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Early Life Histories:

A Study of Past Childhood Diet and Health
Using Stable Isotopes and Enamel Hypoplasia

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Abstract

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ composition of incremental segments of tooth dentine was used to infer infant and childhood diet in a post-medieval London population, and a hunting and gathering Mesolithic/Neolithic group from Latvia. Health was analysed using defects on the tooth enamel caused by stress, termed enamel hypoplasia. The populations, which differ markedly in their economy, diet and health, were selected because of the difference in childhood experiences between the two groups. The results were used to consider questions about childhood, including how early diet may have been influenced by social factors such as class or status, the effect this could have on population dynamics and how childhood diet and health are related.

The results show that the London individuals were rarely breastfed beyond 6 months and in some instances not at all. A small isotopic difference between males and females was observed which could be caused by dietary or physiological differences. The peak incidence of hypoplasia may be related to developmental patterns, rather than stress caused by weaning. The Zvejnieki individuals had a slightly longer breastfeeding duration. Those buried with pendants consumed a different diet in childhood to those without pendants, suggesting a complex social system, possibly indicating that diet was related to the role a person had within the community. There is a suggestion diet may have shifted between the Middle Mesolithic and Late Neolithic, although not dramatically. Neither population have elevated $\delta^{13}\text{C}$ often associated with breastfeeding.

The early life histories of the groups are not compared directly, but general observations concerning the children's lives are considered. It is concluded that economy is not a reliable predictor of infant feeding strategies, as hunter-gatherers provide children with solid foods at a similar time to industrial groups. Intra-population variability was found to be a feature of all socio-economic groups.

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Chapter 1 Early Life Histories and Aims

Understanding the lives of infants and children is important in any population for a number of reasons, yet they are difficult to study. The difficulty with which their lives are studied is at odds with their importance. This has led to studies specifically about childhood and infancy, sometimes referred to as 'early life histories'. The aim of this thesis is to identify and explore the early life histories of selected individuals from two populations, allowing broader questions relating to the populations as a whole to be addressed. These are explored by sampling incremental segments of dentine from teeth and analysing them using $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ stable isotopes. This chemical analysis allows the isotopic composition in a sequence to be identified. This permits shifts within and between individuals to be recognised, from which can be inferred dietary differences over the early years of a person's life. The technique is applied to populations from different ends of the socio-economic spectrum, a post-medieval industrial population from London and a Mesolithic/Neolithic hunter-gatherer population from Latvia. The post-medieval group was selected because of the nutritional deprivation and poor health which they experienced, while the Zvejnieki group was selected because of their economy, reliance on hunting and fishing and superior health.

1.1 Why Study Early Life Histories?

The difficulty in understanding early diet is caused by the underrepresentation of infants in the archaeological record and the often poor representation of early life in historical resources compared to the lives of adults (Baxter 2005). This absence of information concerning childhood and infant feeding practices in the literature is a product of the inability of these individuals in the past to record their own experiences and the disinclination of adult authors to write on the subject. Where historical references to early life experiences exist, their value has to be recognised. No historical resources are available concerning childhood and infant experiences in prehistoric populations and anthropological comparisons are frequently cited which are

inherently tenuous (Baxter 2005). This leaves the archaeological record as the major resource for piecing together facts about childhood and infant diet and health.

Finding information about the earliest part of life, known as infancy, in the archaeological record is not always easy. In past societies, they were sometimes given different privileges and rites of passage from adults, which may be reflected in their visibility, particularly in a funereal context. Segregated burial or different burial rites specifically for the young were practiced by some communities. An example is the infant burial ground at Kylindra on the Greek island of Astypalaia, a cemetery solely for young infants (Hillson 2009). Alternatively, the remains of infants may be completely absent from cemeteries, a phenomenon which is not necessarily due to a lack of respect or interest in their deaths. Infants in societies such as these may have been important, but their remains are not represented archaeologically, which means osteological analysis is impossible (Wileman 2005). This is made more difficult because of the nature of young bone. Due to the high porosity of softer woven bone in the young, taphonomic processes can adversely affect the chances of the survival of infant remains compared to adults (Gordon and Buikstra 1981, Walker *et al.* 1988). The recovery of juvenile skeletons from excavations has also been selective in the past and it seems infants' bones were sometimes overlooked, not screened for, or mistakenly identified as faunal remains (Mays 2002).

The difficulty in obtaining information about early life is at odds with the importance of the role of children, a stage in life beyond infancy when a child arguably has more influence over its life. Although children often had different roles in a society from adults, they were not always insignificant or marginalised. Children were not, and are not, passive agents waiting in line to become adults. Children have the potential to dictate the behaviour of parents and adults and decisions taken by societies (Konner 2009). Considerable effort is taken by societies to provide appropriate care for children to ensure their survival. They are the future of a population and it is in the community's interest to support their young (Belsky *et al.* 1984). Children can also play

functional, economic roles in societies, such as working in industry or being in charge of gathering foods (Kamp 2001, Hawkes *et al.* 1995). Similarly, they can play pivotal roles within a family, older children providing care for the younger ones, or keeping house while adults work (Sear and Mace 2008). In pre-industrial societies, which tend to have a high birth rate and low life expectancy, children make up a large part of the population (Davis 1955). This means their influence and use within a population is potentially great.

