; distal interproximal caries
	lldi1	Root caries beginning at labial CEJ; mesial and distal interproximal caries; chalky discolouration on upper two-thirds of lingual surface
	lldi2	Root caries beginning at labial CEJ; lingual surface is rough and white-beige in colour, extends two thirds down the surface from the incisal edge
	lrdi2	Brown staining on labial surface; chalky white-beige lesions on lingual surfaces that extend around the mesial and distal sides; mesial interproximal caries; caries on labial surface at CEJ
	lrdc	Grey flaky lesion covering almost entire buccal surface, extends across cusp and down the tip of the lingual surface
	lrdm1	Grey flaky lesion covers almost entire buccal surface, extends across occlusal surface and down lingual surface; pit on occlusal surface between distobuccal, distolingual, and mesiolingual cusps
	lldm1	Grey flaky lesion covers almost entire buccal surface, extends across occlusal surface and down lingual side; three pits between cusps on occlusal surface

Burial ID	Tooth	Lesion Description[1]
7A2-S3	uldi2	Smooth surface caries, predominantly on lingual surface, crosses incisal edge to labial surface; enamel missing from lingual surface
	lrdi1	Grey discolouration of enamel on labial surface from 1.63mm to the incisal edge; indentation and pit on incisal edge; caries on lingual surface from 2.89mm to incisal edge; enamel missing from lingual surface
	lldi1	Caries on lingual surface, appears grey and ashy with defined brown edge at 2.74mm, extends from lingual surface across incisal edge to 3.35mm on labial surface; remainder of labial surface is discoloured; some indentation on incisal edge from the lesion; enamel missing from lingual surface
	lldi2	Enamel defect from 3.36mm on labial surface that extends across incisal edge to 4.03mm lingual surface, appears chalky; indentation on incisal edge and loss of enamel and dentine (possible caries) is visible on the labial surface; enamel missing from lingual surface
	lldm1	Enamel missing from lingual surface
7A2-S22	urdm1	Smooth surface caries
7A2-S32	urdc	Possible cervical caries, labial
	urdi2	Smooth surface caries, lingual
	uldi2	Smooth surface caries, lingual
	lrdm1	Possible cervical caries, lingual
	lldi1	Possible cervical caries, labial
7A9-S18	lrdm1	Smooth surface caries
7A9-S53	urdi2	Small pit on incisal edge, grey discolouration on incisal third of labial surface
	lrdm1	Vertical bone loss of alveolar bone around mesiobuccal root
	lrdc	Root caries, lingual
	lldi1	Root caries, labial
	lldi2	Root caries, distal interproximal; cervical caries, labial
	lldc	Root caries, lingual
7A9-S55	urdc	Cervical caries, labial
	urdi2	Cervical caries, mesial & labial
	lldi1	Interproximal caries, mesial near CEJ
7A11-S57	uldi2	Smooth surface caries, lingual
	lrdi1	Smooth surface caries, buccal
	lldi1	Smooth surface caries, buccal

[1]Measurements were taken relative to the CEJ.

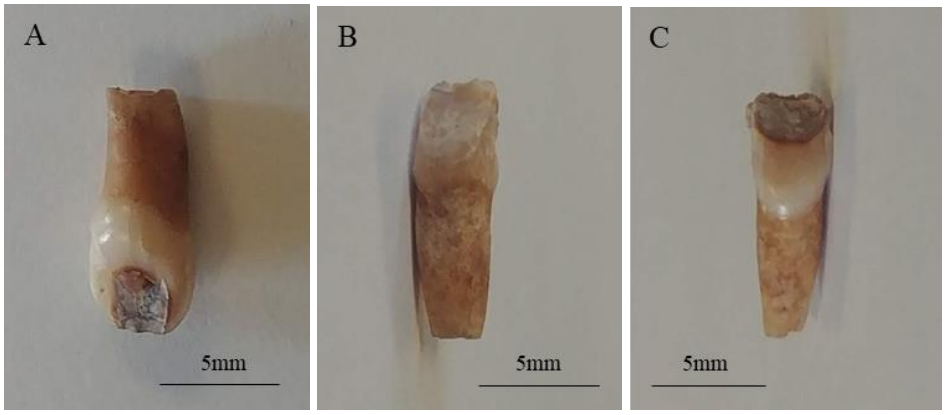

Figure 5.3. Examples of dental lesions on the anterior teeth of 7A2-S3. A) Carious lesion on lingual surface of upper left deciduous second incisor. Enamel is missing from the entire lingual surface, exposing the underlying dentine. B & C) Labial (B) and lingual (C) views of lower right deciduous first incisor of 7A2-S3. Enamel is also missing from the lingual surface of this tooth; grey discoloured enamel is visible on the labial surface. Carious lesion present on lingual surface. Scale bars show 5mm.

5.1.1 7A2-S1

Sixteen deciduous teeth were present in 7A2-S1; 13 of 16 displayed enamel hypoplasia, caries, and/or other dental lesions. Three different lesion patterns were noted and have been described below. The unaffected teeth (n = 3) are all deciduous second molars that had not fully erupted before death.

The four lower deciduous incisors exhibit a pattern distinct from the other teeth (Figure 5.4). Labial surfaces of the crowns appear normal except for some localized areas of light brown staining. The lingual surfaces have a white-beige, chalky appearance that extends from just below the incisal edge to two-thirds down the surface; the lower cervical third of the crowns are not affected. These lesions extend around the mesial and distal sides of the teeth like a diagonal band toward the cervical edge of the labial surface, with clear indentations on the interproximal surfaces (Figure 5.4). All four teeth have caries arising from some area within these lesions. The lower left first and second and lower right first deciduous incisors have caries that begin at the labial CEJ and extend onto the root. There is also a labial cervical caries in the lower right second deciduous incisor, but the decay is

contained within the crown and does not extend onto the root. Interproximal caries are present on the distal lower right first deciduous incisor, mesial and distal lower left first deciduous incisor, and mesial lower left second deciduous incisor.

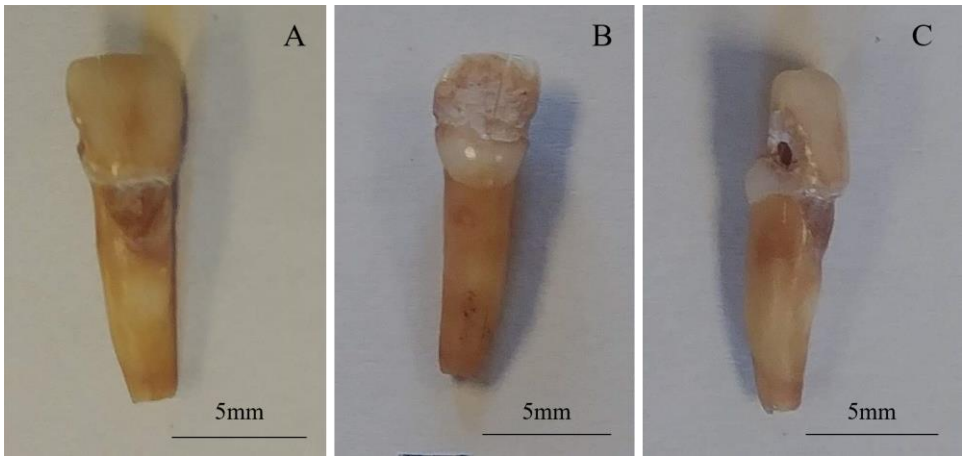

Figure 5.4. Example of lesions on lower deciduous incisors from 7A2-S1. Lower left deciduous first incisor is pictured. Labial view (A) shows a carious lesion extending from the CEJ into the root. Lesion is present on lingual surface (B). Mesial view (C) shows a caries that has developed within the lesion. Scale bars are 5mm.

Three of four upper deciduous incisors are present and all display dental lesions. The labial surfaces of all three teeth appear grey and ashy, with pits and tissue flaking off in some areas (Figures 5.5-5.6). These lesions cover half of the surface of the upper right first deciduous incisor, with some brown discolouration along the border of the lesion (Figure 5.5). Nearly the entire labial surfaces of both second deciduous incisors are affected, but the incisal edges of all three teeth remain intact. The lingual surfaces show linear grooves that extend the mesiodistal length of the tooth but are not visible on the labial surface, possibly obscured by the other lesions. These grooves vary in depth, with the most pronounced, almost trench-like, pitting found on the upper left second deciduous incisor; the upper right first deciduous incisor is the least pronounced. These grooves are likely caries that have begun to develop within underlying linear enamel hypoplastic lesions. The grooves in the left and right upper second deciduous incisors are found at the same distance from the CEJ (Table 5.1), suggesting that the hypoplastic defects formed at the same age.

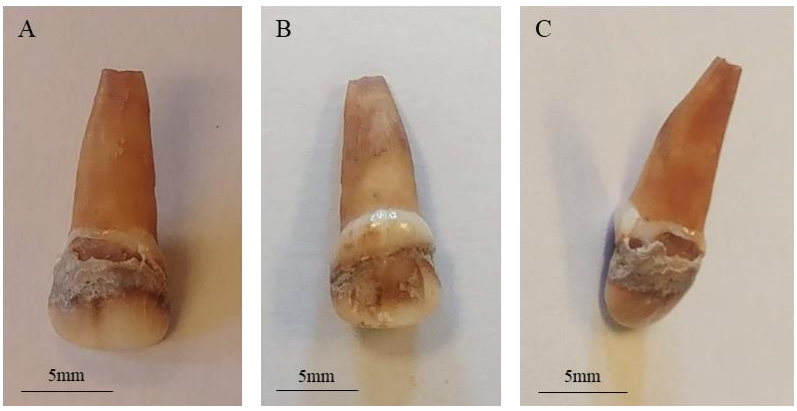

Figure 5.5. Dental lesions on upper right deciduous first incisor of 7A2-S1. Grey, pitted, flaky enamel is visible on the labial surface. Slight indentation is visible across the lingual surface. Photos show labial (A), lingual (B), and disto-labial (C) views. Scale bars show 5mm.

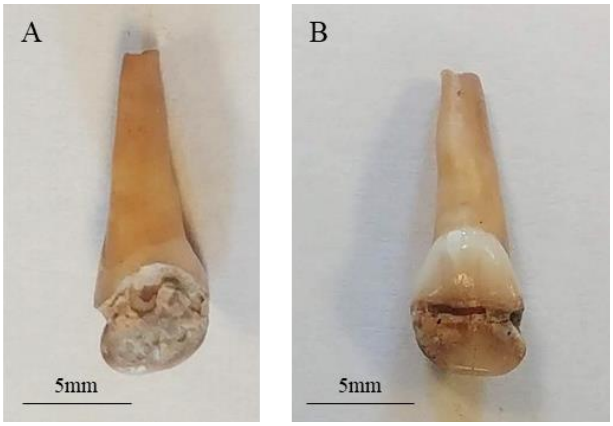

Figure 5.6. Dental lesions on upper left deciduous second incisor of 7A2-S1. A) Labial surface with grey, pitted, flaky enamel is visible on almost the entire crown. B) Lingual surface shows caries that have developed within a hypoplastic groove extending the length of the tooth. Scale bars show 5mm.

Both canines and all four deciduous first molars display a third pattern of lesions (Figures 5.7-5.8). These are similar in appearance to those found on the labial surfaces of the upper deciduous incisors, but in this case, they extend across the occlusal surfaces and appear on both the buccal and lingual sides (Figure 5.7). The tissue appears grey and flaky, with clearly demarcated boundaries between the affected and non-affected areas.

The boundaries are curved or diagonal, not horizontal. In all cases, the lesions cover a greater proportion of the buccal surface, with more normal tissue visible on the labial surfaces. Pits are present on the occlusal surfaces of the lower deciduous first molars.

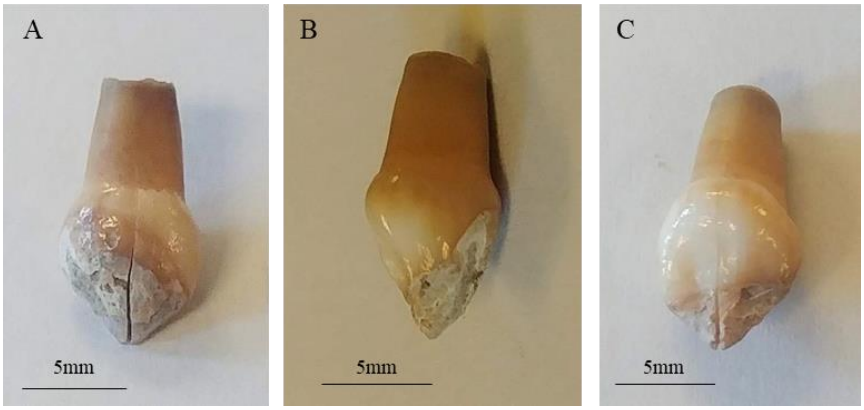

Figure 5.7. Example of lesions present on deciduous canines of 7A2-S1. Upper right deciduous canine is pictured in labial (A), distal (B), and lingual (C) views. Grey, pitted enamel lesions are visible on most of the labial surface, extending across the mesial and distal sides to the lingual surface. Scale bars show 5mm.

Figure 5.8. Example of lesions present on deciduous first molars of 7A2-S1. Photograph shows the right mandible with the lower right deciduous first and second molars. Grey, pitted lesions are present on almost the entire buccal surface of the first deciduous molar, while the second deciduous molar is unaffected. Scale bar shows 1cm.

5.2 Isotopic Analyses

5.2.1 Analytical Error

The isotope results from the international and laboratory standards are shown in Table 5.3. Non-adult dentine samples were analyzed over the course of two days, and the adult bone samples were analyzed separately. On the first dentine run, the magnet jump on the mass spectrometer was not calibrated correctly, causing the program to give some erroneous δ^{13}C results. δ^{15}N results were not impacted. These instances were easily detectable on the mass spectrometer interface and affected five standards (noted in Table 5.3) and two samples (7A11-S63_E, 7A2-S32_F_DUP). The issue was resolved for the second dentine run and was not observed in any samples or standards analyzed on day

two; the bone samples were also not affected. All data impacted by this issue have been removed from consideration.

Table 5.3. Mass spectrometry results for international and laboratory standards run within the trays of bone and dentine collagen samples. δ^{13}C values affected by machine error have been removed.

Sample	Tray[1]	Line	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{Air}$	C:N Ratio	Carbon Error?	Calibration or Check[2]
Keratin	B1	2	–24.13	+6.50	3.75	N	Check
Keratin	B1	3	–24.17	+6.45	3.76	N	Check
Keratin	B1	13	–24.11	+6.54	3.71	N	Check
Keratin	B1	26	–24.11	+6.29	3.72	N	Check
Keratin	B1	33	–24.11	+6.46	3.73	N	Check
Keratin	B1	41	–24.18	+6.39	3.73	N	Check
Keratin	B1	48	–24.13	+6.42	3.72	N	Check
Keratin	D1	2	---	+6.50	3.72	Y	Check (N)
Keratin	D1	3	–24.04	+6.45	3.72	N	Check
Keratin	D1	13	---	+6.63	3.70	Y	Check (N)
Keratin	D1	26	–24.11	+6.57	3.70	N	Check
Keratin	D1	39	–24.02	+6.53	3.71	N	Check
Keratin	D1	52	---	+6.59	3.72	Y	Check (N)
Keratin	D2	2	–24.01	+6.44	3.71	N	Check
Keratin	D2	3	–23.97	+6.32	3.72	N	Check
Keratin	D2	13	–24.05	+6.54	3.71	N	Check
Keratin	D2	26	–24.03	+6.57	3.70	N	Check
Keratin	D2	39	–24.03	+6.44	3.70	N	Check
Keratin	D2	53	–24.02	+6.34	3.73	N	Check
Keratin Mean (SD)			–24.08 (0.06)	+6.47 (0.09)	3.72 (0.02)		
Expected Mean (SD)			–24.05 (0.10)	+6.37 (0.15)			
Szpak SRM-14	B1	7	–13.26	+21.82	3.21	N	Check
Szpak SRM-14	B1	47	–13.64	+21.62	3.22	N	Check
Szpak SRM-14	D1	7	–13.68	+21.70	3.25	N	Check
Szpak SRM-14	D1	54	–13.83	+21.73	3.25	N	Check
Szpak SRM-14	D2	7	–13.65	+21.65	3.25	N	Check

Sample	Tray[1]	Line	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{Air}$	C:N Ratio	Carbon Error?	Calibration or Check[2]
Szpak SRM-14	D2	55	–14.30	+21.48	3.31	N	Check
Szpak SRM-14 Mean (SD)			–13.73 (0.34)	+21.67 (0.11)	3.25 (0.03)		
Expected Mean (SD)			–13.68 (0.09)	+21.62 (0.16)			
USGS-40	B1	6	–26.40	–4.47	4.98	N	In curve
USGS-40	B1	32	–26.38	–4.57	4.98	N	In curve
USGS-40	D1	6	–26.45	–4.57	5.06	N	In curve
USGS-40	D1	33	–26.33	–4.46	5.01	N	In curve
USGS-40	D1	53	---	–4.53	5.04	Y	In N curve; not in C curve
USGS-40	D2	6	–26.43	–4.52	5.04	N	In curve
USGS-40	D2	33	–26.33	–4.53	5.01	N	In curve
USGS-40	D2	54	–26.41	–4.50	5.04	N	In curve
USGS-40 Mean (SD)			–26.39 (0.05)	–4.52 (0.04)	5.02 (0.03)		
USGS-41a	B1	5	+36.52	+47.70	5.00	N	In curve
USGS-41a	B1	20	+36.42	+47.30	5.00	N	In curve
USGS-41a	B1	42	+36.70	+47.65	4.96	N	In curve
USGS-41a	D1	5	+36.47	+47.78	5.05	N	In curve
USGS-41a	D1	20	---	+48.29	5.01	Y	Not in curve
USGS-41a	D1	46	+36.63	+47.32	5.03	N	In curve
USGS-41a	D2	5	+36.49	+47.74	5.03	N	In curve
USGS-41a	D2	20	+36.65	+47.78	5.00	N	In curve
USGS-41a	D2	46	+36.51	+47.13	5.03	N	In curve
USGS-41a Mean (SD)			+36.55 (0.10)	+47.63 (0.35)	5.01 (0.03)		

[1]D1: first dentine run; D2: second dentine run; B1: adult female bone collagen run.
[2]Distinguishes standards used to generate calibration curves from those used as check standards (Szpak et al., 2017). Used for both carbon and nitrogen unless otherwise specified.

Measures of analytical error were calculated following Szpak et al. (2017) using duplicate collagen samples and standards from all three runs. Precision ($u(R_w)$) was found to be 0.1‰ for carbon isotopes and 0.3‰ for nitrogen isotopes, and accuracy ($u(bias)$) was 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$. Total analytical uncertainty (u_c) was 0.2‰ ($\delta^{13}C$) and 0.3‰ ($\delta^{15}N$). Expanded combined uncertainty (U) was calculated to be 0.5‰ for $\delta^{13}C$, and 0.6‰ for $\delta^{15}N$ (95% confidence level, coverage factor $k = 2$; Magnusson et al.,

2012). Calculations of these values can be found in Appendix H (Szpak et al., 2017). The total analytical uncertainty is used as the measure of error; however, to avoid over-interpreting the data, changes in δ^{15}N and δ^{13}C values are only considered when they exceed the expanded combined uncertainty.

Keratin was used to monitor instrumental drift (a consistent increase or decrease in isotope values throughout the run; Carter & Fry, 2013; Szpak et al., 2017), and these results are shown in Figures 5.9-5.10. As the slopes were not significantly different from zero, minimal drift was observed, and no correction factors were used (Figures 5.9-5.10).

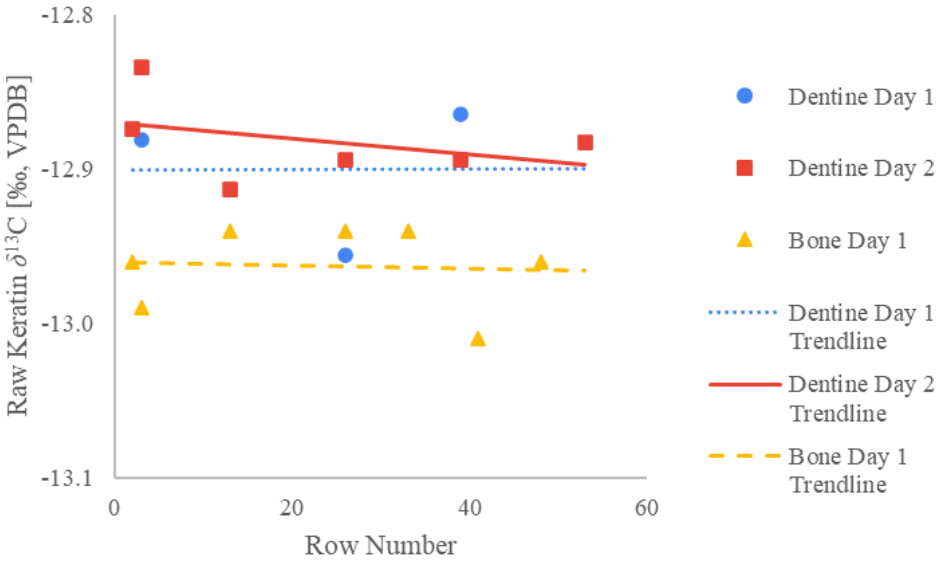

Figure 5.9. Drift in δ^{13}C values of keratin samples from each run (dentine day 1: blue circles; dentine day 2: red squares; bone day 1: orange triangles). Row number indicates the sample's position in the run. Linear trendlines demonstrate minimal drift throughout the day (dentine day 1: $y = 0.00002x - 12.901$, $R^2 < 0.01$, t = 0.006, $p = 0.996$; dentine day 2: $y = -0.0005x - 12.87$, $R^2 = 0.152$, t = –0.847, $p = 0.445$; bone day 1: $y = -0.0001x - 12.96$, $R^2 = 0.0056$, t = –0.168, $p = 0.873$).

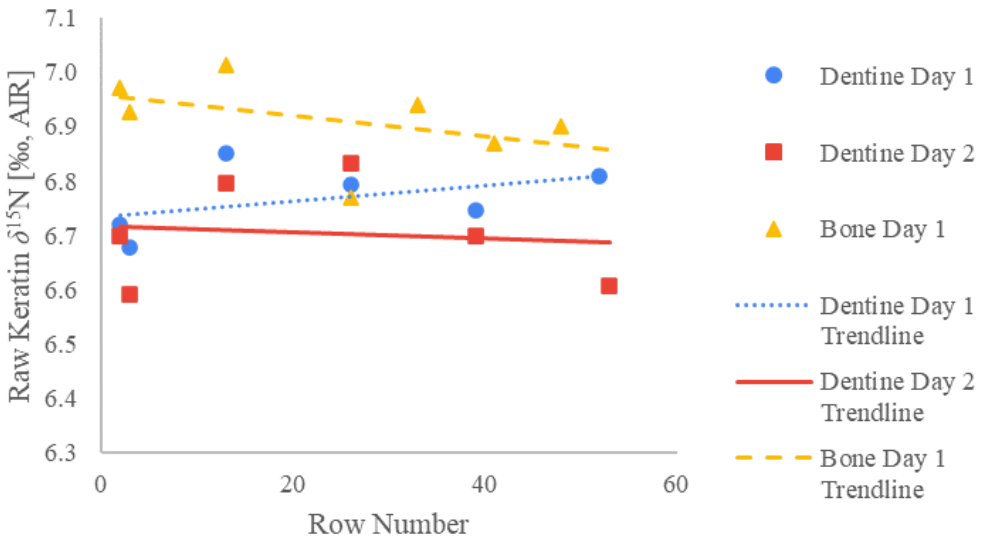

Figure 5.10. Drift in δ^{15}N values of keratin samples from each run (dentine day 1: blue circles; dentine day 2: red squares; bone day 1: orange triangles). Row number indicates the sample's position in the run. Linear trendlines demonstrate minimal drift throughout the day (dentine day 1: $y = 0.0014x + 6.6846$, $R^2 = 0.2$, t = 1.0, $p = 0.374$; dentine day 2: $y = –0.0005x + 6.6665$, $R^2 = 0.0131$, t = –0.23, $p = 0.829$; bone day 1: $y = –0.0019x + 6.9084$, $R^2 = 0.1924$, t = –1.091, $p = 0.325$).

5.2.2 Adult Females

Table 5.4 summarizes the δ^{13}C and δ^{15}N results and quality control indicators of the adult female bone collagen samples ($n = 6$). Collagen yields range from 1.5-12.5%, above the acceptable threshold of 1% (van Klinken, 1999). Carbon and nitrogen content (weight %) and C:N ratios are used to indicate poor quality collagen or the presence of contaminants (e.g., lipids, humic acids) in samples (Guiry & Szpak, 2021; Katzenberg & Waters-Rist, 2018). On average, the adult female collagen samples were 42.8% carbon and 15.3% nitrogen by weight, ranging from 29.9-46.4% and 10.6-16.8%, respectively. These values exceed the minimum weights suggested by Ambrose (1990; 13% C, 4.8% N) and are within the range of values observed in good quality collagen samples by Harbeck and Grupe (2009). Likewise, the C:N ratios are within the typical limits for bone collagen (3.1-3.5; Guiry & Szpak, 2021; van Klinken, 1999), and do not demonstrate a significant

correlation with $\delta^{13}C$ or $\delta^{15}N$ values (Spearman's correlation; $\delta^{13}C$: r = –0.06, p = 0.91; $\delta^{15}N$: r = –0.23, p = 0.66; Guiry & Szpak, 2021). Taken together, these data suggest good quality and uncontaminated collagen, and thus all samples are included in analysis.

The results for the adult female bone collagen samples are shown in Table 5.4. The average $\delta^{15}N_{col}$ and $\delta^{13}C_{col}$ values of the adult females are +10.4 ± 0.5‰ and –19.5 ± 0.3‰, respectively. There is a similar degree of variation in stable carbon and nitrogen compositions, as $\delta^{15}N_{col}$ values range by 1.2‰ (+9.8 to +11.0‰), and the $\delta^{13}C_{col}$ values range by 0.95‰ (–20.0 to –19.1‰). These results will be used to indicate the adult female diet in 18th to 19th century Pointe-aux-Trembles.

When interpreting diet using stable carbon and nitrogen isotope compositions from bone collagen, it is necessary to account for diet-tissue spacing. Based on the most commonly observed diet-tissue spacing values in controlled feeding studies, this thesis uses correction factors of –2.5‰ and –5.0‰ for nitrogen and carbon isotopes, respectively, to estimate the $\delta^{15}N$ and $\delta^{13}C$ values of the foods that were consumed ($\delta^{13}C_{diet,}$ $\delta^{15}N_{diet}$; DeNiro & Epstein, 1981; Fernandes et al., 2012; Froehle et al., 2010; Keegan & DeNiro 1988; van der Merwe & Vogel, 1978). Since studies have observed a range of diet-tissue spacing factors, the adjusted values should only be considered approximate indicators of diet. This gives average dietary $\delta^{15}N$ and $\delta^{13}C$ values of +7.9 ± 0.5‰ and –24.5 ± 0.3‰, respectively (Table 5.4). The $\delta^{15}N_{col}$ and $\delta^{13}C_{col}$ values are used in comparisons to non-adult dentine collagen, while the adjusted values ($\delta^{15}N_{diet}$, $\delta^{13}C_{diet}$) are used for dietary interpretations.

Table 5.4. $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ results and quality control indicators for the adult female bone collagen samples. Dietary $\delta^{13}C$ and $\delta^{15}N$ have been adjusted for diet-tissue spacing (see text).

Burial ID	Bone Sampled	$\delta^{13}C_{col}$ (‰)	$\delta^{15}N_{col}$ (‰)	$\delta^{13}C_{diet}$ (‰)	$\delta^{15}N_{diet}$ (‰)	Collagen Yield (%)	C:N Ratio	Weight % C	Weight % N
7A2-S2	Rib	–19.5	+10.3	–24.5	+7.8	6.7	3.23	46.4	16.8
7A2-S11	Rib	–19.3	+10.0	–24.3	+7.5	12.5	3.25	46.4	16.7

7A2-S20	Mandibular alveolar bone	–19.1	+11.0	–24.1	+8.5	1.5	3.30	29.9	10.6
7A9-S9	Mandibular alveolar bone	–20.0	+9.8	–25.0	+7.3	2.7	3.34	44.5	15.6
7A9-S45	Rib	–19.5	+10.2	–24.5	+7.7	2.6	3.23	44.5	16.0
7A11-S42	Mandibular alveolar bone	–19.5	+10.9	–24.5	+8.4	7.9	3.24	45.4	16.3
Average[1]	---	–19.5 (0.3)	+10.4 (0.5)	–24.5 (0.3)	+7.9 (0.5)	5.7	3.27	42.8	15.3

[1]Standard deviations for $\delta^{13}C$ and $\delta^{15}N$ are noted in parentheses.

The next step in isotopic dietary reconstructions involves finding potential food sources for the community and region and comparing their isotopic values to the dietary $\delta^{15}N$ and $\delta^{13}C$ results. Food sources available in 19th century Montréal included fruits and vegetables, grains, dairy products, sugar, coffee, tea, alcohol (e.g., spruce beer, brandy, rum), beef, veal, lamb, pork, poultry, and fish, both sourced locally and imported from Upper Canada and other surrounding areas (Fougères & MacLoed, 2017; Fyson, 1989; Waywell, 1989). Domestic animals were typically consumed more frequently than wild game, but fishing was common (Vigeant et al., 2017). Guiry et al. (2017) published bone collagen $\delta^{15}N$ and $\delta^{13}C$ results from archaeological samples of cattle and pigs from 19th century southern Ontario, and Morris (2015) used $\delta^{15}N$ and $\delta^{13}C$ results from archaeological animal bone and modern plant data (corrected for the Suess effect) to construct a food web for the Late Woodland period (AD 900-1650) in southern Ontario. Data from these studies have been selected to represent food sources such as beef, pork, fish, small carnivores, omnivores (black bear, wild turkey), and C_3/C_4 plants, and have been compared to the adult female dietary values in Figures 5.11-5.12. Since the animal $\delta^{13}C$ results were derived from bone collagen, they were corrected by –2‰ to represent the $\delta^{13}C$ values of flesh, the body part most likely to have been consumed (DeNiro & Epstein, 1978, 1981). These results suggest adult females derived dietary protein from beef, pork, and possibly fish, and that C_3 plants were more likely to have been consumed than C_4 plants (Figure 5.11).

There are some differences in geographic location between the published work and current study that may have minor effects on the comparability of the results (i.e., southern Ontario versus Montréal). However, since the purpose of this analysis is to gain a general idea of the adult female diet within Pointe-aux-Trembles, this potential source of error was deemed acceptable. Should future research wish to examine the dietary habits of rural Montréal communities in greater detail, faunal samples from the same region should be analyzed.

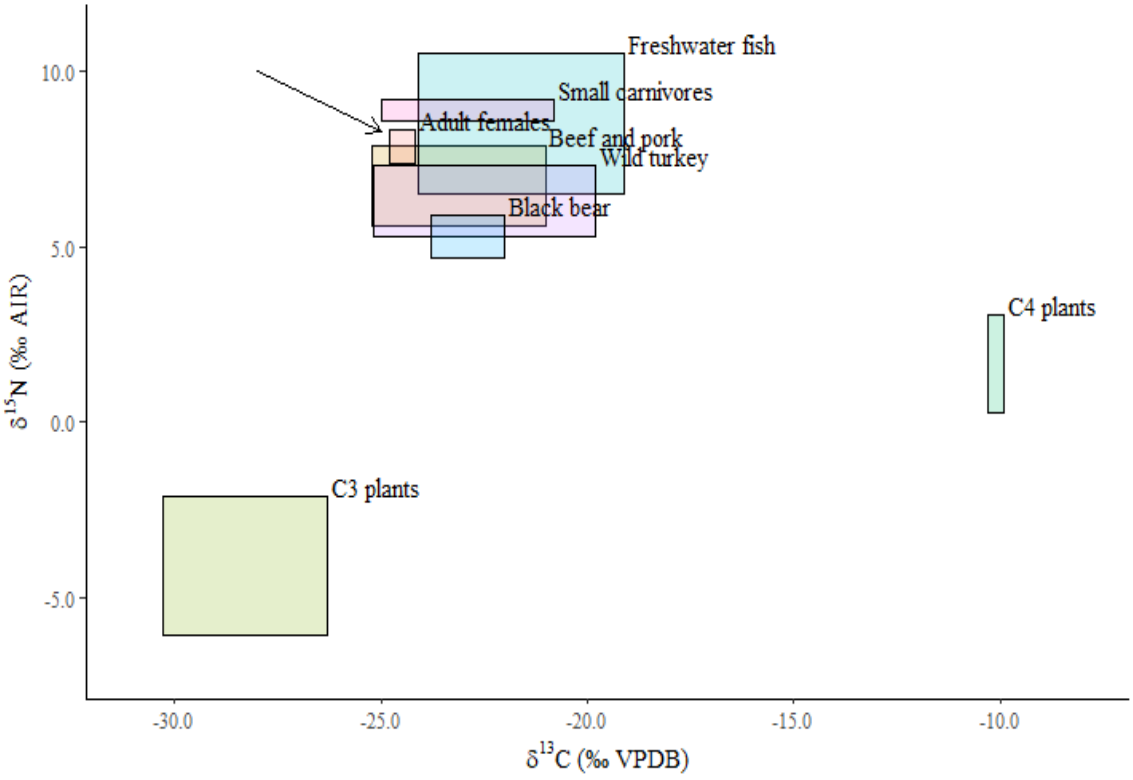

Figure 5.11. Comparison of dietary δ^{15}N and δ^{13}C results from adult female bone collagen samples (indicated by an arrow) to published data from archaeological faunal and modern plant samples in southern Ontario (Guiry et al., 2017; Morris, 2015). Rectangles indicate ±1SD around the mean and correspond to the label in their top right corner. See Figure 5.12 for a close-up of the faunal and adult female samples.

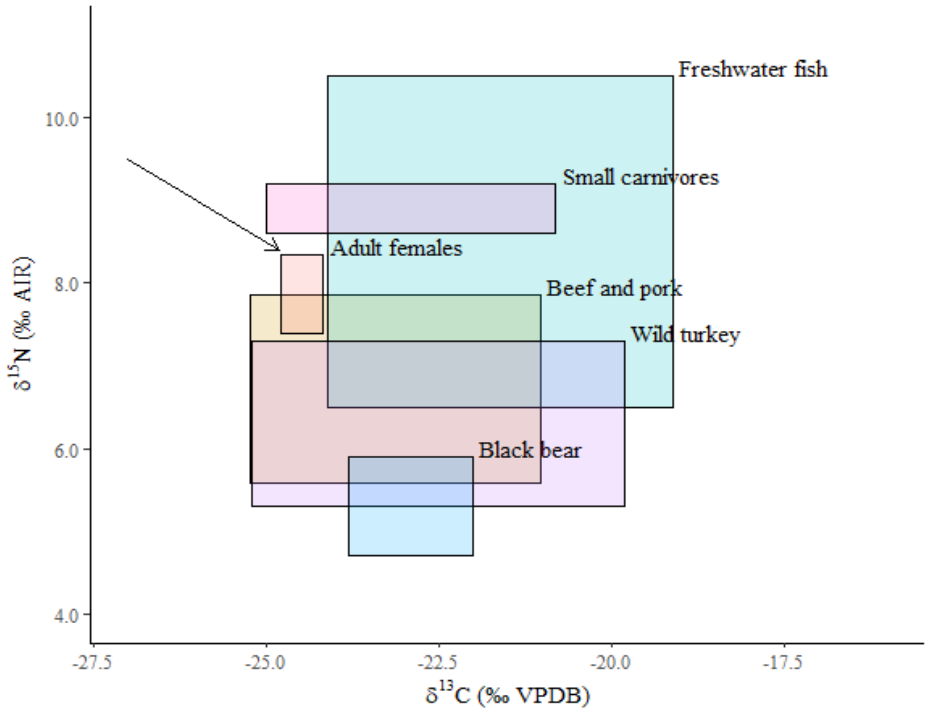

Figure 5.12. Comparison of dietary δ^{15}N and δ^{13}C results from adult female bone collagen samples (indicated by an arrow) to published data from archaeological faunal samples in southern Ontario (Guiry et al., 2017; Morris, 2015). Rectangles indicate ±1SD around the mean and correspond to the label in their top right corner.

5.2.3 Non-Adults

Table 5.5 summarizes the quality control indicators and number of sections taken for all non-adults in the sample (n = 10). Four to 10 sections of dentine were taken from each tooth, averaging 1.5mm per section. A total of 68 sections were taken, but only 62 of these were analyzed due to sample loss or insufficient weight (Table 5.5). One sample (7A11-S63_E) was affected by the aforementioned machine error, leading to an unreliable δ^{13}C measurement. Since the δ^{15}N measurement was not affected, only the δ^{13}C value has been excluded. C:N ratios for all dentine sections are within the acceptable limits for collagen (3.1-3.5), ranging from 3.16 to 3.33 (Guiry & Szpak, 2021; van Klinken, 1999). There is not a significant correlation between C:N ratios and δ^{13}C or δ^{15}N values (Pearson's correlation; δ^{13}C: r = –0.12, p = 0.35; δ^{15}N: r = 0.11, p = 0.39) (Guiry & Szpak, 2021). The carbon and nitrogen content (35.0-46.8% and 12.6-17.2%,

respectively) exceed the minimum of 13% C and 4.8% N and fall within the ranges observed in good quality collagen (Ambrose, 1990; Harbeck & Grupe, 2009). As such, no poor quality or contaminated collagen is suspected, and all 62 nitrogen and 61 stable carbon isotope results are included in analysis.

Table 5.5. Summary of samples and quality control indicators for non-adult dentine collagen.

Burial ID	Age-at-Death (months)[1]	Tooth Sampled	Dentine Length (mm)	Number of Sections[2]	C:N Ratio[3]	Weight % C[3]	Weight % N[3]
7A2-S1	15.5 (14-18)	urdm2	9	7 (6)	3.19-3.25 (3.22)	35.0-45.3 (43.2)	12.6-16.5 (15.7)
7A2-S3	11.5 (8-13.5)	uldc	7	4	3.17-3.22 (3.19)	42.3-43.2 (42.7)	15.3-15.9 (15.6)
7A2-S22	14 (11.5-16)	lrdc	10	8 (6)	3.19-3.22 (3.20)	35.8-42.4 (40.9)	13.0-15.5 (14.9)
7A2-S24	13 (10.5-15.5)	lldc	8	5 (4)	3.20-3.33 (3.24)	43.7-44.6 (44.2)	15.3-16.3 (15.9)
7A2-S32	19 (16-21.5)	uldc	15	9 (7)	3.18-3.21 (3.19)	43.5-44.5 (44.0)	15.9-16.3 (16.1)
7A9-S18	18 (12-19.5)	urdc	11	7	3.18-3.24 (3.20)	41.5-42.9 (42.1)	14.9-15.6 (15.3)
7A9-S53	21.5 (17.5-24)	uldc	13	10	3.16-3.20 (3.18)	41.6-42.9 (42.3)	15.2-15.8 (15.5)
7A9-S55	19.5 (13-21.5)	uldc	11	7	3.16-3.19 (3.18)	42.3-46.8 (43.3)	15.5-17.2 (15.9)
7A11-S57	9.5 (7.5-11)	uldc	7	5	3.17-3.19 (3.18)	43.5-45.0 (44.2)	15.9-16.6 (16.2)
7A11-S63	9 (7.5-11)	lrdc	8	6	3.19-3.22 (3.20)	43.9-45.2 (44.7)	16.0-16.5 (16.3)

[1]Mean age-at-death estimate; range (one standard deviation) noted in parentheses.
[2]Number of sections taken from the tooth. Parentheses are used if the number of samples analyzed differed from the number that was collected.
[3]Range for all tooth sections from the individual; average noted in parentheses.

δ^{13}C and δ^{15}N results for all sections of dentine collagen are reported in Table 5.6. Figures 5.13-5.22 depict these results for each individual in comparison to the adult female δ^{15}N and δ^{13}C collagen means (+10.4‰ and –19.5‰, respectively). All non-adult δ^{15}N values were higher than the adult female average by 0.5-6.3‰ (mean: 3.0‰), with only two samples (7A9-S55_E and 7A9-S18_F) falling within one standard deviation of the adult female δ^{15}N mean. Non-adult δ^{13}C values did not differ from the adult female δ^{13}C values as much, with 28 of 61 samples (46%) within one standard deviation of the

adult female mean and an average difference of +0.5‰. Four individuals had dentine sections whose $\delta^{13}C$ values were all greater than the adult female mean by 0.5-2.2‰ (7A2-S3, 7A2-S32, 7A11-S57, 7A11-S63; Figures 5.14, 5.17, 5.21, 5.22).

Table 5.6. $\delta^{13}C$ and $\delta^{15}N$ results and quality control indicators from non-adult dentine collagen samples.