Given the importance of children within a society and the problems in accessing information about infants and children, piecing together the lives of these individuals is an important contribution to understanding the population as a whole. Using a variety of techniques, it is possible to observe early life experiences, collectively known as 'early life histories'. In this thesis the early lives of individuals from two populations are investigated.

1.2 The Populations and the Hypotheses

The first group for which early life histories are constructed is an industrial era post-medieval London population (c. 1730-1860 AD). Teeth were obtained from a cemetery in Southwark, which is believed to represent the remains of a working class group associated with an almshouse (Teague *et al.* 2013). In life, these people are likely to have suffered hardship during the industrial revolution, a period which is known to have had severe effects on human health and survival (Boast 1997, Luckin 1984, Howe 1997). This makes it an important site for which to consider the dual aspects of health and diet. A body of evidence from historical sources and records pertaining to the cemetery itself was available, making the site well contextualized. The published results from two other post-medieval London populations, from different socio-economic backgrounds, provide a foundation for comparisons between these different groups (Nitsch *et al.* 2011, Beaumont *et al.* 2012b). The study considers both site specific questions relating to the people sampled from Southwark, such as the age they were weaned and their childhood diet, as well as

the broader implications concerning the impact of the industrial revolution on children. The hypotheses are as follows:

- The working class St Saviour's mothers are likely to breastfeed their infants for a shorter period of time compared to those from the middle class because they were under greater pressure to return to work.
- Infant feeding practices were variable within the group because the population was not homogenous. People in the UK were highly mobile during this era and employment could be found in industry. This resulted in a mix of people from different cultural backgrounds, with different beliefs and social attitudes towards infant feeding.
- Male and female children had the same diet as each other.
- There is a correlation between the timing of weaning and stress, as weaning foods were not nutritionally adequate.

The second group is a Mesolithic/Neolithic hunter-gatherer-fisher group from Latvia called Zvejnieki (c. 8150-4190 BP). It is one of the largest cemeteries of its age in Europe, superbly preserved with grave goods, and excavated to a good standard (Zagorskis 2004). A large body of work has been published on different aspects of the site, including a previous isotopic study which focused mostly on the analysis of adults and a large number of faunal remains (Eriksson 2006). This evidence suggests there were shifts in diet throughout the long occupation of the site, but no marked transition from hunting and gathering to farming, as would be expected in Western Europe. A variety of studies have considered weaning in prehistoric populations based on isotope composition e.g. Eerkens and Bartelink (2013), Howcroft *et al.* (2012), Howcroft *et al.* (2014), Jay *et al.* (2008), Richards *et al.* (2003), Schurr (1997), Waters-Rist *et al.* (2011), Clayton *et al.* (2006), Eerkens *et al.* (2011), Fogel *et al.* (1989), Oelze *et al.* (2011) and Triantaphyllou *et al.* (2008). None of these are groups which are directly comparable to those who lived at Zvejnieki during the Mesolithic and Neolithic. Aside from these studies, most of our ideas about hunter-

gatherer childhoods are based on ethnographic parallels, making Zvejnieki an important site to investigate. The hypotheses are as follows:

- A change in infant strategies occurred over time. This is predicted based on skeletal evidence that there were small changes in population numbers through time and a shift in the peak age of female mortality (Zarina 2006).
- Those buried with grave goods had a different diet from those who had none. As pendants were the most common grave good, they are used to consider this hypothesis.

The differences in lifestyles, infant and childhood experiences, health problems and subsistence experienced by the two selected populations make them ideal case studies to explore how childhood is affected by external factors. The St Saviour's group is undernourished, suffered a high rate of childhood mortality and suffered the effects of pollution and work in industry. While the period is historically documented, the effects of these conditions on infants and children are not widely reported. The Zvejnieki group is better fed and healthier, but we know little about childhood nutrition and infant nursing amongst hunter-gatherers. Inter and intra individual variability is difficult to assess. Although no attempt is made to directly compare these different groups, one aim is to see how childhood and infant experiences differ between individuals from diverse backgrounds and to consider whether our preconceived notions of early life in industrial and preindustrial populations have foundations. In the final chapter the results are brought together to test the following hypotheses:

- The length of time an infant is breastfed is dependent on the economy of the population. It is often quoted that communities with hunting and gathering economies breastfeed their infants for longer, while farming and industrial societies breastfeed for a shorter period of time (Fouts 2004, Clayton *et al.* 2006). This is tested with the St Saviour's and Zvejnieki populations.

- Inter-population variability in infant feeding patterns is a feature of all populations, but hunter-gatherer groups are more likely to be heterogeneous.

1.3 Tracking Dietary Change and Health at St Saviour's and Zvejnieki

Infant and childhood diet in the St Saviour's and Zvejnieki population is tracked in the two populations using the incremental dentine technique. This technique involves demineralizing a tooth and cutting the softened dentine into segments horizontally from the crown to the root. As the tooth develops from the cusps to the root, these segments represent different age brackets during the period of the tooth's development, represented by developmental charts (Massler *et al.* 1941). The resultant collagen from each segment was subject to $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ stable isotope analyses, which are commonly used to explore the diet of people in past populations. Comparing these segments allows dietary changes to be tracked over time in each individual. The thesis focuses mostly on the first molar (M1), a tooth which develops from the age of 0 to 8 years old approximately, encompassing a large part of the childhood and infancy. The method is ideal as children's remains were not available, prohibiting the study of children's diet through other isotopic means. Childhood stress, in the form of defects on the enamel known as enamel hypoplasia, is tracked using the same teeth.