Burial ID	Section[1]	Estimated Age (months)[2]	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N Ratio	Weight % C	Weight % N
7A11-S57	7A11-S57_A	-5.5 to -2.4	–18.9	+14.7	3.19	43.5	15.9
	7A11-S57_B	-2.5 to 0.5	–18.8	+15.1	3.18	44.3	16.2
	7A11-S57_C	0.5 to 3.5	–18.9	+15.1	3.17	43.8	16.1
	7A11-S57_D	3.5 to 6.5	–19.0	+15.8	3.17	45.0	16.6
	7A11-S57_E	6.5 to 9.5	–18.9	+15.5	3.17	44.3	16.3
7A11-S63	7A11-S63_A	-5.5 to -3.0	–18.4	+14.6	3.19	43.9	16.0
	7A11-S63_B	-3.0 to -0.5	–18.3	+15.2	3.19	44.8	16.4
	7A11-S63_C	-0.5 to 2.0	–18.2	+15.9	3.19	45.2	16.5
	7A11-S63_D	2.0 to 4.5	–18.1	+16.1	3.19	44.9	16.4
	7A11-S63_E	4.5 to 6.5	---	+16.4	---	---	16.0
	7A11-S63_F	6.5 to 9.0	–18.3	+16.7	3.22	44.7	16.2
7A2-S1	7A2-S1_AB	-5.0 to 1.0	–19.2	+13.3	3.25	35.0	12.6
	7A2-S1_C	1.0 to 4.0	–19.2	+14.6	3.20	45.3	16.5
	7A2-S1_D	4.0 to 7.0	–19.5	+14.9	3.24	44.9	16.1
	7A2-S1_D_DUP	4.0 to 7.0	–19.4	+14.5	3.21	44.3	16.1
	7A2-S1_E	7.0 to 9.5	–19.6	+15.4	3.23	44.8	16.2
	7A2-S1_F	9.5 to 12.5	–19.7	+14.8	3.19	44.6	16.3
	7A2-S1_G	12.5 to 15.5	–19.8	+15.4	3.19	44.6	16.3
7A2-S22	7A2-S22_AB	-5.5 to -0.5	–19.8	+11.1	3.20	41.1	15.0
	7A2-S22_C	-0.5 to 1.5	–18.9	+12.7	3.20	42.0	15.3
	7A2-S22_D	1.5 to 4.0	–19.1	+12.1	3.19	42.4	15.5
	7A2-S22_E	4.0 to 6.5	–19.1	+12.7	3.22	35.8	13.0
	7A2-S22_F	6.5 to 9.0	–19.2	+12.3	3.20	41.7	15.2
	7A2-S22_GH	9.0 to 14.0	–19.4	+12.9	3.21	42.4	15.4
7A2-S24	7A2-S24_A	-5.5 to -2.0	–19.4	+14.5	3.20	44.6	16.2
	7A2-S24_B	-2.0 to 2.0	–19.1	+14.2	3.20	44.5	16.3
	7A2-S24_B_DUP	-2.0 to 2.0	–19.1	+14.1	3.21	44.2	16.1

Burial ID	Section[1]	Estimated Age (months)[2]	δ^{13}C (‰)	δ^{15}N (‰)	C:N Ratio	Weight % C	Weight % N
	7A2-S24_C	2.0 to 5.5	–19.3	+13.8	3.23	44.0	15.9
	7A2-S24_DE	5.5 to 13.0	–19.5	+14.0	3.33	43.7	15.3
7A2-S3	7A2-S3_A	-5.5 to -1.0	–18.9	+12.6	3.20	42.3	15.4
	7A2-S3_B	-1.0 to 3.0	–19.0	+13.8	3.17	43.2	15.9
	7A2-S3_B_DUP	-1.0 to 3.0	–19.1	+13.7	3.19	43.6	16.0
	7A2-S3_C	3.0 to 7.0	–18.8	+15.7	3.18	42.9	15.7
	7A2-S3_D	7.0 to 11.5	–18.8	+16.6	3.22	42.4	15.3
7A2-S32	7A2-S32_AB	-5.5 to 0.0	–18.8	+13.1	3.19	44.5	16.3
	7A2-S32_C	0.0 to 3.0	–18.9	+13.3	3.20	43.5	15.9
	7A2-S32_D	3.0 to 5.5	–18.8	+14.2	3.18	44.0	16.1
	7A2-S32_F	8.0 to 11.0	–18.6	+12.6	3.18	43.8	16.0
	7A2-S32_F_DUP	8.0 to 11.0	---	+11.8	---	---	16.2
	7A2-S32_G	11.0 to 13.5	–18.2	+11.6	3.18	43.7	16.0
	7A2-S32_H	13.5 to 16.5	–17.6	+12.1	3.21	44.2	16.1
	7A2-S32_I	16.5 to 19.0	–17.3	+12.2	3.20	44.3	16.2
7A9-S18	7A9-S18_A	-5.5 to -3.0	–19.0	+13.1	3.19	41.9	15.3
	7A9-S18_B	-3.0 to -0.5	–19.2	+13.8	3.19	42.2	15.4
	7A9-S18_C	-0.5 to 2.0	–19.4	+12.3	3.18	42.2	15.5
	7A9-S18_D	2.0 to 4.5	–19.5	+11.4	3.19	42.0	15.4
	7A9-S18_E	4.5 to 7.0	–19.3	+11.2	3.21	42.9	15.6
	7A9-S18_F	7.0 to 9.5	–19.3	+10.9	3.23	42.2	15.2
	7A9-S18_G	9.5 to 12.0	–19.0	+11.0	3.24	41.5	14.9
7A9-S53	7A9-S53_A	-5.5 to -2.5	–19.1	+13.7	3.18	41.6	15.2
	7A9-S53_B	-2.5 to 0.0	–18.5	+14.3	3.17	42.6	15.7
	7A9-S53_B_DUP	-2.5 to 0.0	–18.5	+14.5	3.17	42.6	15.7
	7A9-S53_C	0.0 to 2.5	–19.4	+11.8	3.20	42.4	15.5
	7A9-S53_D	2.5 to 5.5	–18.6	+13.8	3.19	41.6	15.2
	7A9-S53_E	5.5 to 8.0	–19.2	+12.4	3.17	42.7	15.7
	7A9-S53_F	8.0 to 10.5	–19.2	+11.7	3.16	42.4	15.6
	7A9-S53_G	10.5 to 13.5	–19.2	+12.1	3.16	42.9	15.8
	7A9-S53_H	13.5 to 16.0	–19.2	+11.8	3.18	41.7	15.3
	7A9-S53_H_DUP	13.5 to 16.0	–19.2	+11.9	3.17	42.2	15.5
	7A9-S53_I	16.0 to 18.5	–19.2	+11.5	3.17	42.8	15.7

Burial ID	Section[1]	Estimated Age (months)[2]	δ^{13}C (‰)	δ^{15}N (‰)	C:N Ratio	Weight % C	Weight % N
	7A9-S53_J	18.5 to 21.5	–19.4	+11.7	3.18	42.8	15.7
7A9-S55	7A9-S55_A	-5.5 to -2.0	–19.3	+12.1	3.16	42.3	15.6
	7A9-S55_B	-2.0 to 1.5	–19.2	+12.2	3.17	42.9	15.8
	7A9-S55_C	1.5 to 5.5	–19.3	+11.3	3.17	42.5	15.6
	7A9-S55_D	5.5 to 9.0	–19.2	+11.3	3.17	43.6	16.0
	7A9-S55_E	9.0 to 12.5	–18.7	+10.8	3.18	46.8	17.2
	7A9-S55_F	12.5 to 16.0	–18.8	+11.1	3.19	42.4	15.5
	7A9-S55_G	16.0 to 19.5	–18.6	+11.3	3.19	42.7	15.6

[1]Combined samples are indicated using 'AB,' 'DE,' or 'GH.' 'DUP' denotes duplicate samples.
[2]Negative values indicate months before birth.

5.2.3.1 7A2-S1

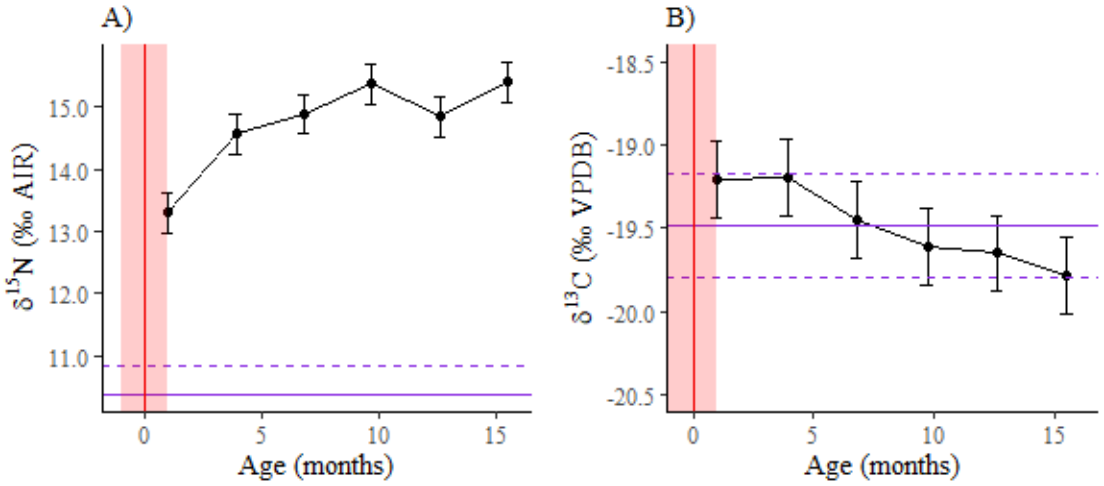

Figure 5.13. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A2-S1. Samples were taken from an upper right deciduous second molar. Age at death: ~15.5 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age of EH formation. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

Dentine sections from 7A2-S1 show a continuous rise in δ^{15}N coupled with initially steady and then decreasing δ^{13}C. From ~1 month of age until the individual's death at

~15.5 months, δ^{15}N values rise by 2.1‰ and remain higher than the adult female mean by 2.9-5.0‰ (Figure 5.13a). δ^{13}C values are within the adult female range and fall by 0.6‰ between the ages of ~4-15.5 months (Figure 5.13b).

As the linear EH present on the upper deciduous second incisors formed prior to ~1 month of age (Table 5.1), this infant likely experienced perinatal and/or maternal stress. It is thus possible that physiological stress contributed to the high δ^{15}N values from the first dentine section (representing ~5 months prenatal to ~1 month postnatal) and thus to the initial 2.9‰ difference between adult and infant δ^{15}N values. However, given the magnitude of difference between adult and infant δ^{15}N values (2.9-5.0‰), it is likely that some breast milk consumption occurred alongside physiological stress.

From ~4-15.5 months, the pattern in δ^{15}N and δ^{13}C presents two competing explanations. First, breast milk may have been the predominant protein source for the entirety of the infant's life, with an increase in alternative C_3 foods accounting for the decreasing δ^{13}C values. Alternatively, the increase in δ^{15}N and decrease in δ^{13}C could constitute a pattern of opposing co-variance observed in individuals experiencing physiological or nutritional stress. The extensive dental lesions observed across the infant's dentition (see Table 5.2) lend support to the latter hypothesis that this infant experienced prolonged physiological stress for much of their life.

5.2.3.2 7A2-S3

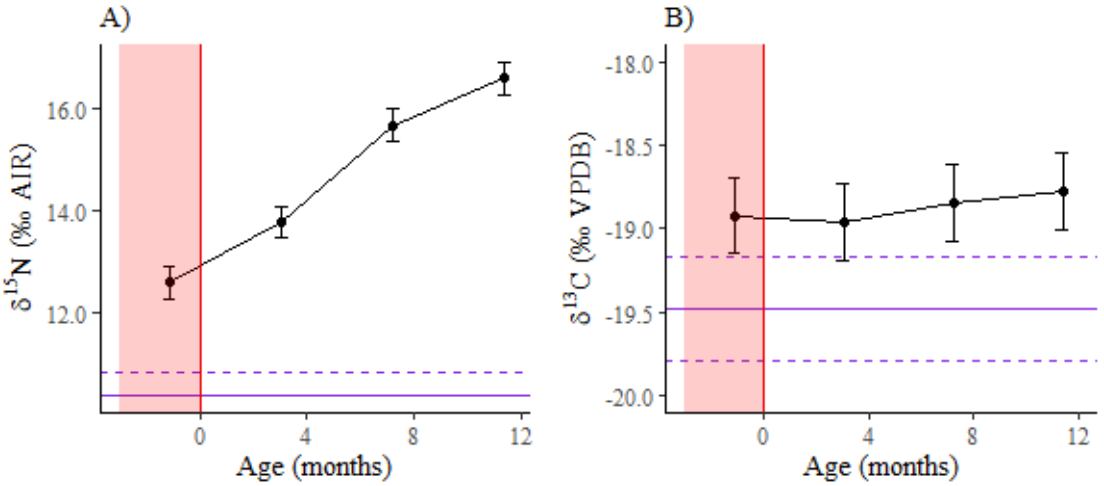

Figure 5.14. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A2-S3. Samples were taken from an upper left deciduous canine. Age at death: ~11.5 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age of EH formation. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

In 7A2-S3, dentine sections show a 4.0‰ rise in δ^{15}N, spanning from the prenatal period to the individual's death at ~11.5 months (Figure 5.14a). δ^{13}C values are roughly similar for the entire period and are 0.5-0.7‰ higher than the adult female mean (Figure 5.14b).

As the infant's δ^{15}N value is 3.4‰ higher than the adult female mean at ~3 months of age, it is possible that this infant was breastfed initially after birth. However, the EH on the infant's lower second deciduous incisor suggests an episode of physiological stress occurred up to ~3 months before birth (Table 5.1). The initial rise in δ^{15}N values may therefore be due to breastfeeding, physiological/perinatal stress, or some combination thereof.

Similarly, the continuous 2.8‰ increase in δ^{15}N from ~3-11.5 months may be due to breast milk consumption, a dietary shift, or physiological stress. Given that the trophic level shift expected from breast milk consumption (2-3‰ in δ^{15}N, ~1‰ in δ^{13}C; Fuller et

al. 2006) is already visible by ~3 months of age, an additional 2.8‰ increase in δ^{15}N is beyond what one would expect to see from continued breastfeeding, suggesting some other factor is responsible for the shift (Beaumont et al., 2018). Consumption of marine protein sources or freshwater fish could account for an increase in δ^{15}N, but one would expect to see a concurrent increase in δ^{13}C, contrary to what is observed. Increasing δ^{15}N and stable δ^{13}C may instead be related to physiological or nutritional stress that affected the infant's nitrogen balance but did not involve catabolism of body fat (e.g., insufficient protein intake; Fuller et al., 2005; Mekota et al., 2006; Neuberger et al., 2013). Given these data, and the presence of dental lesions (see Table 5.2), the most likely explanation for the change in δ^{15}N from ~3-11.5 months of age is physiological or nutritional stress.

5.2.3.3 7A2-S22

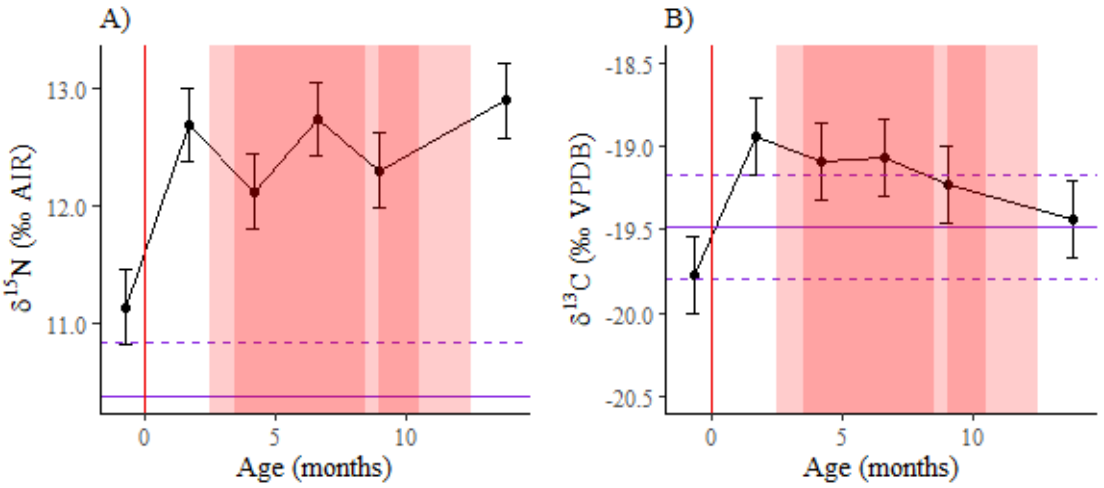

Figure 5.15. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A2-S22. Samples were taken from a lower right deciduous canine. Age at death: ~14 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age at EH formation; darker areas represent overlap in age-at-formation estimates. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

In 7A2-S22, δ^{15}N and δ^{13}C both rise after birth by 1.6‰ and 0.8‰, respectively (Figure 5.15). δ^{15}N values were on average 2.2‰ higher than the adult female mean throughout the postnatal period (~1.5-14 months), suggesting that the infant was breastfed. Between ~1.5-14 months of age, the δ^{13}C values decrease by 0.5‰ to within the adult female range. This suggests that the infant was likely fed C_3 foods in addition to breast milk starting around ~1.5-4 months of age.

EH was present on several teeth from 7A2-S22, suggesting this infant experienced stress in early life (between ~2.5-12.5 months of age; Table 5.1). As the postnatal δ^{15}N results do not exhibit a clear increasing trend (Figure 5.15a), there is no direct isotopic evidence of stress in this individual. However, given the estimated ages of EH formation, it is possible that stress episodes contributed to the variation seen in δ^{15}N (±0.6‰, ~1.5-14 months) and the decrease in δ^{13}C values. Thus, physiological stress is most likely entangled with dietary shifts (e.g., weaning) in this infant.

5.2.3.4 7A2-S24

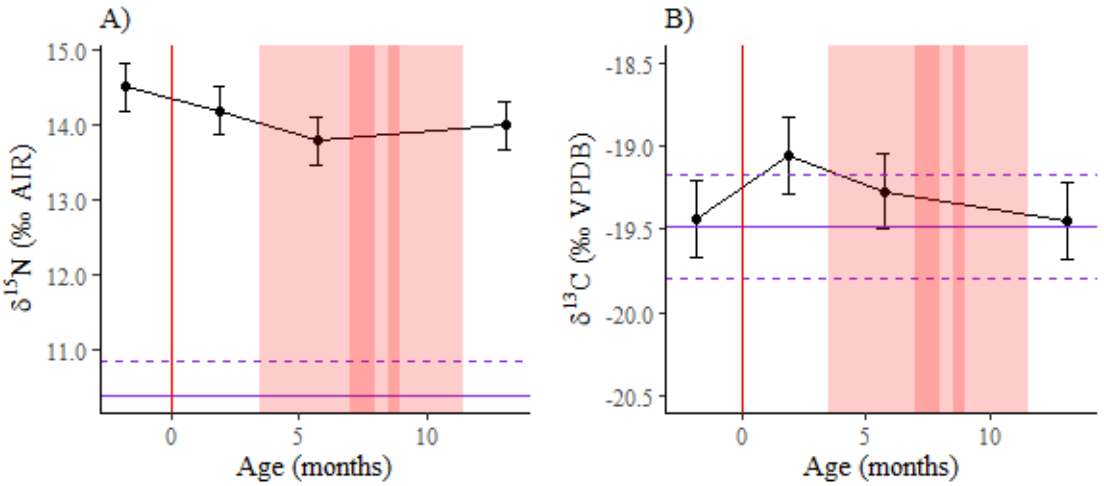

Figure 5.16. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A2-S24. Samples were taken from a lower left deciduous canine. Age at death: ~13 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age at EH formation; darker areas represent overlap in age-

at-formation estimates. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

Dentine δ^{15}N values from 7A2-S24 are consistently higher than the adult female mean by 3.4‰ to 4.1‰ (Figure 5.16a). These values remain stable throughout the infant's life, varying only by 0.7‰. These data suggest that breast milk was the predominant protein source consumed by this infant throughout their life, as there is no clear evidence of weaning before the infant's death. Minor changes (0.4‰) are seen in δ^{13}C values and all are within 0.4‰ of the adult female mean (Figure 5.16b), suggesting potential consumption of C_3 alternative foods from a young age (~2 months). Given the presence of EH that formed between ~3.5-11.5 months of age (most likely ~7-9 months; Table 5.1), it is possible that weaning is entangled with physiological or nutritional stress, thus obscuring the age of weaning initiation and/or cessation.

5.2.3.5 7A2-S32

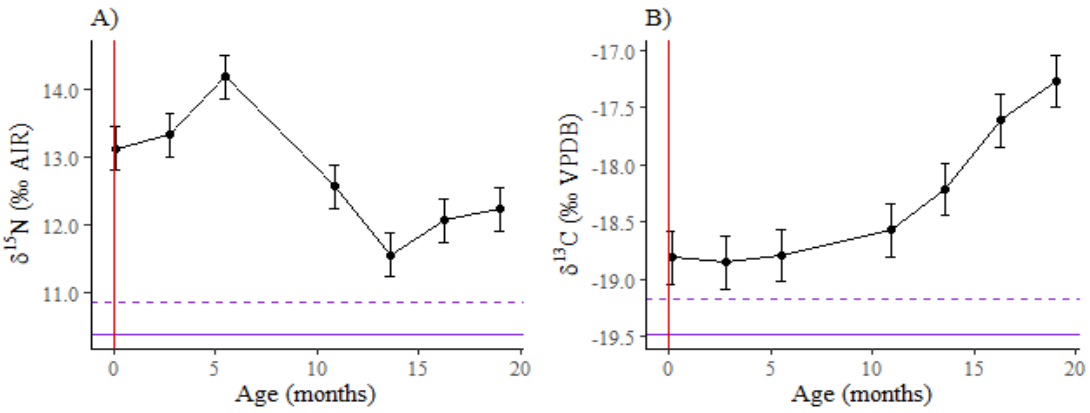

Figure 5.17. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A2-S32. Samples were taken from an upper left deciduous canine. Age at death: ~19 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

Dentine sections from 7A2-S32 show a 1.1‰ increase in δ^{15}N from birth to ~5.5 months of age, followed by a 2.6‰ decrease between the age of ~5.5-13.5 months (Figure 5.17a).

Given this pattern, and the 3.8‰ difference from the adult female mean, this is a clear signal of breastfeeding and gradual weaning. After ~5.5 months of age, other foods besides breast milk would have become important protein sources, with the cessation of weaning just after the infant turned 1 year of age. The δ^{13}C values do not exhibit a trophic level shift associated with exclusive or predominant breastfeeding from birth to ~5.5 months; instead, the values yield a nearly flat line 0.6-0.7‰ higher than the adult female mean (Figure 5.17b). After ~5.5 months, the δ^{13}C values begin to increase, ending with a value of –17.3‰; yielding a +1.5‰ shift from ~5.5-19 months. These data suggest that the weaning diet included foods enriched in ^{13}C (e.g., maize, animals fed maize), and that they continued to be consumed after weaning. From ~13.5-19 months of age, the δ^{15}N values increase from +11.6 to +12.2‰; in conjunction with the increase in δ^{13}C, this could suggest consumption of a small amount of fish or marine food.

5.2.3.6 7A9-S18

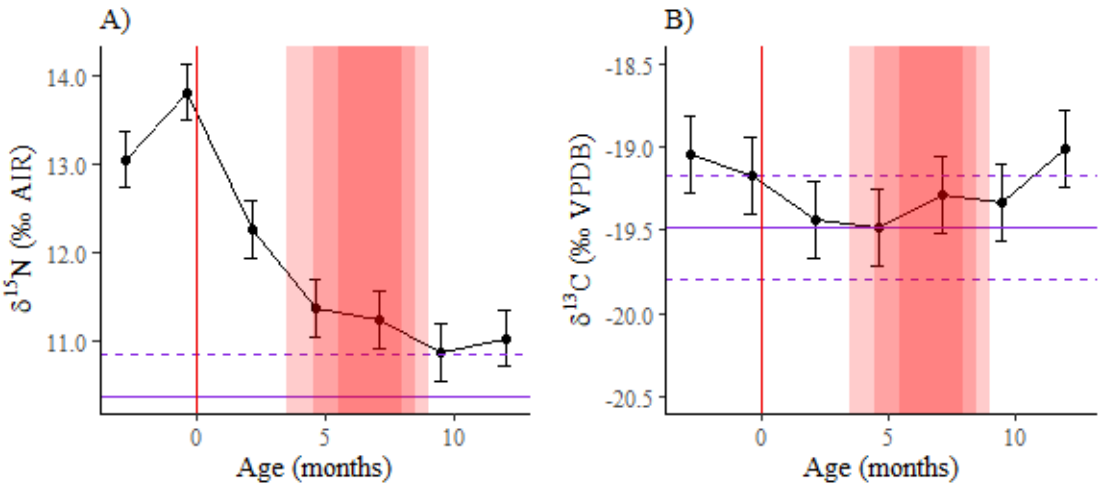

Figure 5.18. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A9-S18. Samples were taken from an upper right deciduous canine. Age at death: ~18 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age at EH formation; darker areas represent overlap in age-at-formation estimates. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

In 7A9-S18, two dentine sections represent the prenatal period: section A formed during the second trimester (~5.5-3 months before birth) and section B formed throughout the third trimester until ~0.5 months before birth. Between the second and third trimesters, there is a 0.8‰ increase in δ^{15}N accompanied by relatively stable δ^{13}C values (0.1‰ decrease; Figure 5.18). This may indicate a change in maternal diet or maternal stress during pregnancy. These interpretations will be explored in greater detail in Chapter 6.