The methods for extracting high resolution information out of teeth are not perfect. We cannot yet sample isotopes at sufficient resolution to follow the growth lines of the teeth perfectly and the method is time consuming, which limits the sample size. Various interpretations of isotope values, as reflections of diet and nutrition, mean multiple interpretations of the data are normal. Nevertheless, the technique is useful as it allows subtle differences between and within individuals to be observed and quantified.

There are potentially several transitional periods during early life which are marked with a change in diet. These transitions can be tracked using the incremental dentine method. The three phases are 1) Infancy, when breast milk may or may not be provided 2) Early childhood, when weaning

often occurs 3) Older childhood, when a diet tailored to this age group may be consumed. During the first phase, breast milk provides the nutrients a child needs as well as immunological protection against pathogens. It does this through its composition of antibodies, cytokines, immunoglobulins and memory cells, which protect the child against pathogens the mother was exposed to. Breastfed infants also have a unique bacterial flora, mainly *Lactobacilli* and *bifidobacteria*, which have prohibitive effects on the growth of pathogenic bacteria (Lönnerdal 2000). The relationship between infant mortality and the provision of breast milk is well-established because of this and the age when infant mortality peaks can, in many cases, be directly related to the age when breast milk is withdrawn (Knodel and Kinter 1977). Many health problems are believed to be alleviated or preventable by the provision of breast milk, these include diarrhoea and respiratory diseases, both of which are common infant ailments (Quigley *et al.* 2007). Other benefits extend into adulthood and cover a range of potentially life changing issues, from increasing the IQ and cognitive abilities of some individuals (Caspi *et al.* 2007, Mortensen *et al.* 2002), decreasing the likelihood of obesity in adult life (Arenz *et al.* 2004) and protecting against a number of adult diseases and health problems (Kramer *et al.* 2003), including some types of cancer (Davis *et al.* 1988), multiple sclerosis (Pisacane *et al.* 1994) otitis media and meningitis (Cunningham 1995).

The association between infant health and diet is historically documented through changing rates of infant mortality. For example, during the American civil war, cotton exports to Manchester decreased, resulting in the loss of jobs in the cotton mills for young women. Without employment, these women remained at home with their children and the incidence of breastfeeding increased as a result. Infant mortality plummeted as a by-product. As cotton imports increased again and women regained their positions of employment, infant mortality would once again return to a higher level as breastfeeding decreased (Fildes 1995). A similar example can be found in infants at the London Foundling Hospital during the 18th century, who experienced a higher incidence of mortality compared to contemporary infants outside the care

of the hospital. At intervals, an influx of infants being brought to the hospital made it hard to find enough suitable wet nurses and many infants were dry fed non-breast milk products as a result. This elevated the level of infant mortality in the hospital (Levene 2005).

The positive buffering effects of breast milk against the environment have to be balanced with the changing nutritional requirements of a child as it matures. Ideally an infant is introduced to foods which provide the individual with a balanced diet, comprising an appropriate range of different food groups which a growing child needs to thrive (Weaver *et al.* 2008). Eventually these requirements are obtainable only from non-breast milk sources. The age when breast milk should begin to contribute less to the diet and other foods are introduced is considered amongst modern health care professionals to be around the age of 6 months (WHO and UNICEF 2003), as it is thought to be at this point when an infant needs more than milk to sustain itself (Langer 2003). The timing of events is crucial for the child, as while no breast milk or early breast milk withdrawal can be detrimental for an infant, children will eventually need other nutrients to remain healthy. While there is a constantly changing idea of when weaning should occur in the western world, weaning patterns are highly culturally specific and ideals about the timing of weaning amongst hunters and gatherers often differ from those proposed by health organizations (Holmes *et al.* 1997, Mabilia 2005, Fouts 2004).

When this dietary change occurs, a child is said to be 'weaning'. The term weaning is used in the literature in several different ways- to signify the introduction of any solid foods before they are required nutritionally, the period when both breast milk and solid foods are consumed, the transitional period when breast milk is gradually withdrawn and solid foods are consumed in increasing quantities or the period when breast milk is completely withdrawn and solid foods are fully relied upon (Greiner 1996). While debate will remain over the exact definition of the phrase, all references to 'weaning' in this context should be considered to refer to the transitional period, when breast milk is replaced over a period of time with other solid foods, finally resulting in the

complete absence of breast milk from the diet. It is acknowledged that many infant feeding patterns are more complex than this, for example mothers may occasionally breastfeed a child after weaning has taken place, but for the majority of individuals, breast milk will remain a minor dietary supplement after solid foods are consumed (Carothers and Gribble 2014).

Before adulthood and after weaning has ended, a child will consume a diet which may be specialised for children or comprised of smaller portions of adult foods. This may depend on which foods are available, types of food which are deemed suitable for children, and the inclination of the child. Like breastfeeding, identifying childhood foods provides a means to help identify cultural trends and shifts in societies. Given the longevity of childhood in humans and the amount of development which a person goes through during this period, diet has to change according to the needs of the individual. Each society has its own ways of facilitating a child's dietary needs, such as utilizing special equipment (Fildes 1986), altering the food by pre-mastication (Pelto *et al.* 2010) or buying pre-prepared foods. The relationship of childhood diet to an adult's diet is also highly specific to a population.

The food a child consumes after weaning can either improve health or cause health problems. Children are particularly vulnerable to nutritional illnesses such as rickets and scurvy which can cause developmental problems (Weick 1967, Rajakumar 2001). Infantile scurvy was a problem during the 19th century, when children's diets lacked vitamin C. The use of pasteurised milk in the 20th century exacerbated the problem, as it was not understood that milk's antiscorbutic properties were destroyed by the heat (Rajakumar 2001). Even after recovery, such health problems can resonate throughout adult life.

In this thesis, the relationship between biological stress and dietary transitions in infancy is considered using the St Saviour's almshouse population, a suitable sample because of the large number of teeth available and high stress level amongst the population. A study is made of the position and frequency of the enamel hypoplasia on the teeth, which denote stressful events

during childhood. This is compared to changes in diet, as observed in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, to see if there is a correlation. The relationship between weaning and hypoplasia is a contentious issue which is still debated. Other indicators of health are discussed where possible in both case studies, to give a general idea of overall health.

1.4 Identifying Social Attitudes through Childhood Diet

Infant and childhood diet is influenced by both the society in which the child is brought up and the parents. Infant feeding is particularly influenced by the work constraints or the absence of the parents, the death of a mother being an obvious cause of early weaning. Other influences are dependent on a range of variables, relating to biological and cultural issues. These may include, amongst other things, the fashions of the period, beliefs and religion (Ineichen *et al.* 1997, Mull 1992), cultural norms (Hannan *et al.* 2005), available weaning foods and preparation equipment, the desire to control parity, education, wealth, class and status (Howie *et al.* 1990, Solem *et al.* 1992). Less obviously, variables such as climate can affect feeding patterns, for example, in northern European countries breastfeeding is known to have declined when the climate became colder and drier during the 19th century. This is because of the relative ease with which it could be stopped, compared to warmer areas where animal milks quickly went bad (Fildes 1995).

Should one of these many variables change, a shift in infant and childhood feeding practice may occur, meaning there is the potential to identify social change through dietary change. Often there is more than one factor influencing the practices of a mother or a society as a whole. As an example, changes in infant mortality in Sweden during the 18th and 19th centuries have been connected with breastfeeding practices. A high incidence of dry feeding and high mortality of infants led to a campaign to increase breastfeeding in areas which practiced dry feeding. The campaign resulted in the education of women, a change of social ideals and the increased use of midwives, which boosted the number of women willing to attempt breastfeeding. Infant mortality subsequently declined. These changes in infant feeding practices occurred at different

rates depending on the class of the women and whether they lived in a rural or urban environment (Brändström *et al.* 1984).

A growing child, past the weaning stage, may or may not have a diet distinct from an adult. As with infants, it will be dependent on foods which are considered suitable for children, but may also be related to factors such as status. For example, highly prized expensive foods may be reserved for adults. The age at which a child comes of age will differ depending on the community, so dietary change may mark social transitions. There is therefore the potential to pick out social constructs by comparing adult and childhood diets through time. Physical differences in the abilities of children might also influence the foods they consume if they are providing for themselves. Bird and Bliege Bird (2000) found that foraging practices amongst the Meriam children of the Eastern Torres Strait was a product of their abilities. In this population, children hunted a wider range of prey than adults. In some societies foods will be selected for a child, whereas in other societies children have a greater opportunity to select their own foods.

Preparation equipment can help children consume foods which would not otherwise be manageable during childhood. At this stage of life, small cutlery and multi-purpose equipment such as pestles and mortars, grinding stones, or food blenders, allow children to consume foods which would otherwise be difficult for them to handle, consume and digest (Fildes 1986). Innovation, ingenuity and material culture are therefore factors in the foods available to a child. Like breastfeeding practices, other factors such as beliefs, religion, fashions and whims can equally influence the time weaning takes place, which foods an infant is introduced to and the diet of children. Amongst the Gogo people in Tanzania weaning time is affected by the season. Because weaning is understood to be stressful for children, they are weaned during 'itika', the beginning of March to the end of April. During this season a wider variety of weaning foods are available, including courgettes and pumpkins which are mashed and combined with sugar

(Mabilia 2005). This means children would be weaned at different ages, depending on the time of year they are born.

There is the potential for separate groups to be identified within a population by their feeding patterns (Fouts 2004). The identification of infant feeding strategies as a means of detecting distinct populations and archaeological shifts over time is also feasible. At Lake Baikal, Siberia, it was found there were slight differences in the experiences of infants during the early and late Neolithic (8,800-5,200 cal BP). While results show breast milk was a major source of protein until 2/3 years, weaning occurred later and over a shorter period of time during the early Neolithic. The authors suggest this slight shift in practices could have had a major biological impact (Waters-Rist *et al.* 2011).

1.5 Identifying Social Change and Demography

Infant feeding patterns have the potential to change the dynamics of a population because of the link between infant mortality and infant feeding strategies. If this relationship was simple, it would be easy to predict which populations were able to sustain themselves, which populations were expanding and which were in decline. The complicating issue is the link between breastfeeding, birth spacing and parity, which must be factored into any predictions about population dynamics.