Following birth, δ^{15}N values drop by 2.4‰ within the first ~4.5 months of age and continue to decrease until they reach the adult female range at ~9.5 months (Figure 5.18a). The δ^{13}C values remain stable and within the adult female range during this time (Figure 5.18b). This pattern suggests that the infant likely was either breastfed for only a short period of time (e.g., a few weeks) or was not breastfed at all and was fed C_3 foods early in life. Given the estimated ages of EH formation (~3.5-9 months; Table 5.1), this infant likely experienced physiological or nutritional stress associated with the transition towards the adult diet.

5.2.3.7 7A9-S53

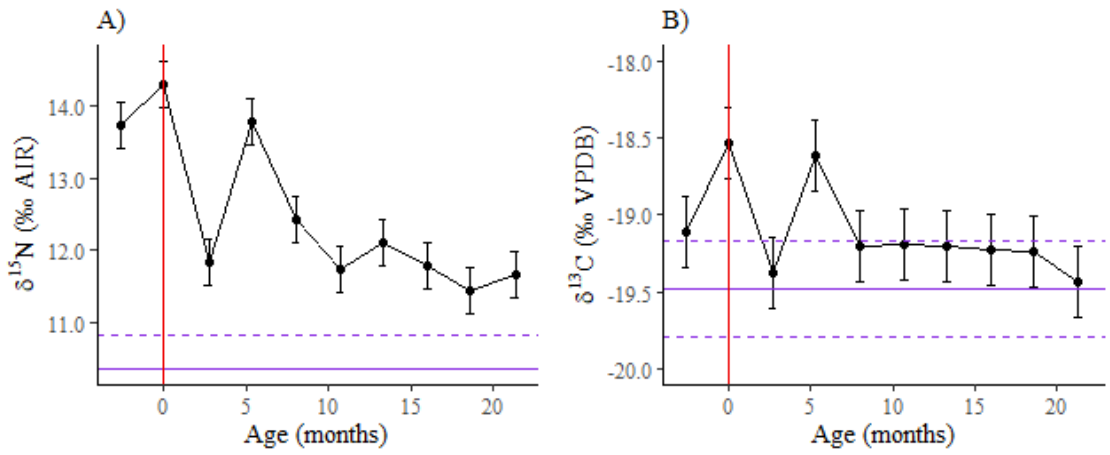

Figure 5.19. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A9-S53. Samples were taken from an upper left deciduous canine. Age at death: ~21.5 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

Dentine sections from 7A9-S53 show a 0.6‰ rise in both δ^{15}N and δ^{13}C during the last ~2.5 months of gestation (Figure 5.19). This is followed by a 2.5‰ decrease in δ^{15}N and a 0.8‰ decrease in δ^{13}C between birth and ~2.5 months of age. Then there is a subsequent rise of 2.0‰ for δ^{15}N and 0.8‰ for δ^{13}C between ~2.5 to 5.5 months. From ~5.5 to 10.5 months, δ^{15}N and δ^{13}C values fall again, by 2.0‰ and 0.6‰, respectively, after which they remain relatively stable for the remainder of the infant's life. δ^{15}N values are 1.1-3.9‰ higher than the adult female mean, while δ^{13}C values are mostly within the adult female range, with the exception of birth and ~5.5 months (0.9-1.0‰ greater).

This pattern suggests the infant was not initially breastfed after birth but began consuming breast milk between ~2.5-5.5 months of age before gradually being weaned from ~5.5-10.5 months. These results may indicate a potential case of emergency breastfeeding or wet nursing in the community (Azad et al., 2019). The δ^{13}C values suggest a weaning diet of C_3 foods that were regularly consumed around 8 months of age.

5.2.3.8 7A9-S55

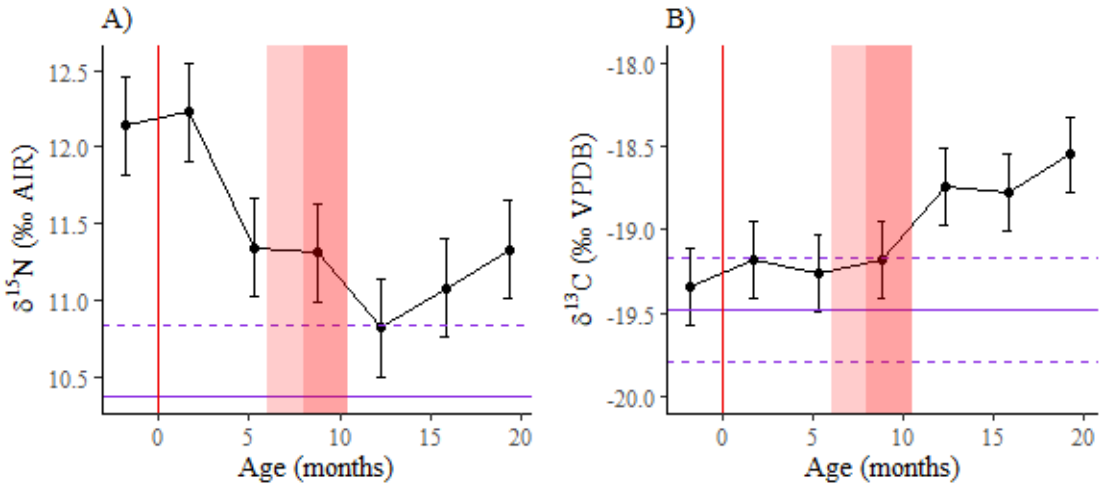

Figure 5.20. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A9-S55. Samples were taken from an upper left deciduous canine. Age at death: ~19.5 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age at EH formation; darker areas represent overlap in age-

at-formation estimates. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

In 7A9-S55, the prenatal dentine section representing ~5.5 to 2 months before birth has a δ^{15}N value of 12.1‰, which is 1.8‰ higher than the adult female mean. Throughout the perinatal period (~2 months before birth until ~1.5 months after birth, represented by section B), this value remains fairly stable (Figure 5.20a). The δ^{13}C values also exhibit minimal change over this period (0.2‰), remaining within the adult female range (Figure 5.20b). Between ~1.5 to 5.5 months of age, δ^{15}N values decrease by 0.9‰, which approaches the adult female range, and continue to decrease by 0.5‰ from ~5.5-12.5 months. This pattern and the 1.8‰ difference from the adult female mean could suggest this infant was breastfed and weaned; however, the decrease in δ^{15}N occurs quite soon after birth. Thus, if they were breastfed, it was likely only for a short period of time. δ^{13}C values lack the trophic level shift expected of breastfeeding and remain stable (–19.2 to –19.3‰) until ~9 months, before increasing by 0.6‰ from ~9-19.5 months. These data suggest an early life diet of C_3 foods, with a potential increase in the consumption of fish, maize, or maize-fed animals in the last ~10 months of life.

The EH present on this infant formed between ~6-10.5 months of age (Table 5.1). As shown in Figure 5.20, this coincides with the weaning period, suggesting that this infant experienced physiological stress associated with a dietary shift.

5.2.3.9 7A11-S57

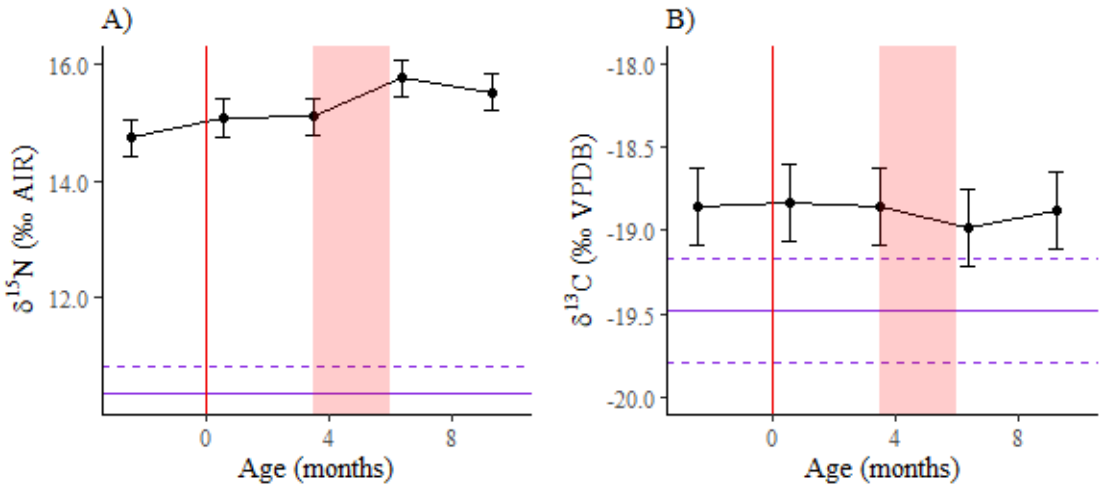

Figure 5.21. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A11-S57. Samples were taken from an upper left deciduous canine. Age at death: ~9.5 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age at EH formation. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

Dentine sections from 7A11-S57 show a 1.0‰ increase in δ^{15}N between ~2.5 months before birth and ~6.5 months of age (Figure 5.21a). All δ^{15}N values are higher than the adult female mean by 4.4-5.4‰. δ^{13}C values remain fairly stable throughout life and are between 0.5-0.7‰ greater than the adult female mean (Figure 5.21b). These data suggest that breast milk was the predominant protein source for the duration of the infant's life. It is not possible to detect if or when weaning foods were introduced to this individual given the lack of meaningful variation in δ^{13}C values.

7A11-S57 displays EH estimated to have formed between ~3.5-6 months of age (Table 5.1), which corresponds to a 0.7‰ increase in δ^{15}N and stable δ^{13}C (0.1‰ decrease). While the isotopic shift alone is not strong evidence of stress, its co-occurrence with EH formation suggests that this infant experienced physiological and/or nutritional stress around 3.5-6 months of age.

5.2.3.10 7A11-S63

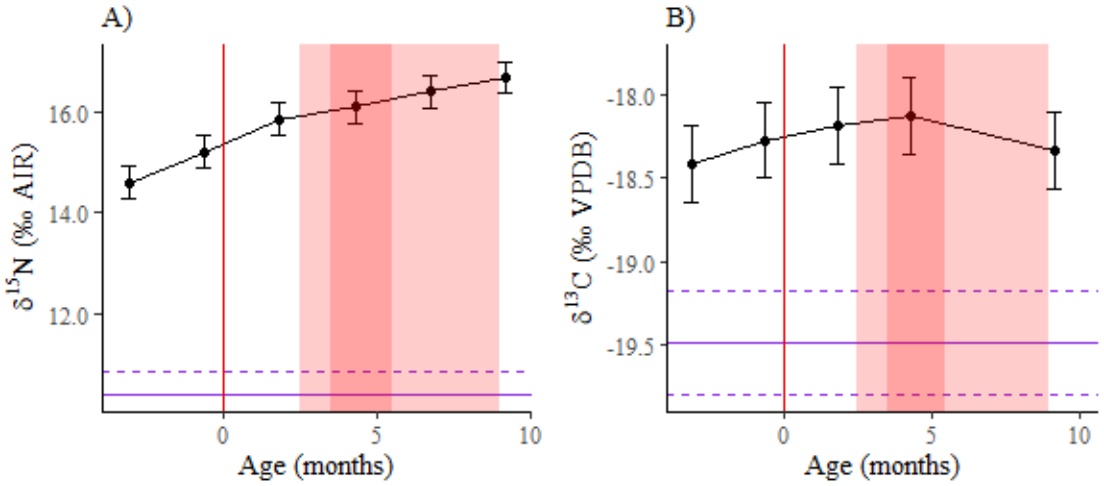

Figure 5.22. δ^{15}N (A) and δ^{13}C (B) values from dentine collagen samples against approximate age for 7A11-S63. Samples were taken from a lower right deciduous canine. Age at death: ~9 months. Vertical red line represents birth. Purple horizontal lines represent the adult female range (solid: mean; dashed: one standard deviation). Red shaded area shows estimated age at EH formation; darker areas represent overlap in age-at-formation estimates. Analytical error bars show 0.3‰ for nitrogen and 0.2‰ for carbon.

Two dentine sections (A and B) from 7A11-S63 represent the prenatal period: the first from ~5.5-3 months before birth, and the second from ~3-0.5 months before birth. There is a slight rise (0.6‰) in δ^{15}N values over this time with minimal (+0.1‰) change in δ^{13}C values (Figure 5.22). Following birth, the infant's δ^{15}N values rise by a total of 1.5‰ to a final value of 16.7‰, which is 6.3‰ higher than the adult female mean. Minimal variation (0.2‰) is observed in the δ^{13}C values, although they are on average 1.3‰ higher than the adult female mean.

The initial 0.7‰ rise in δ^{15}N values after birth and the +1.3‰ difference between infant-adult δ^{13}C values suggests this infant was breastfed. The continued 0.8‰ increase in δ^{15}N after ~2 months of age may suggest that breast milk was the infant's predominant protein source until death. However, the EH observed on this individual's dentition formed

between ~3.5-9 months of age, suggesting that physiological and/or nutritional stress may have contributed to the changes in $\delta^{15}N$ and $\delta^{13}C$ values over this time. Since weaning may have been entangled with nutritional/physiological stress, the ages of weaning initiation, cessation, and the introduction of weaning foods are unclear.

5.2.3.11 Trends

Table 5.7 summarizes the interpretations for all individuals. Most infants (at least 6 of 10) were breastfed, with complementary or alternative foods introduced between ~1.5-5.5 months (7A2-S22, 7A2-S24, 7A9-S18, 7A9-S53, 7A9-S55) or ~5.5-11 months of age (7A2-S32, 7A9-S53). Short or absent breastfeeding was noted in two infants (7A9-S18, 7A9-S55), and both infants display EH that formed during the transition to adult foods. Most weaning foods were likely C_3 plants or animals that consumed C_3 plants, but 7A2-S32 and 7A9-S55 likely consumed some foods enriched in ^{13}C, whether derived from C_4 plants or higher trophic level aquatic foods. Based on 7A9-S53 and 7A2-S32, the age of weaning cessation appears to be 10.5-13.5 months, but it is unclear in the other four infants (7A2-S22, 7A2-S24, 7A11-S57, 7A11-S63). In these individuals, weaning may have been entangled with nutritional/physiological stress, as demonstrated by EH that formed during the last few months prior to death. Two infants (7A2-S1, 7A2-S3) demonstrate isotopic evidence for a prolonged episode (or episodes) of nutritional or physiological stress, and one other (7A9-S18) demonstrates a potential stress episode at ~3 to 0.5 months before birth, thus possibly representing maternal stress.

Table 5.7. Summary of infant feeding and stress interpretations made using changes in $\delta^{13}C$ and $\delta^{15}N$ values from each non-adult individual.

Burial ID	Age-at-Death (months)	Estimated Age (months)	Change (‰)[1] $\delta^{15}N$	Change (‰)[1] $\delta^{13}C$	Interpretation of BWP[2]	Alternative Foods	Weaning Cessation	Stress Episode[3] (months)
7A2-S1	15.5	1 to 15.5	*2.1*	*-0.6*	Possible breastfeeding	Unclear	Unclear	4 to 15.5; see Table 5.1
7A2-S3	11.5	-1 to 11.5	*4.0*	0.1	Possible breastfeeding	Unclear	Unclear	3 to 11.5; see Table 5.1
7A2-S22	14	-0.5 to 1.5 1.5 to 9	*1.6* ±0.6*	*0.8* -0.3	Breastfed	C_3 foods introduced	Unclear	4 to 14

		9 to 14	*0.6*	-0.2		between 1.5-4m		
7A2-S24	13	2 to 13	-0.2	-0.4	Breastfed	C_3 foods introduced between 2-5.5m	Unclear	Possibly 5.5 to 13
7A2-S32	19	Birth to 5.5 5.5 to 13.5 13.5 to 19	*1.1* *-2.6* *0.7*	0.0 *1.5*	Breastfed, gradually weaned (5.5-13.5m)	C_4 foods introduced between 5.5-11m; possibly some fish from 13.5-19m	13.5m	None
7A9-S18	18	-3 to -0.5 -0.5 to 4.5 4.5 to 12	*0.8* *-2.4* -0.3	-0.1 -0.3 0.5*	Short or absent breastfeeding	C_3 foods introduced by 2m	9.5m (if breastfed)	Possible maternal stress (-3 to -0.5); see Table 5.1
7A9-S53	21.5	-2.5 to 0 0 to 2.5 2.5 to 5.5 5.5 to 10.5 10.5 to 21.5	0.6* *-2.5* *2.0* *-2.0* ±0.3	*0.6* *-0.8* *0.8* *-0.6* -0.2	Initially not breastfed; started 2.5-5.5m; weaned 5.5-10.5m	C_3 foods consumed 0-2.5m and after 5.5-8m	10.5m	None
7A9-S55	19.5	1.5 to 5.5 5.5 to 12.5 12.5 to 19.5	*-0.9* -0.5 0.5	-0.1 *0.5* 0.2	Short or absent breastfeeding with early weaning (starting ~1.5-5.5m)	C_3 foods introduced 1.5-5.5m; possible increase in C_4 foods 9-19.5m	12.5m (if breastfed)	None; see Table 5.1
7A11-S57	9.5	0.5 to 6.5	*0.7*	-0.2	Breastfed	Unclear	Unclear	3.5 to 6
7A11-S63	9	-3 to -0.5 -0.5 to 9	*0.6* *1.5*	0.1 ±0.2	Breastfed	Unclear	Unclear	2 to 9

[1]Changes that exceed expanded combined uncertainty (N: ±0.6‰; C: ±0.5‰) are italicized. Red: increasing values; blue: decreasing values; black, not italicized: insignificant change.
[2]BWP = breastfeeding and weaning practices.
[3]Based on isotopic data. See Table 5.1 for stress episodes indicated by EH.
*Values do not exceed the error range due to rounding.

Figures 5.23 and 5.24 show changes in $\delta^{15}N$ and $\delta^{13}C$ with age for all individuals. Prenatal sections contain dentine that formed *in utero*. Eight of 10 individuals have prenatal sections, while 7A2-S1 and 7A2-S32 do not. Three individuals (7A9-S18, 7A9-S53, 7A11-S63) demonstrate a rise in $\delta^{15}N$ throughout the last three months of gestation

(mean 0.6‰). $\delta^{13}C$ rises by 0.6‰ for 7A9-S53 but does not change considerably for 7A9-S18 and 7A11-S63 (±0.1‰).

Prenatal $\delta^{15}N$ and $\delta^{13}C$ are on average 3.1‰ and 0.4‰ greater than the adult female means, respectively. This difference is significant for $\delta^{15}N$ (Welch's t-test, t = 7.0, df = 12.3, *p*-value < 0.01, 95% CI: 2.19-4.17) and $\delta^{13}C$ (Welch's t-test, t = 2.3, df = 13.6, *p*-value = 0.03, 95% CI: 0.0-0.9). For those individuals who were not breastfed (7A9-S18, 7A9-S53) or show a clear age of weaning cessation (7A2-S32, 7A9-S55), $\delta^{15}N$ and $\delta^{13}C$ values are significantly higher than the adult female means during the post-weaning period by 1.1‰ and 0.6‰, respectively (Welch's t-test; $\delta^{15}N$: t = 5.0, df = 8.8, $p < 0.01$, 95% CI: 0.6-1.6; $\delta^{13}C$: t = 3.0, df = 18.3, *p*-value < 0.01, 95% CI: 0.2-1.1).

The last dentine section taken from each tooth represents the final months before the individual's death. These sections demonstrate more variability in $\delta^{15}N$ than do the first sections (i.e., those that represent the pre- or perinatal periods), but this is not the case for $\delta^{13}C$ (Figure 5.25).

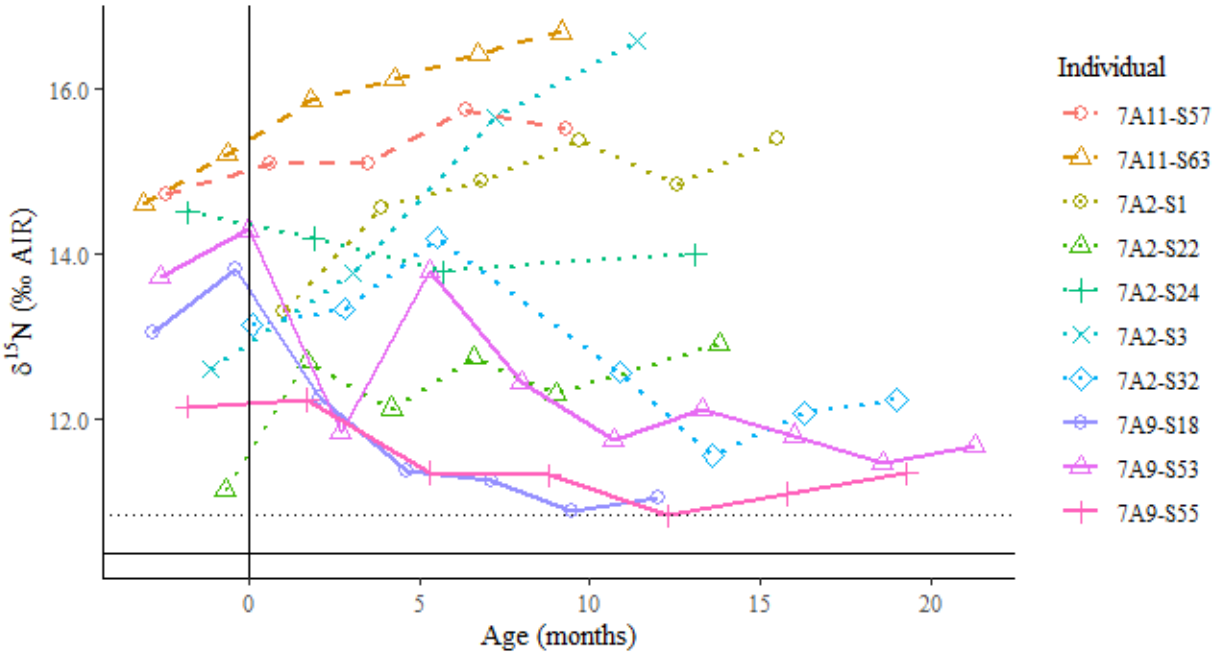

Figure 5.23. δ^{15}N profiles against age for all infants (n = 10). Vertical line represents birth. Horizontal lines represent adult female range (solid: mean; dashed: one standard deviation).

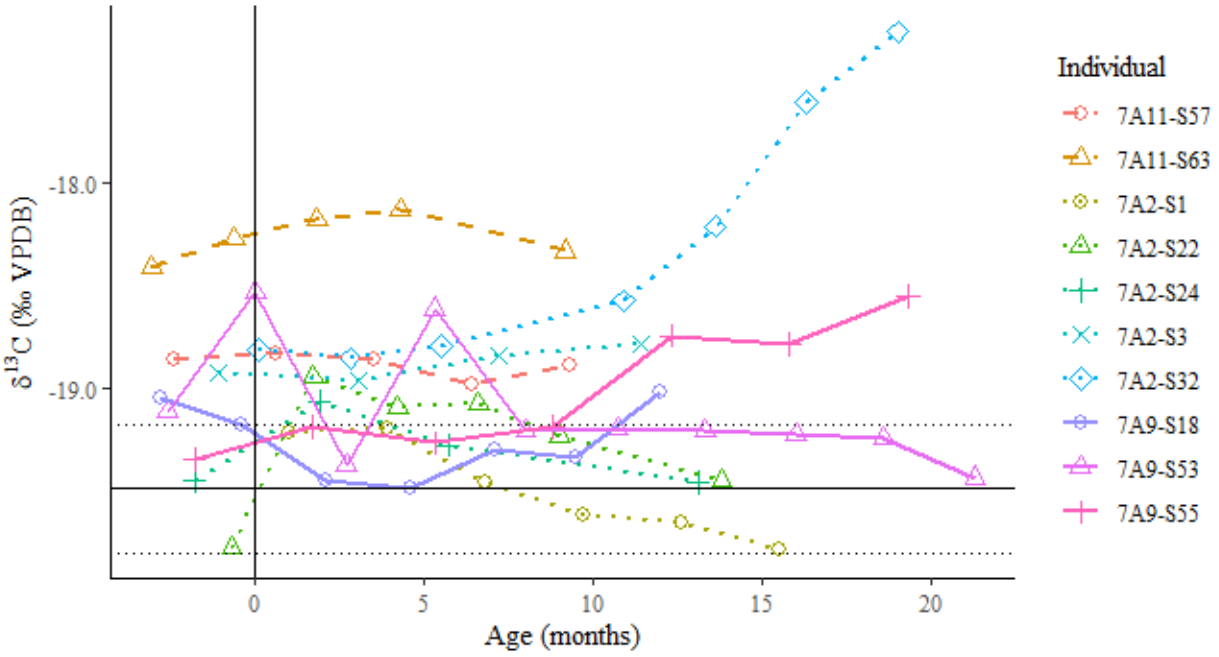

Figure 5.24. δ^{13}C profiles against age for all infants (n = 10). Vertical line represents birth. Horizontal lines represent adult female range (solid: mean; dashed: one standard deviation).

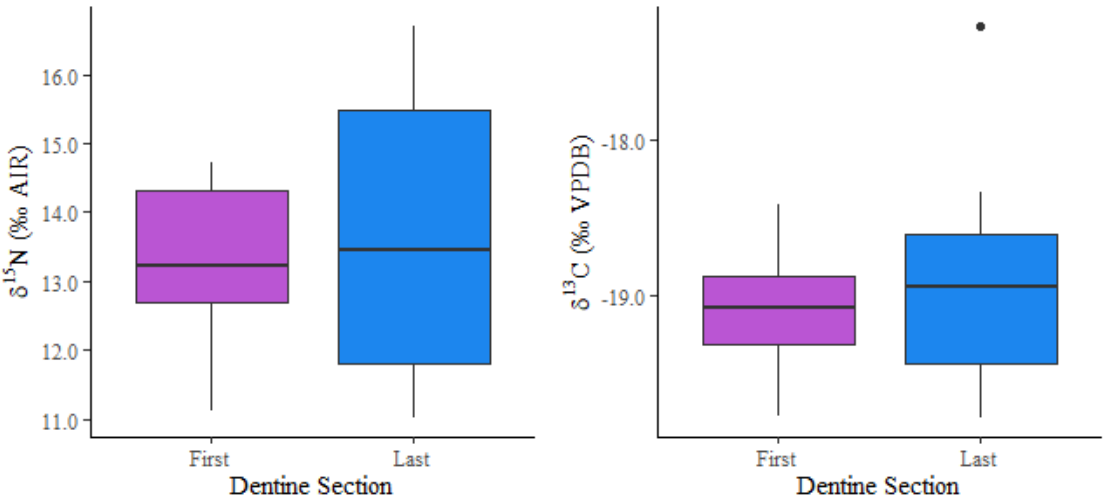

Figure 5.25. Boxplot demonstrating the variation in δ^{15}N (left) and δ^{13}C (right) values from the first and last dentine sections of each non-adult. δ^{15}N: first = +13.3 ± 1.2‰, last = +13.7 ± 2.2‰; δ^{13}C: first = –19.1 ± 0.4‰, last = –18.9 ± 0.7‰

Chapter 6

6 Discussion

This chapter will combine historical, archaeological, archival, and clinical literature to interpret the results of isotopic and dental analyses. First, potential reasons for the dental lesions observed among the non-adults are described. The adult female results are then compared to other sites in Québec, and the difference between adult and non-adult isotopic values is discussed. Next, infant feeding practices in Pointe-aux-Trembles and potential sources of stress among the non-adults are considered. The chapter concludes with a discussion of the key limitations inherent in this research.

6.1 Dental Lesions

Several dental lesions were noted among the non-adults in this sample. This section will discuss conditions that are known to cause enamel hypoplasia and dental caries, and potential factors that may have led to the other lesions observed in the dental remains.

6.1.1 Enamel Hypoplasia

Enamel hypoplasia is generally used as a non-specific indicator of stress in bioarchaeology (Dąbrowski et al., 2021; Goodman & Rose, 1990; Lewis, 2018). Several factors have been associated with EH development, including hereditary and acquired conditions that can affect teeth in the prenatal, perinatal, and postnatal periods (Salanitri & Seow, 2013; Towle & Irish, 2020). Developmental conditions like amelogenesis imperfecta and congenital syphilis can both lead to hypoplastic or malformed enamel (Crawford et al., 2007; Hillson et al., 1998). Prenatally, low birth weight, maternal vitamin D deficiency, premature birth, and fetal undernutrition have been associated with EH development in modern populations or animal studies (Aine et al., 2000; Corrêa-Faria et al., 2013; Hillson, 2005; Salanitri & Seow, 2013). Birth trauma, respiratory distress, and neonatal tetany have been linked to enamel defects around birth (Franco et al., 2007; Hillson, 2014; Lewis, 2018). After birth, rickets, scurvy, and other nutrient and mineral deficiencies (e.g., vitamins A and K, calcium, magnesium, zinc), as well as general malnutrition experienced during dental development can lead to EH (Hillson, 2005;

Lewis, 2018; Salanitri & Seow, 2013). These deficiencies could be related to insufficient nutrient intake, or poor absorption of nutrients from the digestive tract (Salanitri & Seow, 2013). Metabolic and contagious diseases, including diabetes, measles, and tetanus can also cause stress that leads to EH (Hillson, 2005; Pascon et al., 2019; Salanitri & Seow, 2013), and EH may be caused by trauma during tooth development (Skinner & Hung, 1989; Towle & Irish, 2020). Finally, excess consumption of fluoride ions (fluorosis) can lead to pit- and plane-form EH (Hillson, 2005).

All prenatal, perinatal, and postnatal factors listed here could have played a role in the development of EH within this sample. In the absence of contextual information, it is not possible to retrospectively identify the specific causes of EH for each individual; however, Section 6.4 will use historical evidence to discuss sources of stress in 18th and 19th century Pointe-aux-Trembles that may have affected these infants.

All of the defects observed in deciduous teeth would have formed within the first year of life, with some occurring during the perinatal period (Table 5.1). This suggests that the stressors experienced by the infants occurred at a young age. Further, as all deciduous teeth begin forming prior to birth, it is possible that some of the defects formed prenatally. Histological analyses that assess the formation of the defect in relation to the neonatal line would be required to confidently identify these cases.

6.1.2 Dental Caries

As with EH, dental caries have a multifactorial etiology and several endogenous and exogenous factors influence their development. Certain genes and variation in the composition of the oral microbiome may pre-dispose individuals to caries development (Chokshi et al., 2016; de Jesus et al., 2020; Hillson, 2008; Ortiz et al., 2019), and oral hygiene is considered a key factor in their formation in modern populations. Several studies have found associations between vitamin D deficiency and caries (Almoudi et al., 2019; Anderson et al., 1934; Brown et al., 2012; Hujoel, 2013; Kim et al., 2018; Schroth et al., 2016), and some suggest maternal vitamin D deficiency during pregnancy can increase the risk of caries in infants (Suárez-Calleja et al., 2021; Tanaka et al., 2015). Further, malnutrition and iron-deficiency anemia, as well as conditions that decrease oral

pH (e.g., chronic vomiting) have been tied to caries development (Jevtić et al., 2015; Kim et al., 2005; Lewis, 2018). Diet plays an important role, as the consumption of certain foods directly influences the bacterial activity responsible for caries development. Diets rich in foods with a high sugar or starch content promote such activity and have been linked to caries (Hillson, 2008; Jevtić et al., 2015). Finally, teeth with EH are at a higher risk of caries due to a weakened state of the enamel (Hillson, 2008, 2018; Lewis, 2018).

Within this sample, caries were frequently observed on the anterior teeth and were often present on tooth roots. Typically, caries develop more readily on molars than they do on anterior teeth (Hillson, 2008), but this is not the case within this sample. This may in part be related to the timing of dental eruption: since deciduous incisors erupt earlier than molars, they may have been exposed to the cariogenic environments for longer (Hillson, 2008).

As the non-adults in this sample were all <3 years of age at death, the caries observed in these infants would be considered early childhood caries (ECC), which have been associated with practices such as nocturnal breastfeeding and food sharing (Anil & Anand, 2017; Bonsall et al., 2016). Additionally, root caries and non-carious cervical lesions are associated with gingival recession and may be caused by chemical degradation from acids in the oral environment (Hillson, 2018; Igarashi et al., 2017; Valena & Young, 2002). Acids may be from dietary sources or gastrointestinal distress, and Section 6.4.3 will discuss evidence for the latter in Pointe-aux-Trembles.

6.1.3 Other Dental Defects

Three other dental lesions were observed in this sample: vertical bone loss associated with periodontitis, loss of enamel from the lingual surfaces of anterior mandibular teeth in 7A2-S3, and the lesions present on 7A2-S1. Periodontitis is not commonly observed in infants, but may develop in individuals with gingivitis, severe malnourishment, and systemic conditions such as scurvy and leukemia (Dommisch et al., 2018; Nazir, 2017; Lewis, 2018). Individuals from modern populations that vomit frequently often display erosion of enamel on the lingual surfaces of their teeth (Igarashi et al., 2017; Kim et al.,

2005; Marder, 2013), but lingual enamel loss may also be caused by activity-induced surface abrasion (e.g., Lukacs & Pastor, 1988) or post-mortem damage.

The lesions present on 7A2-S1 were more extensive than those on any of the other individuals within the sample, and the locations of the lesions can help narrow down potential causative factors. The lesion patterning varied according to tooth type and region in the mouth, and such patterns are unlikely to have occurred entirely because of taphonomic influences. Though it remains possible that some postmortem chipping or damage may have occurred, the lesions are likely related to developmental or exogenous factors. The presence of EH on two of the incisors suggests systemic stress was experienced early in life, and the isotopic profile (Figure 5.13) suggests the infant experienced nutritional or disease stress from ~4-15.5 months of age. However, if stress during tooth development were to account for all of the observed lesions, one would expect the deciduous second molars to be affected as well since they form at the same time as the affected teeth (Hillson, 1996). Since lesions are present on all erupted teeth, but absent from the unerupted teeth, this suggests something influenced the oral environment during the infant's life. It is also possible that both developmental disturbances and exogenous factors contributed to their development. A recent paper from Tesi and colleagues (2023) identified extensive lesions on deciduous teeth from medieval northern Italy and suggested they were related to stress during the fetal period that continued after birth and was compounded by secondary exogenous influences. A complete case study of 7A2-S1 is beyond the scope of this thesis but is recommended for future research. More in-depth consideration should be given to amelogenesis imperfecta, molar incisor hypomineralization, dental fluorosis, frequent vomiting caused by gastrointestinal distress, nutritional deficiencies (e.g., rickets, scurvy), brucellosis, tuberculosis, congenital syphilis, and mercurial treatment (Ioannou et al., 2016; Tesi et al., 2023). Evaluation of these should include assessment of skeletal remains as well as techniques beyond macroscopic analysis (e.g., Ioannou et al., 2015; Lombardo et al., 2022; Tesi et al., 2023).

6.1.4 Summary

To summarize, there are a plethora of conditions that can contribute to EH, caries, and other dental lesions. The connection between EH and stress has long been recognized (Goodman & Rose, 1990) and as such, EH is used as a general indicator of stress in this thesis. Caries and periodontitis in this sample may be related to consumption of cariogenic foods at a young age, or an acidic oral environment caused by gastrointestinal distress. The dental lesions present on 7A2-S1 may be related to stress, but further analysis of this individual is recommended to diagnose the cause. Ultimately, at least eight of 10 infants in this sample show dental lesions indicative of stress (EH), and potential sources will be discussed in relation to the historical context in Section 6.4.

6.2 Adult Females

This section will discuss the results of adult female bone collagen analyses, first by comparing them to individuals from other archaeological sites in Québec, and then by comparing them to the non-adults in the current study sample.

Before discussing the adult female isotopic results, it is important to acknowledge the limitation surrounding sample size (n = 6). Bioarchaeological research is often plagued by such issues due to preservation and excavation biases. Statistical analyses conducted by Pearson and Grove (2013) suggest that a minimum of eight individuals is required for isotopic studies of past diets, and samples with fewer individuals may have larger discrepancies between the calculated sample and true population means. This suggests that inferences about adult females based on these data should be made with caution. However, the range of δ^{15}N values found here (+9.9-10.9‰) overlaps with that of dentine collagen from first and third permanent molars of adult females analyzed in previous studies of Pointe-aux-Trembles (M3s: +10.1-11.8‰, n = 3; M1s: +7.1-11.3‰, n = 5 selected from age groups over 2 years of age) (Gutierrez, 2019; Gutierrez et al., 2021). Thus, while the true population mean may not be captured by the adult females in the current study sample, their agreement with other studies suggests they can still provide a good idea of δ^{15}N values for comparative purposes. One should bear this limitation in mind throughout the discussion below.

6.2.1 Comparison with Isotopic Data from Other Sites

The adult female $\delta^{13}C$ and $\delta^{15}N$ values from Pointe-aux-Trembles are similar to adult collagen isotope values from other archaeological sites within Québec, but $\delta^{15}N$ appears to be slightly lower. Notre-Dame and Saint Antoine are two urban cemeteries located near the core of Montréal, and Saint-Matthew is located in Québec City. The adult collagen $\delta^{15}N$ and $\delta^{13}C$ results of previous studies conducted on these cemeteries are summarized in Table 6.1 alongside the adult female results from the present work (Gutierrez, 2019; Morland, 2010; Sadlowski, 2023; Vigeant et al., 2017). Mean $\delta^{13}C$ values from Pointe-aux-Trembles are similar to those found in the urban cemeteries, suggesting C_3-based diets were common across these regions. This is consistent with conclusions drawn by Vigeant and colleagues (2017) that suggest settler-colonial Canadian populations did not adopt local maize-consumption practices on a large scale. The $\delta^{15}N$ values observed in Pointe-aux-Trembles also overlap those found in the urban cemeteries but fall towards the lower end of the range in all cases, and the mean $\delta^{15}N$ from Pointe-aux-Trembles is 0.7-1.5‰ lower than the mean $\delta^{15}N$ from other sites (Table 6.1). This may suggest that individuals from urban areas had access to and consumed a wider variety of higher trophic level dietary protein sources than individuals from rural areas. Alternatively, lower $\delta^{15}N$ in Pointe-aux-Trembles may be related to a state of positive nitrogen balance due to repeated pregnancies in women from the community. This is explored in more detail in the next section (6.2.2). It should be noted that a larger sample size from Pointe-aux-Trembles could increase the range of observed $\delta^{15}N$ values and erase any difference between rural and urban sites; as such, additional research is recommended before firm conclusions can be drawn.

Table 6.1. Adult bone and dentine collagen $\delta^{13}C$ and $\delta^{15}N$ results from studies of other cemeteries in Québec. Adult female bone collagen data are included for reference.

Publication	Cemetery	$\delta^{13}C$ Range (‰)	$\delta^{13}C$ Mean (‰)	$\delta^{15}N$ Range (‰)	$\delta^{15}N$ Mean (‰)
Current thesis	Pointe-aux-Trembles	–20.0 to –19.1	–19.5	+9.8 to +11.0	+10.4
Vigeant et al., 2017	Notre-Dame-de-Montréal	–20.5 to –18.9	–19.6	+9.7 to +14.4	+11.5

Gutierrez, 2019	Notre-Dame-de-Montréal	N/A	N/A	+10.1 to +13.1	+11.9
Sadlowski, 2023	Saint Antoine, Montréal	–20.1 to –19.1	–19.9	+10.3 to +12.7	+11.1
Morland, 2010	Saint-Matthew, Québec City	–21.2 to –16.8	–19.5	+10.1 to +13.3	+11.5

6.2.2 Comparison with Non-Adult Dentine Collagen Results

This study found a significant difference between the δ^{15}N and δ^{13}C values from the adult female bone collagen and those of the non-adult dentine collagen. During the prenatal period, non-adult δ^{15}N and δ^{13}C were an average of 3.1‰ and 0.4‰ higher, respectively, than the adult means. Additionally, the post-weaning δ^{15}N values of non-adults remained higher than the adult females by 1.1‰. This section will consider possible explanations for this difference, including procedural factors, normal physiological processes, dietary differences, stress during pregnancy, and factors that may lower average nitrogen isotope signatures in adult females.

Several studies have discussed the importance of following the same processing procedure when comparing isotopic data from different samples (e.g., Cheung et al., 2022; Katzenberg & Waters-Rist, 2018; Vigeant et al., 2021). When all samples are prepared following the same procedure, methodology is eliminated as a potential factor driving variation in the results. Adult and non-adult collagen samples were prepared according to the same procedure with three exceptions: (1) bone samples were selected from adults, whereas dental samples were selected from children; (2) bone samples were sonicated to remove debris caught in between trabeculae, whereas dental samples were cleaned manually; and (3) a lower concentration of HCl was used for the dental samples (0.1M versus 0.5M). These steps are not expected to have produced substantial differences in the results, as bone and dentine are comparable tissues for collagen analysis, and both sonication and manual cleaning are adequate, commonly applied techniques that are not expected to alter collagen isotope ratios. Further, studies that

address HCl concentration in different treatment protocols suggest they are not responsible for the differences in isotope values observed in this sample (Pestle, 2010; Vigeant et al., 2021). Since it is unlikely that these factors affected the results, the differences between adult and non-adult isotopic results should be related to physiological or dietary factors.

Some studies have found that fetal δ^{15}N and δ^{13}C values are higher than those of the mother during pregnancy (Beaumont et al., 2015; Beaumont et al., 2018; de Luca et al., 2012). In a cohort study of over 200 mother-infant pairs, mean δ^{15}N and δ^{13}C values from infant hair were an average of 0.9‰ and 0.4‰ higher, respectively, than mean maternal isotope values at birth (de Luca et al., 2012). The authors speculate that physiological mechanisms either (1) increase δ^{15}N values in infants during fetal growth or (2) lower maternal values during pregnancy (de Luca et al., 2012). Beaumont and colleagues (2018) evaluated non-adult dentine collagen from Anglo Saxon Raunds Furnells, U. K., that had formed *in utero* and found that the carbon isotope signatures were 0.7‰ higher than the adult female mean, while nitrogen isotope signatures were 3.0‰ higher. They suggest this large difference in δ^{15}N reflects factors impacting maternal physiology during pregnancy, rather than a normal physiological offset (Beaumont et al., 2015, 2018). In the current study, the difference between prenatal and maternal δ^{13}C (0.4‰) is consistent with de Luca et al.'s (2012) results, suggesting the carbon offset is normal. However, as with Beaumont et al. (2018), the 3.1‰ difference in δ^{15}N exceeds what one would expect from mother-infant pairs, suggesting that factors beyond normal physiological processes are at play. These factors fall into two main categories: (1) those that would increase prenatal non-adult δ^{15}N values more than anticipated, or (2) those that would decrease adult female δ^{15}N values.