Breastfeeding inhibits certain hormones, delaying ovulation and restricting the fertility of women and the chances of conceiving again. Extending the length of breastfeeding potentially prolongs this period of limited fertility, thereby decreasing the number of children per female (Anderson *et al.* 1986, Chen *et al.* 1974). Women who understand the link between elongated breastfeeding and conceiving again may choose to deliberately utilise it, breastfeeding for longer because of the contraceptive effect (Howie and McNeilly 1982). This choice may be influenced by a mother's concern over supporting more than one infant at a time, particularly if she is practicing extended

breastfeeding. It may also be important economically, as a family may desire to limit the number of offspring to make sure there are enough provisions for all the family (Bavel 2004).

To summarize, elongated breastfeeding in the past and in developing countries lowers infant mortality, meaning more children survive to adulthood. However, frequent breastfeeding delays ovulation and women are likely to have fewer children during their lives, limiting population numbers. The contraceptive effect of breastfeeding is not reliable and it is difficult to predict because it may be influenced by factors such as the state of a woman's nutrition (Potter 1975). On the other hand, infant mortality is influenced by a variety of factors, such as medical intervention and environment, making it another factor which is difficult to predict. The relative influence of mortality, parity and birth spacing on the population is complex. There are cases where there is no link between parity, infant feeding and birth spacing. In some of these groups fertility and parity is controlled artificially, including those with access to contraceptives or more natural methods of birth control. For example, Knodel and Walle (1967) demonstrated using data from three 19th and 20th century German states that fertility was not affected by breastfeeding and it did not impact infant mortality. A more reasonable explanation for different birth rates across these areas was the practice by some of family planning, or behaviour which limited the number of births.

Given that population numbers can be influenced, at least in some circumstances, by infant feeding practices, changes in infant rearing strategies could potentially have major effects on many different aspects of a society. It has been argued that the Neolithic Revolution, a period when mobile hunter-gatherers across the Near East and Europe became farmers, was a consequence of a boom in population numbers (Cohen 1977). Theoretically this could be caused by a change in mobility patterns, energy expenditure, mortality and infant feeding strategies, although plenty of alternative theories exist. For a summary see Weisdorf (2005). Less dramatic examples are more plentiful, for example, Finnish people in areas which did not practice

breastfeeding during the 19th century had shorter birth intervals and a greater number of children compared to areas which did not breastfeed. This is a common trend during this period across Europe (Lithell 1981).

Mobility, economy and subsistence strategies are areas which affect and can be affected by infant feeding patterns. Economies are influenced strongly by the structure of societies, as the demographics influence the number of individuals who are able to contribute positively to the economy. An increase in the child population has been argued to decrease economic progress, while a greater adult population increases productivity (Crenshaw *et al.* 1997). Similarly, subsistence strategies can be greatly affected by infant and childhood feeding patterns. The availability of weaning foods, and hence the timing when weaning takes place, is dependent on crop production, environment or hunting and gathering niche (Sellen and Smay 2001). Variable childhood feeding strategies are therefore to be expected depending on the subsistence strategy of the group, although some populations or parts of society will have more foods available to them than others.

Subsistence strategy influences sedentism, and as a rule mobility decreases as a society becomes more reliant on crop production. Sedentism is also frequently quoted as a trigger for increased fertility and a reduction in birth spacing (Roth 1985). There is a common belief in the stereotype that hunting and gathering societies elongate the breastfeeding period, while farming communities tend to shorten the breastfeeding period. This is seen with the Bofi foragers and farmers of the Northern Congo Basin, central Africa, who despite frequently interacting on a social level with each other, and being united in language and background, choose to raise their children differently. The farmers believe providing breast milk over a prolonged period causes infants to become lazy and the mother's work load is lessened by early weaning. In contrast, the foragers believe the child's health is at risk by early weaning and breast milk withdrawal should be instigated by the child (Fouts 2004).

Given the factors involved in birth spacing, the relationship between subsistence, sedentism and infant feeding is an over simplification of a more complex picture. The example of the Bofi people shows that ethnically identical groups with different economies can have different infant feeding patterns from each other (Fouts 2004). While this conforms to the stereotype, there is no difference in birth rates between the two Bofi groups, in contrast to expected trends (Fouts 2004). This is a cautionary note, consolidated by Schurr and Powell (2005) who state there can be variability within societies with the same subsistence economy and similarities between societies with different economies. Other ethnographic examples draw similar conclusions. The Agta hunter-gatherer women from the Philippines, have the same parity, age at menarche and age of first pregnancy as those who do not engage in hunter-gathering activities (Goodman and Armelagos 1985b). One factor known to have a major influence on parity is energy expenditure. Women with high energy expenditures, such as those hunting and gathering, may have a low parity, unrelated to infant feeding or mortality. An insufficient calorie intake combined with a high level of physical activity can cause hypothalamic dysfunction and disturbance of the GnRH pulsatility, resulting in the disruption of the menstrual cycle and infertility (Warren and Perlroth 2001, Loucks 2003). This is suggested as a reason for the low parity rate amongst the hunting and gathering !Kung people from the Kalahari (Bentley 1985).

Although it may not be possible to untangle the web of factors which causes changes in a population, understanding childhood feeding and health provide a piece of the puzzle. Gaining knowledge of infant feeding allows the information to be included in population simulation models.

1.6 Aims

The general aims of the thesis are summarized as follows:

Aim 1. To gain information about early life histories, specifically relating to diet and health, in the absence of documentation or archaeological evidence.

Aim 2. To utilize and develop a methodology which allows early life histories to be studied in populations with few children's remains or textual resources.

Aim 3. To study childhood experiences at St Saviour's Almshouse and Zvejnieki cemetery, answering the hypotheses proposed about each site.

Aim 4. To consider the relationship between diet and health at St Saviour's, particularly the connection of health to the period when a child is weaned.

Aim 5. To gain information which can be used to consider broader issues about childhood and societies as a whole, such as trends relating to the economy of a population.

In the following chapters, the background to the techniques and methodologies are discussed and evaluated. The thesis is then split into two parts, the first gives the background and the results from the St Saviour's almshouse site and the second the background and results for Zvejnieki. The two parts of the thesis are brought together in the conclusion, where general trends and economic variability is analysed.

Chapter 2 Exploring Early Life Histories

The gaps in the archaeological record and interpretive problems associated with identifying childhood and infancy through other means, has created a need for bioarchaeological methods providing information about early life histories. Stable isotope analysis is the favoured approach to infer diet, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ being the most commonly used isotopes for this purpose. This chapter reviews the stable isotope methods used to explore early life histories. It provides a background on how stable isotopes are used to understand diet and reviews literature on studies which have aimed to answer questions about early life histories. The use of teeth to understand diet and health is introduced, tooth structure is described and their sampling methods are discussed and evaluated. Problems commonly encountered when using stable isotope methodologies are reviewed, which illustrates why the incremental dentine sampling technique is undertaken. Finally, the meaning and use of linear enamel hypoplasia to understand health is considered and some of the techniques used to record incidences of stress are discussed.

2.1 Using Stable Isotopes to Investigate Past Diets

2.1.1 Carbon and Nitrogen Isotopes

$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ isotope methodologies are based on the principle that the food consumed is digested and incorporated into the tissues of the body. The chemical composition of the tissues therefore reflects the isotopic composition of the diet. This can be summarized using the widely quoted phrase 'you are what you eat'. Carbon and nitrogen have two stable isotopes, $^{12}\text{C}/^{13}\text{C}$ and $^{14}\text{N}/^{15}\text{N}$. The ratios of these isotopes in a tissue, such as collagen, can be measured using a mass spectrometer. This provides a value relative to a standard. In the case of carbon this is VPDB (Vienna Pee Dee Belemnite) (Craig 1957), with nitrogen this is AIR (Ambient Inhalable Reservoir) (Mariotti 1983). The values are expressed using the delta notation (δ), which indicates the difference between the sample and the standard. The values are measured in parts per mil (‰).

The values obtained are of value because they have been shown to reflect the diet of an individual (Van der Merwe 1982).

Nitrogen in the tissues of the body is derived from dietary protein. In the body, the ^{15}N is preferentially selected over the ^{14}N isotope during a process called fractionation. Molecules with the ^{14}N isotope are more easily broken down compared to those with the ^{15}N isotope, the result is that they are more readily excreted from the body in urine (Steele and Daniel 1978). The ^{15}N on the other hand is more likely to be incorporated into the tissues of the body during protein synthesis. While nitrogen is only obtained from dietary protein, carbon can be obtained from three major sources in the diet- protein, lipids and carbohydrates. Lipids are depleted in ^{13}C , while proteins are enriched in ^{13}C relative to carbohydrates. This means it is important to understand what part of the diet is most influential in the tissue's isotopic composition (Krueger and Sullivan 1984). There are two different models on what the $\delta^{13}\text{C}$ reflects, the first being that ^{13}C is 'routed', meaning ^{13}C from specific parts of the diet are preferentially used in tissue synthesis. The alternative is that ^{13}C may be derived from all parts of the diet, sometimes referred to as 'scrambling' (Lee-Thorp *et al.* 1989, Schwarcz 1991, Ambrose and Norr 1993, Krueger and Sullivan 1984). It is now widely accepted that carbon from amino acids and proteins is routed into the body's tissues, but there is still speculation about the proportion of carbon which is routed, with various estimates being proposed. Jim *et al.* (2006) predict 51.3% of carbon in collagen is routed from protein, while Fernandes *et al.* (2012) produced a model which showed 75% of the carbon in collagen was routed from proteins, the remaining coming from carbohydrates and lipids.

The use of $\delta^{15}\text{N}$ in dietary reconstruction was established by Deniro and Epstein (1981), who realised that ^{15}N is passed from plants on to consumers. It was shown that ^{15}N became enriched at each level of a food web by around 3-6‰. This predictable step-wise enrichment means the isotopes in an organism indicate the mean trophic level at which it feeds (Minagawa and Wada 1984, Schoeninger and DeNiro 1984). $\delta^{13}\text{C}$ is sometimes associated with a trophic level effect, as

there is some evidence that there may be small elevations when comparing organisms moving up the food chain. It is, however, minor compared to the elevation in $\delta^{15}\text{N}$ (DeNiro and Epstein 1978, McConnaughey and McRoy 1979, Tieszen *et al.* 1983). Schoeninger (1985) found that herbivorous animals from Kenya were lower in $\delta^{13}\text{C}$ by 1.2‰ compared to carnivores, although it is concluded that many of the values from organisms with different diets overlap.