It is possible that the prenatal δ^{15}N values are reflecting increases in maternal δ^{15}N signatures from diet or stress that were not recorded in the mother's skeletal tissues (Beaumont et al., 2015). Since bone collagen samples represent average values observed over a few years, fetal dentine collagen may be recording shorter-term fluctuations in maternal δ^{15}N that are not reflected in bone (Beaumont, 2020). Mothers may have increased their dietary protein intake or consumed fish or higher trophic-level foods

during pregnancy (Beaumont et al., 2018). These changes in diet would be expected to increase the δ^{13}C results as well, and evidence for this pattern may be seen in 7A9-S53 (Figure 5.19). Maternal stress during pregnancy could also cause increases in δ^{15}N that would not be associated with increasing δ^{13}C (Fuller et al., 2005), and the other two infants with multiple prenatal dentine sections (7A9-S18, 7A11-S63; Figures 5.18, 5.22) demonstrate this pattern. This suggests that, within this sample, both short-term changes in maternal diet and stress during pregnancy could be contributing to elevated prenatal δ^{15}N in non-adults, thus increasing the offset between infant and adult female values.

The mean adult female δ^{15}N signatures may also be lower than expected due to the effects of repeated pregnancies in the community. Some research has suggested that maternal δ^{15}N values decrease during pregnancy (Beaumont et al., 2015; D'Ortenzio et al., 2015; Fuller et al., 2004). In a longitudinal study of δ^{15}N and δ^{13}C signatures in hair from pregnant women, Fuller and colleagues (2004) found up to a 1.1‰ decrease in δ^{15}N throughout pregnancy without a consistent change in δ^{13}C. Similar results were observed in a study of hair samples from modern and archaeological women (D'Ortenzio et al., 2015). While short term changes in δ^{15}N are not typically reflected in bone (Nitsch et al., 2010), long-term or chronic conditions can be (Katzenberg & Lovell, 1999). If pregnancies were frequent enough and if the women died recently after giving birth, a pregnancy effect may be visible. Fertility among 18th to 19th century settler-Canadians, and particularly those in Montréal, was very high (Henripin, 1954; Thornton & Olson, 1991), and Robert (2011) found that fertility was higher among wet nurses than mothers in the general Montréal population, contrary to what one would expect with lactational amenorrhea. Wet nurses from 17th to 18th century Pointe-aux-Trembles gave birth to an average of 10.6 children each (Robert, 2011), suggesting that repeated pregnancies were common in this community. Thus, it is possible that the average δ^{15}N signatures observed among adult females in the current study are up to 1‰ lower than one would expect from their diets because women in this community were often pregnant. The observation that post-weaning infant δ^{15}N values remain 1.1‰ higher than the adult female mean is also consistent with this hypothesis.

To summarize, there are a number of possible reasons why prenatal non-adult δ^{15}N and δ^{13}C values were higher than the adult female means. The δ^{13}C offset is likely related to normal differences observed between mothers and infants during pregnancy (de Luca et al., 2012). Fetal δ^{15}N values are normally offset by approximately +1‰ (de Luca et al., 2012), but this may be exacerbated by changes in diet or maternal stress during pregnancy, and/or repeated pregnancies in Pointe-aux-Trembles. These explanations need not be mutually exclusive (Figure 6.1). The adults included in this sample were probably not the mothers of the infants being analyzed; thus, the average values represented by bone collagen may be up to 1‰ lower due to high rates of fertility, but the mothers of the non-adults analyzed in this sample may have experienced stress or changes in diet that raised their own δ^{15}N signatures. After a certain point, the costs of childbearing and breastfeeding may have placed excessive stress upon some mothers (Lackey et al., 2021), leading to higher δ^{15}N values for those individuals. Overall, the 3.1‰ difference in δ^{15}N values exceeds what we would expect from typical physiological processes, and some combination of dietary changes, pregnancy, and/or maternal stress is responsible. Further research is necessary to better understand this observation.

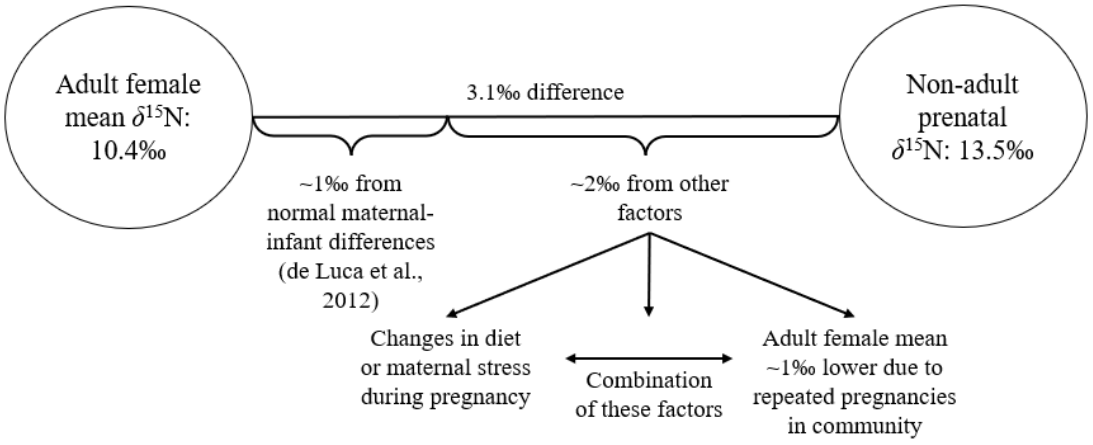

Figure 6.1. Figure demonstrating potential explanations for differences between adult and non-adult δ^{15}N values.

6.3 Infant Feeding in Pointe-aux-Trembles

This section returns to the first two research questions posed by this study (see Chapter 1) to discuss infant feeding practices in Pointe-aux-Trembles.

6.3.1 Research Question 1: Were infants in this sample breastfed? If so, for how long?

The isotopic data from this study suggest that most (at least 6/10) infants in the sample were breastfed, and these results corroborate and build upon those of a previous isotopic analysis of infant feeding practices in Pointe-aux-Trembles (Gutierrez et al., 2021). Gutierrez and colleagues (2021) analyzed permanent and deciduous teeth from 17 individuals, some of whom overlap with the current sample. By using a different methodology, the current study offers a higher resolution with which to interpret dietary transitions in early life and thus expands upon their results. Gutierrez and colleagues' (2021) analysis of permanent teeth from adults (i.e., survivors) suggested they were breastfed and gradually weaned as infants, with weaning beginning around 6 months and ending by 2 years of age. Breastfeeding and gradual weaning were both noted in the current study, though, when observable, weaning was completed by ~10.5-13.5 months. This earlier age may reflect diversity in weaning practices within Pointe-aux-Trembles but is most likely related to methodological differences. A difference between survivors and non-survivors is also possible but challenging to discern given the available data. Since Gutierrez and colleagues (2021) only derived a few samples from deciduous teeth in their analysis (usually two per tooth), their interpretations of these individuals were limited, though they suggested the presence of early weaning and/or *in utero* stress in three individuals (7A2-S24, 7A2-S32, and 7A9-S18). The current study found isotopic evidence for *in utero* stress in 7A9-S18 but not 7A2-S32 or 7A2-S24. Overall, the results from this study offer additional insight into early life diet and infant feeding practices in this community and have helped to refine the interpretations produced by Gutierrez and colleagues (2021).

Historical sources describing 18th to 19th century Montréal suggest the presence of breastfeeding in Pointe-aux-Trembles should be anticipated, though this expectation is

somewhat complicated. Wet nursing was a common practice at the time, both in Europe and in settler populations in Québec (Fildes, 1986; Gauvreau, 1987; Robert, 2011). Pointe-aux-Trembles is a community known to have engaged in wet nursing during the 1700s, with archival records demonstrating that several children were sent from urban families to Pointe-aux-Trembles to be cared for and fed by a wet nurse (Robert, 2011). Generally, the women hired as wet nurses were expected to breastfeed the children in their care and thus, one might anticipate that breastfeeding was a common practice in Pointe-aux-Trembles (Robert, 2011). However, Robert (2011) notes that some women hired as wet nurses may have stopped breastfeeding their own children to accommodate those sent into their care, and Gutierrez and colleagues (2021) suggests this as a possible explanation for early weaning and/or the absence of breastfeeding in some infants from Pointe-aux-Trembles. This notion complicates the assumption of breastfeeding because, if the cemetery is comprised of children born to wet nurses, one might expect to see early weaning and/or the absence of breastfeeding. It is thus important to consider the origins of the children in this study sample, and establish whether they were born to local families, including to mothers employed as wet nurses, or if they were children sent from urban families who died in the nurse's care.

The archival analysis conducted in the current study (Appendices B and C) demonstrates that most (74%) of the infants buried in the Saint-Enfant-Jésus cemetery were baptized in Pointe-aux-Trembles, while 16% had been baptized elsewhere (the remaining 10% of records were incomplete or inaccessible). These data suggest that the burials excavated from this cemetery, and thus the infants included in the isotopic sample, are more likely to have been born to local families than to have been sent from other regions. Of the 16% of infants baptized elsewhere, 38% were baptized in Notre-Dame and 27% in Longue-Pointe (6% and 4% of the total infant burials, respectively). As such, the cemetery could contain children who died in the care of a wet nurse, albeit to a much smaller degree. Thus, while it is plausible that some of the infants analyzed isotopically were from urban communities, most were likely from rural families in Pointe-aux-Trembles. Using this context, the isotopic results suggest that women in Pointe-aux-Trembles usually breastfed their own infants, as well as those from urban families.

For many of the infants in this sample, the duration of breastfeeding and the age of weaning cessation are unclear. This may be because some infants died before they were fully weaned. It is also possible that evidence of weaning is obscured or entangled with confounding factors like nutritional or physiological stress (Beaumont et al., 2018). The isotopic pattern used to identify weaning is a decrease in δ^{15}N and δ^{13}C towards the adult female range as the infants consume less breast milk and take on diets similar to adults (Fuller et al., 2006). During times of stress, δ^{15}N values can rise if the body begins to break down its own muscle tissue for energy (Fuller et al., 2005; Mekota et al., 2006; Neuberger et al., 2013). If breast milk consumption decreases during times of nutritional stress, the rise in δ^{15}N will erase isotopic evidence of weaning, making the age of weaning unclear. This is likely the case for 7A2-S1 and 7A2-S3 (Sections 5.2.3.1, 5.2.3.2), as they demonstrate clear isotopic evidence of stress, as well as 7A2-S22, 7A2-S24, 7A11-S57, and 7A11-S63 who have EH lesions that formed while δ^{15}N values rose or remained high. Confounding stress may also play a role in the wide range of δ^{15}N values observed in postnatal dentine sections near the end of life (Figure 5.25).

6.3.2 Research Question 2: What complementary foods were consumed, and when were they introduced?

This study suggests that some infants in Pointe-aux-Trembles were fed complementary foods at an early age, with foods initially introduced to five infants between ~1.5-5.5 months. For the remaining five infants, alternative foods were introduced to one individual (7A2-S32) between ~5.5-11 months, but the timing is unclear in the rest of the sample. Current recommendations from the World Health Organization (WHO) are for complementary foods to be introduced around 6 months, and prior to 4 months would be considered early (WHO, 2023). Thus, when characterized according to WHO recommendations, complementary feeding occurred early for half of the infants in this sample, and in the majority of infants for whom this timing could be determined.

Early complementary feeding has also been described in historical sources. During the pre-industrial era, it was common for women not to breastfeed infants immediately after birth due to concerns and taboos surrounding colostrum (Fildes, 1986; Thulier, 2009). Today, colostrum is widely recognized as an important source of immunologic and

developmental factors (Ballard & Morrow, 2013; Garwolińska et al., 2018), but in the past, colostrum was thought to be dangerous (Thulier, 2009). Additionally, a historical source from 19th century Montréal reports that exclusive breastfeeding was a rare practice during this time (Grenier, 1871). They describe mothers facing difficulty breastfeeding initially after birth and note that they would often feed infants alternative foods like diluted milk, porridge, bread, cookies, or flours/cornstarch (Grenier, 1871). Other weaning foods included meat/animal products, pastries, and fruit (Grenier, 1871).

Based on the isotopic data, most of the infants were fed C_3 weaning foods with some C_4 influences noted in select infants. These data support the observations made by Grenier (1871), as porridge, flours, and bread from the region were all derived from C_3 plants. Two individuals demonstrate an increase in $\delta^{13}C$ which could be related to consumption of foods enriched in ^{13}C, including C_4 foods, animals that consumed C_4 foods, or fish. Meat or animal products may have included beef, pork, lamb, veal, poultry, and marine and freshwater fish, as these foods are known to have been available in 19th century Montréal (Fyson, 1989; Vigeant et al., 2017). When compared to Figure 5.12, the post-weaning $\delta^{15}N$ and $\delta^{13}C$ values of two infants (7A2-S32, 7A9-S55) suggest consumption of freshwater fish. Some research has combined $\delta^{13}C$ results from bone collagen and carbonate to calculate the proportion of C_3 versus C_4 foods in one's diet (Froehle et al., 2012; Vigeant et al., 2017). Future research could combine the collagen data from this study with analyses of enamel carbonate to explore the utility of these techniques in identifying weaning foods in Pointe-aux-Trembles.

Grenier (1871) also notes that infants experiencing distress were often given alcohol or narcotics (e.g., opium) by their parents to calm them. Grenier (1871) does not state which type of alcohol was used most often, but brandy, wine, gin, rum, and local spruce beer were available in 19th century Montréal markets (Fyson, 1989; Vigeant et al., 2017). It is currently not possible to determine isotopically whether these infants were fed alcohol, but given the historical account, the possibility that these products were consumed during the weaning period cannot be discounted.

6.4 Stress in Pointe-aux-Trembles

6.4.1 Research Question 3: Do infants in this sample show dental or isotopic evidence of nutritional or disease stress?

This study has found evidence of stress in infants from Pointe-aux-Trembles. Given the high rates of infant mortality and historical descriptions of life in 18th to 19th century Montréal, some evidence of stress in infants was anticipated. However, with EH in eight of 10 infants and isotopic patterns of stress in at least two infants, the rates at which signs of stress were observed exceeded expectations. Taken together, there were only two infants (7A2-S32, 7A9-S53) who did not demonstrate dental or isotopic evidence of stress. By combining historical studies and reports on infant mortality in 18th to 19th century Montréal with bioarchaeological evidence, the following sections will explore the potential causes of the stress observed in infants from Pointe-aux-Trembles. Epidemics and food shortages are first considered, followed by infant feeding practices, gastrointestinal upset, and maternal stress.

6.4.2 Epidemics and Food Shortages

Factors that account for the high rates of infant mortality in 18th to 19th century Montréal include disease burden and food shortages (see Chapter 3; Amorevieta-Gentil, 2010; Bruckner et al., 2018; Grenier, 1871). Syphilis was endemic to Montréal by the late 1700s and epidemics such as smallpox, measles, typhus, and cholera were precipitated by increased population growth and decreased quality of living conditions (Amorevieta-Gentil, 2010; Bruckner et al., 2018; Pelletier et al., 1997). These crises tended to affect urban areas more than rural communities (Pelletier et al., 1997). However, burial records from the Saint-Enfant-Jésus cemetery show increases in infant deaths during several of the epidemics from 1709 to 1843 (PRDH, 2018; Figure 6.2), suggesting these epidemics did affect the community of Pointe-aux-Trembles. Infants in Pointe-aux-Trembles may have been exposed to one of these diseases, and since disease stress can lead to increased δ^{15}N and decreased or stable δ^{13}C (D'Ortenzio et al., 2015; Katzenberg & Lovell, 1999) as well as EH (Salanitri & Seow, 2013), it may be a cause of the stress observed in this sample. Further, Amorevieta-Gentil (2010) suggests that poor harvests or famines were common in 18th century Montréal, with at least one occurring approximately every ten

years. This may have led to nutritional deficiencies or malnutrition, which are known to cause EH and/or isotopic patterns of stress (Beaumont & Montgomery, 2016; D'Ortenzio et al., 2015; Fuller et al., 2005; Mekota et al., 2006; Neuberger et al., 2013; Salanitri & Seow, 2013; Walter et al., 2020). Given that archival and historical evidence support the presence of epidemics in 18th century Pointe-aux-Trembles and food shortages in Montréal, and that they can both lead to the isotopic and dental signs of stress observed in this sample, they are considered a likely source of stress that affected infants in Pointe-aux-Trembles.

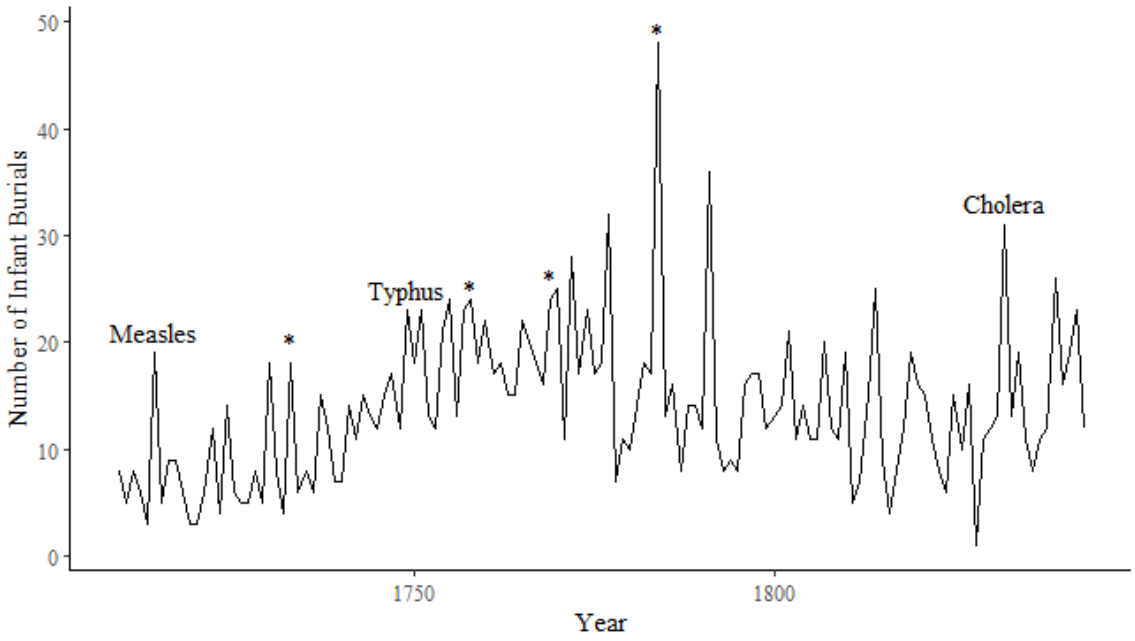

Figure 6.2. Number of infant (≤3 years of age) burials in the Saint-Enfant-Jésus cemetery in Pointe-aux-Trembles from 1709-1843 (PRDH, 2018). Epidemics that correspond to spikes in infant burials are noted, with asterisks (*) depicting smallpox (Amorevieta-Gentil, 2010).

6.4.3 Infant Feeding and Gastrointestinal Distress

One aspect of infant feeding practices that can be discussed in the context of stress is early complementary feeding. The observations of a Montréal contemporary (Grenier, 1871) describe gastrointestinal (GI) distress (repeated vomiting, diarrhea) as a large source of infant mortality in 19th century Montréal and suggest this is because infants

were fed alternative foods too early in life. They note a pattern in which infants fed adult food would experience vomiting and diarrhea, and subsequent weight loss and growth stunting from inadequate nutritional intake (Grenier, 1871). As previously discussed (Section 6.3.2), the isotopic data do demonstrate early complementary feeding in Pointe-aux-Trembles. Based on research in modern populations, infants <6 months of age who are not exclusively breastfed have an increased risk of diarrheal morbidity and mortality, and this is thought to be related to a higher risk of consuming foods contaminated with bacteria (Lamberti et al., 2011; Tang et al., 2015). Microbial contaminants may have been present in or on the implements used to prepare and provide alternative foods (e.g., bottles or other feeding devices, water used to soak bread or cornstarch), exposing infants to a higher pathogenic load and increasing their risk of GI upset and death (Fildes, 1986; Stevens et al., 2009). The effects of this may have been amplified if the increased bacterial exposure occurred alongside the decrease in the breast milk consumption, as breast milk provides important immunological protection during the first few months of life (Ballard & Morrow, 2013; Thornton & Olson, 2011). Thus, there exists a mechanism that could connect early complementary feeding to stress in infants from Pointe-aux-Trembles. Due to the small sample size in the current study (and small number of individuals without signs of stress), it is not possible to test for an association between early complementary feeding and variables such as EH, but this could be explored further in future research with larger samples.

Gastrointestinal stress can affect infants regardless of the age they are weaned or fed complementary foods, and the archival data compiled in the current study provide evidence that GI stress likely affected infants in Pointe-aux-Trembles. Previous studies and historical sources demonstrate that GI upset was common in urban Montréal (Grenier, 1871; Thornton & Olson, 1991), but Pelletier and colleagues (1997) suggest this may not be as prevalent in less densely populated areas. By examining seasonal patterns of burial records, one can see a rise in infant deaths in summer months (Figure 6.3). Of the 1934 infants buried in the Saint-Enfant-Jésus cemetery, 709 (37%) died between June and August, which is more than twice the number of infants who died during the winter (305/1934, 16%). Higher rates of infant mortality in summer months can be attributed to increased bacterial growth and contamination of water sources

(Amorevieta-Gentil, 2010; Pelletier et al., 1997; Thornton & Olson, 1991), suggesting that GI upset was likely a considerable source of infant stress and mortality in Pointe-aux-Trembles.