Ecosystems with large numbers of trophic levels, such as marine and aquatic ecosystems, can be identified because they have more elevated $\delta^{15}\text{N}$ values than those with only a small number of trophic levels. This allows the identification of organisms with a large marine product component in their diets (Schoeninger *et al.* 1983). $\delta^{13}\text{C}$ is elevated in marine ecosystems, but is highly variable in freshwater systems, often being depleted relative to C3 terrestrial systems but sometimes as elevated as marine ecosystems (Schoeninger and DeNiro 1984, Katzenberg and Weber 1999, Tauber 1981). Chisholm *et al.* (1982) found there was a 7.9‰ difference in the $\delta^{13}\text{C}$ between the flesh of marine and terrestrial animals. This observation has allowed questions about the relative influence of marine and terrestrial subsistence to be addressed. For example, in a study of Mesolithic and Neolithic Denmark, Tauber (1981) used $\delta^{13}\text{C}$ to show that Mesolithic man was subsisting on a marine based diet, while during the Neolithic, terrestrial products were more frequently consumed. In a similar study, Hayden *et al.* (1987) used $\delta^{13}\text{C}$ to establish Upper Palaeolithic diets were not based on exploiting fish.

While in some countries, $\delta^{13}\text{C}$ is almost exclusively used to detect marine influences on the diet, in large parts of the world, $\delta^{13}\text{C}$ is used to track the intake of C3 or C4 plants. These are plants which can be distinguished by their photosynthetic pathways. This physiological difference means the C4 plants are enriched in ^{13}C compared to C3 plants (Van der Merwe and Vogel 1978, Smith and Epstein 1971). This enrichment can be passed along a food chain. In one of the earliest studies looking at the relative consumption of C4 and C3 foods in the diet, Vogel and Van der Merwe (1977) tracked the change from pre-horticultural practices to maize consumption by comparing

sites of different ages in New York State (maize is distinguishable because it is a C4 plant). Using the same technique, the transition has also been tracked in other parts of the USA and Canada (Schwarcz *et al.* 1985, Katzenberg *et al.* 1995, Katzenberg 2006, Boutton *et al.* 1984, Bender *et al.* 1981). Numerous other studies have followed suit, identifying the proportion of C4 and C3 plants in the diet from all over the world (Burleigh and Brothwell 1978, Cerling *et al.* 1997, Ericson *et al.* 1989). The ability to track C4 versus C3 foods in the diet allows environmental reconstructions, climate and temperature to be evaluated, including the movement of people, because of the conditions favoured by C4 and C3 plants (Teeri and Stowe 1976, Tieszen *et al.* 1979, Van der Merwe 1989).

The isotopes from an organism have to be compared to producers and consumers within their own food chain to draw conclusions about the trophic level occupied by the organism. This is because the baseline isotopic values can differ between ecosystems. Manipulation of the environment through human practices such as the manuring of crops can enrich the ^{15}N in producers and elevate the $\delta^{15}\text{N}$ throughout the food chain (Bogaard *et al.* 2007). Environmental factors unrelated to human activity may similarly affect the $\delta^{15}\text{N}$. Heaton *et al.* (1986) showed that variability in $\delta^{15}\text{N}$ in southern Africa was caused by differences in climate, with $\delta^{15}\text{N}$ more elevated in arid environments. A number of other studies have also demonstrated this effect (Sealy *et al.* 1987, Ambrose 1991, Schwarcz 1991).

A variety of factors unrelated to trophic level, may influence $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values within a food chain and an individual's tissues. One of these is disease and malnutrition, which can elevate $\delta^{15}\text{N}$ in an animal. If protein is limited, the body will reuse protein from the body's tissues, creating a trophic level effect. White and Armelagos (1997) found $\delta^{15}\text{N}$ in Nubian mummies who had osteopenia had more elevated values than healthier individuals. In a study of modern individuals with a known medical record, Katzenberg and Lovell (1999) concluded wasting diseases cause

elevated $\delta^{15}\text{N}$. A variety of other studies, looking at different species, have since reached the same conclusion (Voigt and Matt 2004, Cherel *et al.* 2005, Fuller *et al.* 2005).

2.1.2 Carbon and Oxygen Isotopes in Enamel Carbonate

The principle focus of this thesis is on dietary reconstruction using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopes in collagen, but $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotopes in bone mineral and enamel are important tools in early life history studies. The isotopes in collagen represent to a large degree the protein component of the diet, while the mineral component of bone and teeth can provide information about the rest of the diet. The $\delta^{13}\text{C}$ in carbonates is not biased towards the dietary protein, reflecting instead the whole of the diet (Ambrose and Norr 1993, Tieszen and Fagre 1993, Jim *et al.* 2004). $\delta^{13}\text{C}$ analysis of dental enamel can therefore provide information about foods consumed, based on the principles outlined above.

There are three stable isotopes of oxygen, ^{16}O , ^{17}O and ^{18}O the ratios of which are measured on a mass spectrometer relative to the VPDB standard. $\delta^{18}\text{O}$ in bone and enamel apatite reflects the origin of the water consumed and to a lesser degree the foods which are consumed. Water in the body is enriched in ^{18}O relative to the water consumed because of preferential expiration of the ^{16}O isotope. $\delta^{18}\text{O}$ has been used for seasonal reconstruction. Koch *et al.* (1989) were able to track seasonality in the tusks of late Pleistocene mammoth and mastodons because precipitation in the winter has lower $\delta^{18}\text{O}$ values. Using the same principles, paleoenvironmental and climatic reconstruction has been possible, along with human movement (Ayliffe and Chivas 1990, Zanazzi *et al.* 2015, Bryant *et al.* 1994, Fricke *et al.* 1998, Evans *et al.* 2006). $\delta^{18}\text{O}$ has also been used in the reconstruction of early life histories, based on the principle that breast milk is enriched in the ^{18}O isotope. Breast milk consumed by an infant will therefore result in bone mineral enriched in ^{18}O (Wright and Schwarcz 1998, Roberts *et al.* 1988).