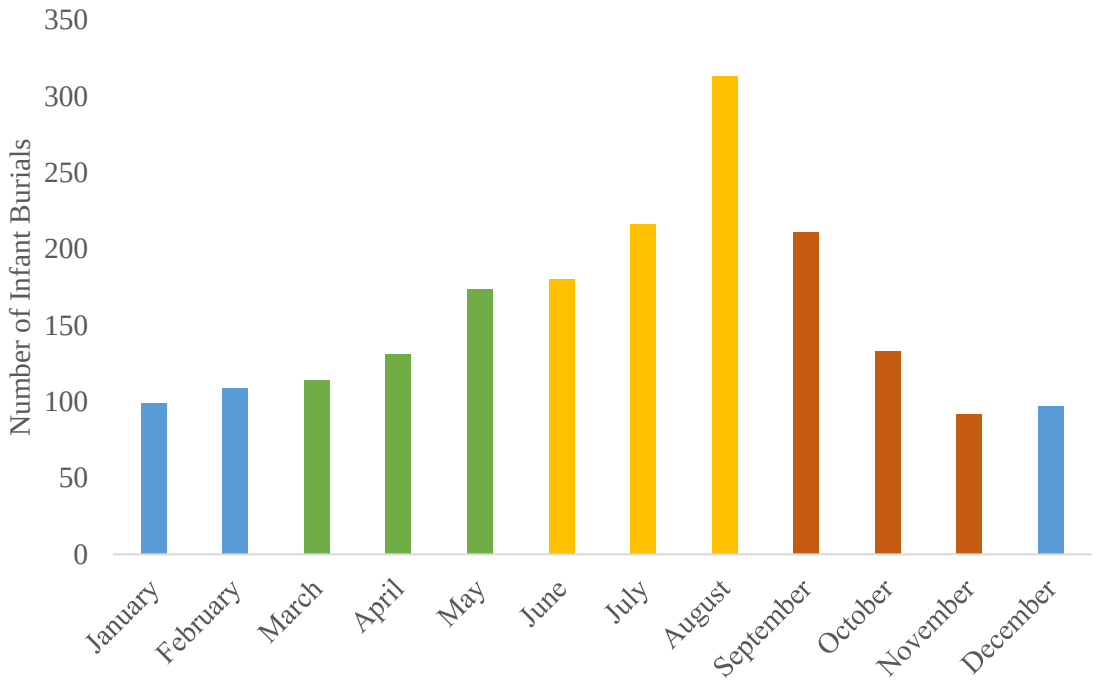

Figure 6.3. Burials of infants (≤3 years of age at death) recorded in Pointe-aux-Trembles from 1709-1843 by month and season (PRDH, 2018). Winter (blue): December-February; Spring (green): March-May; Summer (yellow): June-August; Fall (red): September-November.

There is potential for GI stress to leave isotopic and dental evidence in bioarchaeological remains. Based on research in modern individuals with bulimia nervosa, recurrent vomiting does not produce significant alterations in δ^{15}N values (Hatch et al., 2006). However, frequent GI stress is entangled with malnutrition and nutrient deficiencies: vomiting and/or diarrhea can lead to poor absorption of nutrients, and deficiencies can impair the immune functions necessary for recovery (Giannattasio et al., 2016). If infants experienced nutritional stress due to GI disorders, this may cause isotopic or dental signs of stress (e.g., EH). Additionally, frequent bouts of vomiting can lead to dental lesions such as caries (Igarashi et al., 2017; Kim et al., 2005; Marder, 2013). Since there is

historical evidence that GI distress affected infants in Pointe-aux-Trembles, it is a possible source of the dental lesions and nutritional stress observed in this sample.

6.4.4 Maternal Stress

The infants may also be reflecting signs of maternal stress. As alluded to in Section 6.2.2, repeated pregnancies and extended periods of breastfeeding in wet nurses may have exhausted women in Pointe-aux-Trembles (Lackey et al., 2021). Additionally, nutritional deficiencies were likely present given the frequency of food shortages experienced in Montréal and surrounding communities, and domestic work, poor living conditions, and disease burden would all have contributed to fatigue in women (Amorevieta-Gentil, 2010). The first 1000 days (i.e., nine months gestation and first two years of life) is considered a critical period for growth and development, and infants are largely dependent upon their mothers or caretakers/wet nurses for survival and nutrition during this time (Suzuki, 2018). Maternal stress during pregnancy would have directly influenced fetal physiology and, as discussed above, could have led to increased prenatal δ^{15}N signatures and the observed EH. Additionally, many nutrients (e.g., vitamins C and D) in breast milk reflect their availability to the mother or lactating female (Bae & Kratzsch, 2018; Bravi et al., 2016). If environmental or behavioural factors (such as wet nursing or food shortages) led to the depletion of these nutrients in women, this would be reflected in the breast milk provided to infants, thus potentially resulting in nutritional deficiencies (e.g., rickets) in infants despite being breastfed. As such, the high rates of stress observed in this sample may in part be related to stress affecting mothers and wet nurses in Pointe-aux-Trembles.

6.5 Limitations

6.5.1 Representativeness of the Sample

Due to the nature of the samples used in bioarchaeological research, it is often not possible to assume that the individuals being studied are representative of the entire population (DeWitte & Stojanowski, 2015; Waldron, 2007; Wood et al., 1992). Obvious biases may be introduced through sample preservation and excavation processes, and issues of sample size were previously discussed in Section 6.2 with respect to the adult

females. Given that the cemetery studied in this thesis was active for over 130 years, it is unlikely that 10 infants are able to capture the entire diversity of infant feeding practices that took place over this time. Less obvious bias may be introduced by the fact that this research analyzed individuals who died in infancy, and thus who may have been more sickly and frail than those who survived infancy (DeWitte & Stojanowski, 2015; Wood et al., 1992). If individuals who survived into adulthood were fed differently, such variation would not be reflected in the current study. This issue, however, was unavoidable given the focus on deciduous dentition as a means of capturing the prenatal period and a finer resolution of early life (Section 3.5.2). Given these limitations, conclusions drawn based on this sample should only be taken as representative of a subsample of the population, not the community of Pointe-aux-Trembles at large. Combining the current results with information from historical sources and results from other studies (e.g., Gutierrez et al., 2019, 2021) can help strengthen conclusions, but this limitation remains nonetheless. Future analyses of permanent teeth that contain tissue deposited in infancy from older individuals (adolescents, adults) could be undertaken to assess if the trends are the same or different.

6.5.2 Methodological Limitations

The next set of limitations to be discussed are those related to the methods. The sampling techniques employed in this study were selected to minimize sources of error but could not eliminate them entirely. Oblique incremental dentine sections were taken following the approximate direction of dentine growth lines, adapted over the length of the tooth. Compared to horizontal sectioning approaches, this reduces the mixture of developmental layers between sections; however, some blurring of the sections still occurs (Eerkens et al., 2011). Second, the methods used to estimate ages per section rest on the assumption that, within each tooth, all sections were taken at the same distance apart. This can be challenging to achieve when taking oblique sections, but the decrease in blurred time resolution was deemed an acceptable trade-off. Further, the method applied herein did not use the neonatal line as a point of reference for distinguishing between pre- and postnatal dentine (as in Burt & Garvie-Lok, 2013; Burt & Amin, 2014), and the typical timing of birth (40 weeks gestation) was used instead. Modern populations show variation in birth

timing, with most falling between 38 and 42 weeks (Declercq et al., 2023). Assuming a 40-week gestation period introduces some room for error; however, the consideration of sections around birth as perinatal helps to account for these fluctuations in birth timing.

Finally, the ages-at-death used in calculations of age per section were the mean age estimates based on patterns of dental development (AlQahtani et al., 2010; Gustafson & Koch, 1974; Moorrees et al., 1963a, 1963b). We know the ages at which stages of development are achieved can vary and using a mean age estimate does not account for this. To test how much this would affect interpretations, graphs were produced for each infant using the upper and lower standard deviations of the age-at-death estimate. None of the individual interpretations were substantially different from those made using the mean age-at-death estimate. Since each dentine section represents a few months of development, they tend to capture the range of variation in age-at-death, and while the specific ages may change, the broader trends remain the same. This is illustrated with an example in Figure 6.4. Altogether, these factors mean that the ages represented by each dentine section are not as clear-cut as depicted in the graphs, and such limitations must be considered in interpretations. Because of the steps taken to minimize and recognize the effects of these factors, they are unlikely to significantly affect the conclusions drawn in the current study.

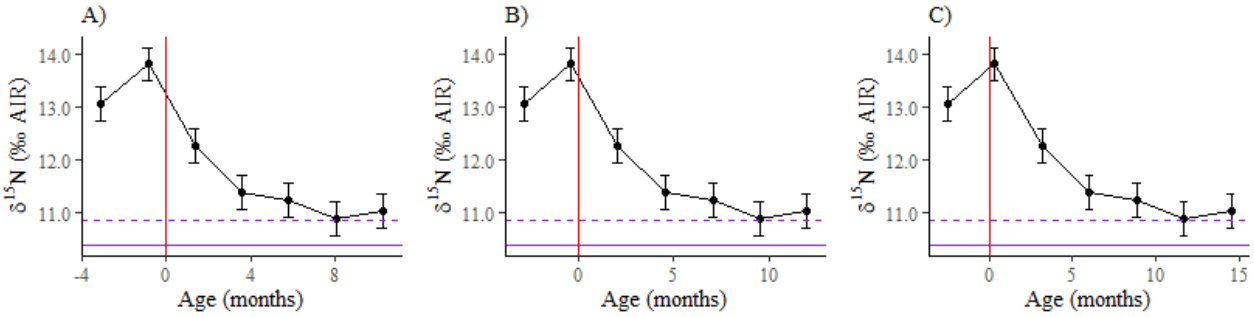

Figure 6.4. Graphs demonstrating the effects of using a range of age estimates for 7A9-S18. δ^{15}N results are plotted against age-at-death using the lower (A; -1SD), mean (B), and upper (C; +1SD) age estimates.

6.6 Conclusion

There was a high prevalence of EH and dental lesions (e.g., caries) in this sample of infants from 18th to 19th century Pointe-aux-Trembles. The EH indicates that many of the infants experienced stress early in life, as the majority of hypoplastic lesions formed before one year of age. Caries may have developed from certain feeding practices (e.g., cariogenic weaning foods, nocturnal breastfeeding) or an acidic oral environment, and lesions such as those present on 7A2-S1 likely indicate some form of nutritional or physiological stress.

Isotopic results for the adult female sample demonstrate a C_3 diet that was similar to other regions in Montréal at the time (Gutierrez, 2019; Morland, 2010; Sadlowski, 2023; Vigeant et al., 2017). Adult female δ^{15}N values may be slightly lower compared to those in other communities and to the non-adults in Pointe-aux-Trembles. This may be related to repeated pregnancies, maternal stress, and/or a pregnancy diet, but more research is necessary to understand this observation.

The majority of non-adults in this sample were most likely born to local families, and this study observed that breastfeeding was common among these infants, with complementary feeding beginning between ~1.5-11 months and the cessation of breastfeeding occurring around one year (~10.5-13.5 months) of age. However, there is diversity in breastfeeding practices within any community, and Pointe-aux-Trembles is no exception. The isotopic data demonstrate typical breastfeeding and weaning curves, possible emergency breastfeeding (7A9-S53), short to absent breastfeeding (7A9-S18, 7A9-S55), and infants who may have died or experienced nutritional/physiological stress before breast milk consumption ceased. This variation likely plays a role in the wider range of δ^{15}N values observed in postnatal dentine sections. C_3 weaning foods appeared to be the most common, though some infants were likely fed freshwater fish and/or C_4 foods. Dental or isotopic signs of stress were observed in the majority of infants (8/10), and these could be related to disease burden, frequent food shortages, GI distress, and/or maternal stress known to have affected 18th to 19th century Montréal and Pointe-aux-Trembles (Amorevieta-Gentil, 2010; Grenier, 1871; Thornton & Olson, 1991, 2011).

Chapter 7

7 Conclusion

This thesis aimed to improve our understanding of infant feeding practices and stress in 18th to 19th century Pointe-aux-Trembles, Québec. This chapter will review the main findings of this research and their contribution to the field of bioarchaeology. Suggestions for future research are also provided.

7.1 Main Findings

As a rural community, Pointe-aux-Trembles was both separated from and intertwined with the city of Montréal. The growth and urbanization of Montréal led to population densities and living conditions that increased the spread of parasitic and infectious diseases, which was part of the reason for the high infant mortality rates throughout the 18th and 19th centuries (Amorevieta-Gentil, 2010; Pelletier et al., 1997). While living conditions were said to be better in rural communities, food shortages and contaminated water did impact the residents of rural Pointe-aux-Trembles. Likewise, communicable diseases were not bound by city limits. As Pointe-aux-Trembles was located on the road between Québec City and Montréal, travel through the village was common, and spikes in infant deaths occurred during the years that smallpox, measles, typhus, and cholera epidemics occurred in Montréal (Amorevieta-Gentil, 2010). Infant feeding practices in rural areas were also interconnected with urban spaces by means of wet nursing, as wet nurses in rural communities would often receive infants born in Montréal to feed and care for (Robert, 2011). This picture of life in Pointe-aux-Trembles forms the backdrop against which the isotopic evidence for infant feeding and stress can be understood.

This study found evidence for breastfeeding in 18th to 19th century Pointe-aux-Trembles. The δ^{15}N and δ^{13}C results from at least six of 10 infants suggest they were breastfed. While a sample of 10 infants is not expected to be representative of the whole population, this evidence suggests that many women in this community breastfed their infants. Weaning was complete by ~10.5-13.5 months of age in two of 10 infants, but the age of weaning cessation was unclear in the rest of the sample. Complementary foods were

introduced to five infants between ~1.5-5.5 months of age, and to one other between ~5.5-11 months, but the timing was unclear in the other four infants. When compared to WHO recommendations, complementary feeding was thus initiated at a young age (i.e., prior to 6 months; WHO, 2023; Grenier, 1871). C_3 foods such as porridge and bread were the most common complementary foods, but two infants may have consumed some C_4 foods (i.e., C_4 plants or animals that consumed C_4 plants) or fish.

This study found evidence that infants from Pointe-aux-Trembles experienced nutritional or physiological stress. Several infants displayed EH and/or dental lesions, and isotopic patterns of stress were observed in at least two infants. As EH was present on the deciduous teeth of eight of 10 infants, it suggests these infants experienced stress within their first year of life. This may be related to disease burden, food shortages, and GI distress associated with contaminated water or food sources known to have affected Montréal (Amorevieta-Gentil, 2010; Fougères & MacLoed, 2017). These factors, and GI distress in particular, may have contributed to the other dental lesions observed in this sample (e.g., caries, periodontitis). Furthermore, infant stress may have been related to stress in adult females during pregnancy or lactation, or the introduction of contaminated complementary foods early in life (Grenier, 1871). Overall, since the majority of infants (8/10) show dental and/or isotopic evidence of stress, this study reveals that life in 18th to 19th century Pointe-aux-Trembles posed significant challenges to infant health and survival.

7.2 Future Directions

Several avenues for future research have already been mentioned throughout this thesis. These include the application of other techniques to produce more precise and accurate estimates of age at EH formation, further investigations of the dental lesions observed within the sample (e.g., those present on 7A2-S1), analyses of enamel carbonate, inclusion of permanent teeth, and a more complete analysis of adult dietary habits in Pointe-aux-Trembles that incorporates local faunal samples. Further analyses of EH and dental lesions would improve our understanding of the stressors facing infants and allow us to identify cases of prenatal/maternal stress. Analyses of enamel carbonate could provide more information about weaning foods, their introduction, and the contributions

of C_3 versus C_4 foods. Additionally, while this study focused on deciduous teeth, including permanent teeth that formed during infancy (e.g., permanent first molars) could permit comparisons of infant feeding practices between individuals who did and did not survive infancy. Finally, by isotopically analyzing local faunal samples and increasing the sample size of the adults, more accurate reconstructions of adult dietary habits could be produced. This would allow us to better understand potential dietary differences between urban and rural communities.

Future research could also explore the women in Pointe-aux-Trembles in more detail. In the process of collecting and analyzing the isotopic data for this thesis, some observations were made regarding the adult female bone collagen results. Their $\delta^{13}C$ values (–19.5 ± 0.3‰) were similar to those found in other regions of Québec (Gutierrez, 2019; Morland, 2010; Sadlowski, 2023; Vigeant et al., 2017), and no unusual differences were noted between adult and infant $\delta^{13}C$ values. However, the same cannot be said for $\delta^{15}N$. The $\delta^{15}N$ values from Pointe-aux-Trembles females (+10.4 ± 0.5‰) were within the range of the other communities, but the mean values were 0.7-1.5‰ lower. Adult female $\delta^{15}N$ values were also 3.1‰ lower than prenatal non-adult $\delta^{15}N$ values and 1.1‰ lower than post-weaning non-adult $\delta^{15}N$. These findings suggest that factors beyond normal physiological processes were impacting their $\delta^{15}N$ signatures. These observations are not fully understood due to the small sample size included in this study, but hypotheses include differences in diet between urban and rural communities and/or during pregnancy, high fertility, and maternal stress. Isotopic analyses that include males and females, and that incorporate evidence of stress or pathology, could allow us to explore these hypotheses further. Additionally, examination of archival records pertaining to adult burials in Pointe-aux-Trembles could consider fertility and the number of pregnancies experienced by women, as well as the frequency with which women in the community were nulliparous. Since this community is known to be home to wet nurses, such work could provide better insight into the health and experiences of women engaged in this practice.

With respect to the non-adults, future research could compare infant feeding practices across time and space within 18th and 19th century Montréal. As Ethnoscop (2016)

identified three different periods of cemetery use, increasing the sample size of the non-adults analyzed could permit comparisons of subsamples from different layers within the cemetery, and possibly speak to changes in infant feeding practices over time. Further, isotopic investigations of infant feeding in urban communities would improve our understanding of the similarities or differences in breastfeeding and weaning practices throughout Montréal and its surrounding rural areas (e.g., Gutierrez et al., 2021).

Finally, the results of this research will be combined with non-dental paleopathological data to better understand diet and disease within Pointe-aux-Trembles. Evidence of growth stunting, nutritional deficiencies (e.g., rickets), or conditions such as congenital syphilis could help refine our understanding of what contributed to the signs of stress observed in this sample. Considering such conditions alongside infant feeding practices could also allow us to explore the relationship between early life diet and disease.

7.3 Significance and Contribution

A central goal of bioarchaeology is to understand the diverse behaviours and lived experiences of past peoples, and no study of life in the past would be complete without discussion of women and children. The more research has focused on these groups, the clearer their societal contributions and experiences have become. This project has shed light on the short lives of some infants from 18th to 19th century Pointe-aux-Trembles, and as such, it contributes to the body of knowledge surrounding the lives of women and children during an important transitional period of French-Canadian history. This research marks a small step towards improving our understanding of how infants were fed and cared for, the impact this may have had on infant morbidity and mortality, and the dynamic social and biological relationships between infants, mothers, and wet nurses. Wet nurses were responsible for feeding hundreds of infants in and around Montréal, many of whom (namely foundlings) may not have received care otherwise. The lives of these women, those of the infants in their care, and the complex relationship between wet-nursing practices and the health and survival of past generations is a significant part of Canadian history. These topics deserve better attention in bioarchaeology, and this study marks one step in that direction.

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Appendices

Appendix A: Abbreviations and acronyms

Abbreviation	Phrase
BWP	Breastfeeding and weaning practices
CAM	Crassulacean Acid Metabolism
CDJ	Cement-dentine junction
CEJ	Cement-enamel junction
CI	Confidence interval
CRM	Cultural resource management
dH_2O	Distilled water
ECC	Early childhood caries
EDJ	Enamel-dentine junction
EH	Enamel hypoplasia
GI	Gastrointestinal
LHPC	Localized hypoplasia of the primary canine
PRDH	Programme de Recherche en Démographie Historique
SD	Standard deviation
USGS	United States Geological Survey
VPDB	Vienna Pee Dee Belemnite
WHO	World Health Organization
Sample Tooth Identification Codes	
urdi1	Upper right deciduous first incisor
lldi2	Lower left deciduous second incisor
uldc	Upper left deciduous canine
urdm1	Upper right deciduous first molar
lrdm2	Lower right deciduous second molar
URM1	Upper right permanent first molar
Stages of Tooth Formation (Moorrees et al., 1963a, 1963b)	
Cr_c	Crown complete
R_i	Initial root formation
Cl_i	Initial cleft formation
$R_{1/4}$	Root length ¼
$R_{1/2}$	Root length ½
$R_{3/4}$	Root length ¾
R_c	Root length complete
$A_{1/2}$	Apex half closed
A_c	Apical closure complete

Appendix B: Methods of searching for and analyzing burial records

The infants studied in this thesis were interred in the Saint-Enfant-Jésus cemetery in Pointe-aux-Trembles between 1709-1843. The *Programme de Recherche en Démographie Historique* (PRDH) database contains records of baptisms, births, deaths, marriages, and burials recorded by Catholic authorities in Québec during this time. These records were examined to provide additional context relevant to the Saint-Enfant-Jésus cemetery and the individuals included in the isotopic sample.

The goals of this analysis were to (1) gather demographic information (age, sex, etc.) on the infants buried in the cemetery between 1709-1843; (2) visualize patterns of mortality that occurred during this time, including the years and months/seasons when deaths where high; and (3) better understand where the infants were from and if they had potentially been sent to a wet nurse in Pointe-aux-Trembles.

Access to PRDH was acquired via the University of Western Ontario's member subscription. Records were accessed in 2023 and the most recent update to the database had been in 2018. Searches were conducted using the following parameters:

- Name fields were left blank
- From: 1709-01-01
- To: 1843-12-31
- Role: subject
- Type: burial
- Sex: M + F
- Parish: Montréal, Pointe-aux-Trembles (St-Enfant)

Burial acts for all individuals ≤3 years of age at death were examined. This range was selected to account for potential discrepancies between estimated biological age and the chronological ages recorded in the register, thus accounting for error in dental age estimates and ensuring all infants in the isotopic sample would be included in the archival sample.

The record ID, date of burial, sex, age, date of birth, birth parish, date of baptism, baptism parish, and date of death were recorded for each individual where available. All ages were converted to months to evaluate trends in age-at-death. The total number of burial acts per year were gathered from aggregated data provided by PRDH.

To address the third goal, this analysis followed methods modified from Gauvreau (1987) and Robert (2011). Infants who were buried in Pointe-aux-Trembles but born in another parish were identified as potentially having been sent to a wet nurse. Because very few records contained location of birth, the baptism parish was used as a proxy. While this may introduce some error, the baptism location is still a useful indication of the home parish, as there were minimal differences between the dates of birth and baptism observed in the archival sample, and Amorevieta-Gentil (2010) suggest that it was common to baptize infants as soon as possible after birth. Due to the scope and time constraints of this Master's thesis, additional data gathered by Gauvreau (1987) and Robert (2011) (e.g., family residence, direct mention of foster care in other registers) were not considered in this project.

There are several limitations inherent in this analysis. First, while the PRDH database is a rich resource for archival records from this time, it is possible that some acts are missing (e.g., records that may have been lost) (Amorevieta-Gentil, 2010). Second, it assumes that the infant's family lived in the birth/baptism parish. This does not control for travel through the region, as it is possible mothers may have given birth in a different town, or infants may have died and been buried while traveling through Pointe-aux-Trembles. Further analysis of residence information from familial records could address this point. Additionally, it assumes that infants born in Pointe-aux-Trembles were cared for by their own mothers, rather than another lactating female or wet nurse in the community. Finally, these data are based on records of infants who died. While this is useful for better understanding the cemetery population, it likely underestimates wet nursing in the community as children who survived the practice would not be included (Robert, 2011). All data used in this thesis have been considered with these limitations in mind.

Appendix C: Additional tables and figures from archival data

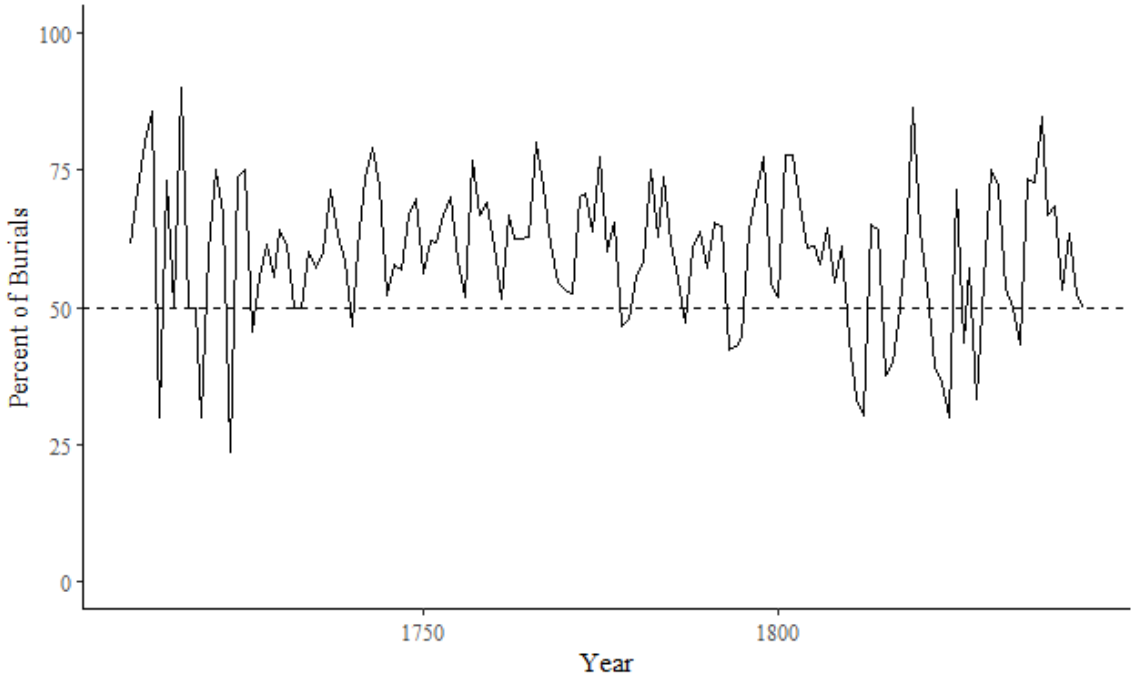


Figure C.1. Percent of burials in Pointe-aux-Trembles (1709-1843) that were of infants ≤3 years of age (PRDH, 2018). Dashed line shows 50%.

Table C.1. Yearly burials of infants (≤3 years of age) in Pointe-aux-Trembles (1709-1843) according to sex (PRDH, 2018).

Burial Year	Female	Male	Unidentified	Total
1709	2	6	0	8
1710	3	2	0	5
1711	2	5	1	8
1712	3	3	0	6
1713	0	3	0	3
1714	11	5	3	19
1715	1	3	1	5
1716	5	4	0	9
1717	1	8	0	9
1718	4	2	0	6
1719	2	1	0	3
1720	2	1	0	3

Burial Year	Female	Male	Unidentified	Total
1721	3	3	0	6
1722	6	6	0	12
1723	1	3	0	4
1724	10	4	0	14
1725	2	4	0	6
1726	2	3	0	5
1727	1	4	0	5
1728	2	6	0	8
1729	3	2	0	5
1730	9	9	0	18
1731	3	5	0	8
1732	2	2	0	4
1733	6	12	0	18
1734	1	5	0	6
1735	7	1	0	8
1736	3	3	0	6
1737	7	8	0	15
1738	7	5	0	12
1739	3	4	0	7
1740	3	4	0	7
1741	2	12	0	14
1742	4	7	0	11
1743	8	6	1	15
1744	7	6	0	13
1745	6	5	1	12
1746	8	7	0	15
1747	6	10	1	17
1748	6	6	0	12
1749	14	9	0	23
1750	10	8	0	18
1751	9	14	0	23
1752	9	3	1	13
1753	5	7	0	12
1754	10	11	0	21
1755	14	9	1	24
1756	6	7	0	13
1757	8	15	0	23
1758	12	9	3	24
1759	10	8	0	18
1760	11	11	0	22

Burial Year	Female	Male	Unidentified	Total
1761	9	8	0	17
1762	10	8	0	18
1763	5	10	0	15
1764	6	9	0	15
1765	10	11	1	22
1766	10	9	1	20
1767	6	12	0	18
1768	6	10	0	16
1769	11	12	1	24
1770	9	16	0	25
1771	3	8	0	11
1772	9	18	1	28
1773	4	13	0	17
1774	11	12	0	23
1775	7	10	0	17
1776	10	8	0	18
1777	16	16	0	32
1778	5	2	0	7
1779	5	6	0	11
1780	1	9	0	10
1781	6	8	0	14
1782	6	11	1	18
1783	5	11	1	17
1784	23	24	1	48
1785	5	8	0	13
1786	8	8	0	16
1787	2	5	1	8
1788	5	8	1	14
1789	6	8	0	14
1790	9	3	0	12
1791	20	16	0	36
1792	4	5	2	11
1793	0	6	2	8
1794	1	8	0	9
1795	5	1	2	8
1796	10	6	0	16
1797	6	9	2	17
1798	5	12	0	17
1799	5	6	1	12
1800	7	6	0	13

Burial Year	Female	Male	Unidentified	Total
1801	3	10	1	14
1802	9	12	0	21
1803	4	7	0	11
1804	9	4	1	14
1805	4	5	2	11
1806	5	5	1	11
1807	5	13	2	20
1808	3	6	3	12
1809	7	4	0	11
1810	8	10	1	19
1811	2	3	0	5
1812	2	3	2	7
1813	5	8	2	15
1814	8	16	1	25
1815	3	4	2	9
1816	3	1	0	4
1817	5	0	3	8
1818	7	4	1	12
1819	6	12	1	19
1820	4	10	2	16
1821	9	6	0	15
1822	6	5	0	11
1823	1	7	0	8
1824	2	4	0	6
1825	6	8	1	15
1826	6	4	0	10
1827	7	7	2	16
1828	1	0	0	1
1829	4	7	0	11
1830	6	5	1	12
1831	6	5	2	13
1832	17	14	0	31
1833	7	6	0	13
1834	7	12	0	19
1835	8	2	1	11
1836	3	5	0	8
1837	5	6	0	11
1838	2	10	0	12
1839	6	19	1	26
1840	5	10	1	16

Burial Year	Female	Male	Unidentified	Total
1841	9	9	1	19
1842	9	13	1	23
1843	8	4	0	12
Blank	37	24	4	65
Total	852	1011	71	1934

Table C.2. Infants (≤3 years of age) buried in Pointe-aux-Trembles (1709-1843) but baptized elsewhere (PRDH, 2018).

Baptism Location	Total
Baie-du-Febvre (St-Antoine-de-Padoue)	1
Berthierville (Ste-Genevieve-de-Berthier)	1
Boucherville	8
Chambly	4
Deschambault	1
Iberville (St-Athanase-de-Bleury)	1
La Durantaye (St. Michel)	2
Lachenaie (St-Charles)	4
L'Assomption	9
Laval	2
Laval (St-Francois-de-Sales)	2
Laval (St-Vincent-de-Paul)	1
Longue-Pointe	83
Mascouche (St-Henri)	2
Notre-Dame-de-Montréal	118
Pierrefonds	1
Repentigny	4
Rivière-des-Prairies	30
Sault-au-Recollet	3
St-Denis-sur-Richelieu	1
St-Jaccques (St-Jaccques-de-I'Achigan)	1
St-Nicolas (Lévis)	1
Terrebonne (St-Louis-de-France)	4
Trois-Rivières	1
Varennes (Ste-Anne)	20
Verchères (St. François-Xavier)	2
Total	307

Appendix D: Ethics application approval letter

Western Research

Date: 11 May 2022

To: Dr Andrea Waters-Rist

Project ID: 120770

Study Title: Changing societal structures in 19th century Montréal: Implications for infant feeding practices

Short Title: Changing societal structures in 19th century Montréal: Implications for infant feeding practices

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: 03/Jun/2022

Date Approval Issued: 11/May/2022 16:24

REB Approval Expiry Date: 11/May/2023

Dear Dr. Andrea Waters-Rist

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 Acknowledged:

Document Name	Document Type	Document Date	Document Version
Order of Preference for Dental Elements	Supplementary Tables/Figures	07/Mar/2022	1
Ethics_Section 3.25_Part 1	Sponsor Correspondence	14/Mar/2022	1
Ethics_Section 3.25_Part 2	Sponsor Correspondence	14/Mar/2022	1
Ethics_Section 3.25_Part 1_Translated	Sponsor Correspondence	14/Apr/2022	1
Ethics_Section 3.25_Part 2_Translated	Sponsor Correspondence	14/Apr/2022	1
Ethics_Section 3.25_Part 3	Sponsor Correspondence	28/Apr/2022	1
Ethics_Section 3.25_Part 3_Translated	Sponsor Correspondence	29/Apr/2022	1

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.

Sincerely,

Ms. Zoë Levi, Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

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

Appendix E: Estimated formation ages for crowns and whole teeth

	Tooth type	Deciduous dentition[1]			Permanent dentition[2]		
		Initiation (weeks gestation)[3]	Crown Completion (months postnatal)	Apex Completion (years postnatal)	Initiation (years)	Crown Completion (years)	Apex Completion (years)
Upper dentition	First incisor	13.0-16.0 (14.0)	1.5	1.5	0.25-0.3	4.0-5.0	9.0-10.0
	Second incisor	14.7-16.5 (16.0)	2.5	2.0	0.8-1.0	4.0-5.0	10.0-11.0
	Canine	15.0-18.0 (17.0)	9.0	3.3	0.3-0.4	6.0-7.0	12.0-15.0
	First premolar	-	-	-	1.5-2.0	5.0-6.0	12.0-13.0
	Second premolar	-	-	-	2.0-2.5	6.0-7.0	12.0-14.0
	First molar	14.5-17.0 (15.5)	6.0	2.5	0.0	2.5-3.0	9.0-10.0
	Second molar	16.0-23.5 (19.0)	11.0	3.0	2.5-3.0	7.0-8.0	14.0-16.0
	Third molar	-	-	-	7.0-10.0	12.0-16.0	18.0-25.0
Lower dentition	First incisor	13.0-16.0	2.5	1.5	0.25-0.3	4.0-5.0	9.0-10.0
	Second incisor	14.7	3.0	1.5	0.25-0.3	4.0-5.0	10.0-11.0
	Canine	16.0	9.0	3.3	0.3-0.4	6.0-7.0	12.0-15.0
	First premolar	-	-	-	1.5-2.0	5.0-6.0	12.0-13.0
	Second premolar	-	-	-	2.0-2.5	6.0-7.0	12.0-14.0
	First molar	14.5-17.0	5.5	2.3	0.0	2.5-3.0	9.0-10.0
	Second molar	17.0-19.5 (18.0)	10.0	3.0	2.5-3.0	7.0-8.0	14.0-16.0
	Third molar	-	-	-	7.0-10.0	12.0-16.0	18.0-25.0

[1]Sources: Lunt & Law (1974) as presented in Hillson (1996, p. 124) and Birch & Dean (2014)
[2]Sources: Schour & Massler (1940) as presented in Hillson (1996, p. 123)
[3]Parentheses denote average values

Appendix F: Example of recording sheets used for assessing dental remains

THE UNIVERSITY OF ARIZONA
ARIZONA STATE MUSEUM

DENTAL INVENTORY & PATHOLOGY
PERMANENT - RECORDING FORM (3a)

Mark a dash if not observable

Provenience: _____

Designation/ID: _____

	Right								Left							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Maxilla	M^3	M^2	M^1	PM^2	PM^1	C	I^2	I^1	I^1	I^2	C	PM^1	PM^2	M^1	M^2	M^3
Inventory (1-9)																
Development (1-14)																
Caries (1-7)																
Abcesses (1-2)																
Calculus (1-3)																
Chipping (#)																
Periodontitis (1-2)																
Attrition Score*																
Mesio-Buccal (1-10)				*[Attrition scores: I, C, PM (1-8); M (1-10)]												
Mesio-Lingual (1-10)																
Disto-Lingual (1-10)																
Disto-Buccal (1-10)																
M-D diameter (mm)																
B-L diameter (mm)																
Crown height (mm)																

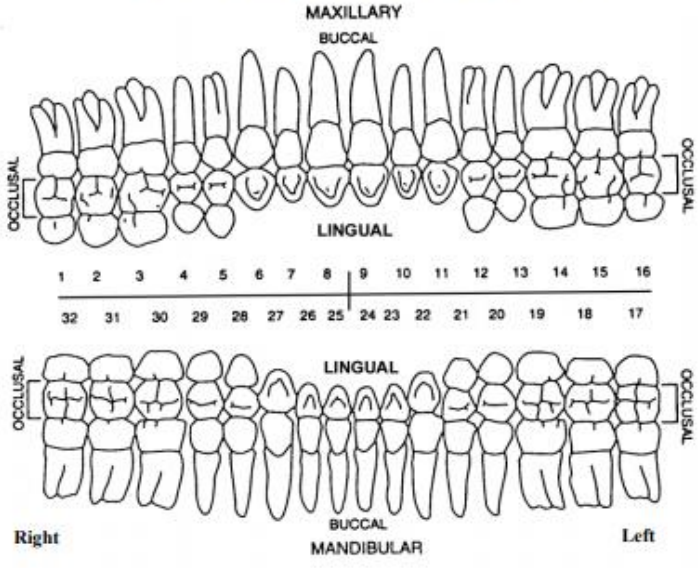
	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17
Mandible	M^3	M^2	M^1	PM^2	PM^1	C	I^2	I^1	I^1	I^2	C	PM^1	PM^2	M^1	M^2	M^3
Inventory (1-9)																
Development (1-14)																
Caries (1-7)																
Abcesses (1-2)																
Calculus (1-3)																
Chipping (#)																
Periodontitis (1-2)																
Attrition Score*																
Mesio-Buccal (1-10)				*[Attrition scores: I, C, PM (1-8); M (1-10)]												
Mesio-Lingual (1-10)																
Disto-Lingual (1-10)																
Disto-Buccal (1-10)																
M-D diameter (mm)																
B-L diameter (mm)																
Crown height (mm)																

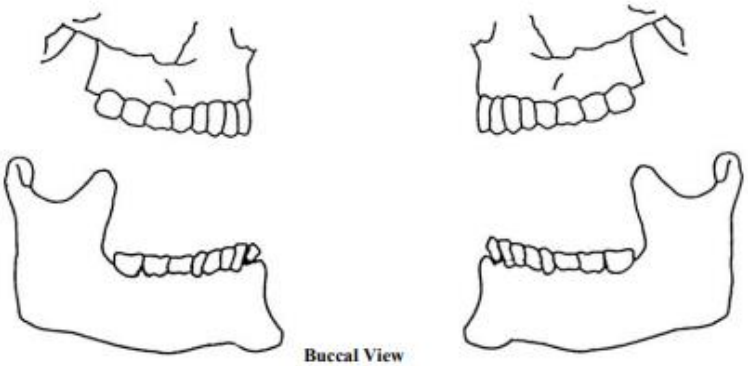
Enamel Defects																
Tooth																
Defect No. on Tooth																
Defect Type (1-7)																
Distance from CEJ (mm)																
Color (1-4)																

THE UNIVERSITY OF ARIZONA
ARIZONA STATE MUSEUM

DENTAL INVENTORY & PATHOLOGY
PERMANENT - RECORDING FORM (3a)

Note pathology locations and severity, wear, and any additional observations.





Buccal View

Additional observations:

THE UNIVERSITY OF ARIZONA
ARIZONA STATE MUSEUM

DENTAL INVENTORY & PATHOLOGY
DECIDUOUS - RECORDING FORM (3b)

Mark a dash for not observable

Provenience: _____

Designation/ID: _____

	Right									Left
	51	52	53	54	55	56	57	58	59	60
Maxilla	M^2	M^1	C	I^2	I^1	I^1	I^2	C	M^1	M^2
Inventory (1-9)										
Development (1-14)										
Caries (1-7)										
Abcesses (1-2)										
Calculus (1-3)										
Chipping (#)										
Attrition Score*										
Mesio-Buccal (1-10)										
Mesio-Lingual (1-10)										
Disto-Lingual (1-10)										
Disto-Buccal (1-10)										
M-D diameter (mm)										
B-L diameter (mm)										
Crown height (mm)										
	70	69	68	67	66	65	64	63	62	61
Mandible	M^2	M^1	C	I^2	I^1	I^1	I^2	C	M^1	M^2
Inventory (1-9)										
Development (1-14)										
Caries (1-7)										
Abcesses (1-2)										
Calculus (1-3)										
Chipping (#)										
Attrition Score										
Mesio-Buccal (1-10)										
Mesio-Lingual (1-10)										
Disto-Lingual (1-10)										
Disto-Buccal (1-10)										
M-D diameter (mm)										
B-L diameter (mm)										
Crown height (mm)										

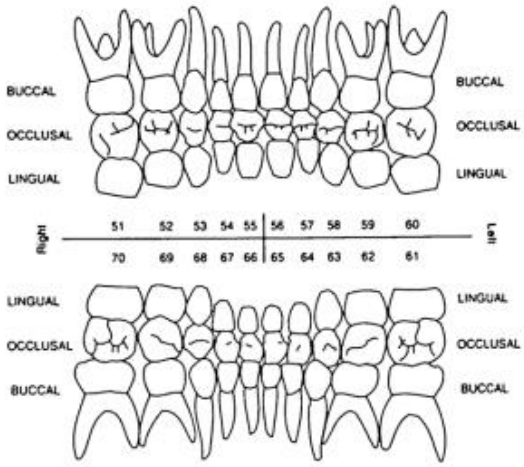
Enamel Defects															
Tooth															
Defect No. on Tooth															
Defect Type (1-7)															
Distance from CEJ (mm)															
Color (1-4)															

THE UNIVERSITY OF ARIZONA
ARIZONA STATE MUSEUM

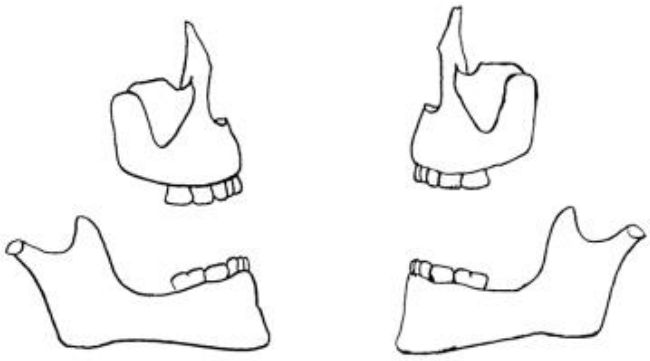
DENTAL INVENTORY & PATHOLOGY
DECIDUOUS - RECORDING FORM (3b)

Note pathology locations and severity, wear, and any additional observations.

MAXILLARY



MANDIBULAR



Buccal View

Additional observations:

Appendix G: Results of dental scoring and measurements

Dental remains were scored and measured following Buikstra and Ubelaker (1994). Results may be found in Additional Files within the Western University Electronic Thesis and Dissertation Repository.

Appendix H: Analytical error calculations

Accuracy, precision, and standard analytical uncertainty were calculated following Appendix G of Szpak et al. (2017). The spreadsheet used for calculations may be found in Additional Files within the Western University Electronic Thesis and Dissertation Repository.

Curriculum Vitae

Name:	Sydney Holland
Post-secondary Education and Degrees:	University of Victoria Victoria, British Columbia, Canada 2016-2021 B.Sc. The University of Western Ontario London, Ontario, Canada 2021-2024 M.A.
Honours and Awards:	Faculty of Science Dean's List University of Victoria 2017-2018 Excellence Scholarship University of Victoria 2016-2020 President's Scholarship University of Victoria 2020-2021 Natural Science and Engineering Research Council of Canada Undergraduate Student Research Award 2020 Ontario Graduate Scholarship The University of Western Ontario 2021-2022 Social Science and Humanities Research Council of Canada Canada Graduate Scholarship – Master's 2022-2023
Related Work Experience:	Undergraduate Research Assistant University of Victoria 2019-2021 Graduate Teaching Assistant The University of Western Ontario 2021-2023

Graduate Research Assistant
The University of Western Ontario
2023-2024

Publications:

Kurki, H., Holland, S., MacKinnon, M., Cowgill, L., Osipov, B., & Harrington, L. (2022). Appositional long bone growth: Implications for measuring cross-sectional geometry. *American Journal of Biological Anthropology, 179*(4): 1-16. doi: 10.1002/ajpa.24602

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