2.2 Constructing Early Life Histories using Nitrogen and Carbon

Isotopes

Since the discovery that stable isotopes can reveal dietary information, the technique has been regularly applied to human and animal remains from a range of populations. The application of the method to the study of early life histories was first realised in 1989, when it was discovered that $\delta^{15}\text{N}$ can be used to track the introduction and withdrawal of breast milk in the same way that it can track the trophic level of an organism (Fogel *et al.* 1989). When a child feeds from its mother it effectively becomes a trophic level higher than her because it is consuming human derived protein. Fogel *et al.* (1989) used modern fingernail samples from infant and mother pairs to observe this, showing that infants had elevated $\delta^{15}\text{N}$ values compared to their mothers after being breastfed for several months. Having established the relationship using modern nail samples, the authors used bone collagen from pre-horticultural and post-horticultural Native American skeletal assemblages to see if a similar breastfeeding related trophic level effect could be observed. This established that the bone collagen, like the fingernail samples, also showed an elevated $\delta^{15}\text{N}$ value of between 2.5-4‰ compared to the adult values. In this case, no trophic level effect was seen in the $\delta^{13}\text{C}$.

Following the initial recognition that a breastfeeding and weaning signal could be distinguished in a living population, a number of archaeological studies began to be published. Katzenberg *et al.* (1993) made an isotopic study of the 16th century site of MacPherson from Southern Ontario. They analysed the bone collagen of different aged individuals, which included 10 individuals under the age of 3 years. This study did not seek to age the breastfeeding and weaning life events, but did show there were differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ depending on the age of the individuals.

Larger studies with more specific questions have subsequently been undertaken, many of which compare the isotopes of different aged individuals. Schurr (1998) published a weaning study

based on Angel site, in the Lower Ohio Valley, dating to 1300-1450. The age of the individuals was based on dental development, the length of the limb bone diaphysis and epiphyseal fusion of the bones. A comparison of the $\delta^{15}\text{N}$ of these individuals, from a range of ages, revealed breastfeeding declined around the age of 2 years. Herring *et al.* (1998) made a similar study with a larger sample of 60 individuals, focusing solely on the remains of children up to 3 years of age. This aimed to identify the age of breastfeeding and weaning. These results, combined with information from historical resources, suggested the children from St. Thomas' Anglican Church, Ontario, were breastfed for an extended period of time of up until 14 months, although there was variability within the population. Many other studies considering a variety of populations have since been published which are based on the same principles. e.g. Jay *et al.* (2008), Pearson *et al.* (2010), Clayton *et al.* (2006), Nitsch *et al.* (2011), Turner *et al.* (2007) and Haydock *et al.* (2013).

Using the same theory but with a variation on the methodology, Waters-Rist *et al.* (2011) used $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ stable isotope analysis to look at variation between the metaphysis and diaphysis of long bones in sub-adults. The diaphysis (the main shaft of the bone) forms earlier in life and slowly grows and remodels. The metaphysis (the bone which forms between the shaft and the ends of the bone) forms later, the result is that the collagen sampled from here is a reflection of the diet before death. A comparison of these two parts of the bone was used to identify feeding trends in the Early and Late Neolithic of Baikal, Siberia. It also allowed a comparison across the Neolithic to be made, providing an insight into continuity and change throughout the era.

The use of $\delta^{13}\text{C}$ to track trophic level in early life history studies appears to be variable. Some authors note a trophic level effect in $\delta^{13}\text{C}$ of approximately 1‰ due to breastfeeding (Dupras and Tocheri 2007) and there is some evidence that $\delta^{13}\text{C}$ is more sensitive than $\delta^{15}\text{N}$ at detecting the introduction of non-breast milk foods, particularly when C4 foods are introduced (Richards *et al.* 2002, Fuller *et al.* 2006a). The use of $\delta^{13}\text{C}$ to track weaning foods is particularly applicable to

populations where C4 plants such as maize and millet were consumed, as these can be made into weaning foods such as porridge (Wright and Schwarcz 1998). In contrast, other studies have found that $\delta^{13}\text{C}$ did not affect the breast milk component of the diet (Fogel *et al.* 1989, Waters-Rist *et al.* 2011).

2.2.1 The Challenges with Traditional Bone Collagen Methods

The standard method used to assess childhood and infant feeding practices using $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in a population requires bone from known age individuals, or skeletons which can be readily aged. Ideally, these individuals would be from different age categories, to allow a full projection of diet throughout childhood. A spectrum of infants, toddlers, young children and older children would be ideal, as $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values from the bone collagen of each individual represents the diet of an age category. This requirement makes the technique more applicable to studies of cemeteries which represent the full demography of a population. Where a wide choice of aged individuals is available for bone collagen studies, the method relies on accurately aging individuals using either historical documentation or osteological criteria. The osteological criteria used for aging skeletons, such as tooth eruption and long bone measurements, can be biased by health and environmental conditions, which can retard growth and development. Schurr (1998) reported the precision of the age ranges in his paper using the criteria detailed above. The precision is reported as ± 4 months at 1 year old and ± 16 months at 5 years old, which creates reasonably wide age ranges, particularly after infancy.

Using bone collagen to study past diet has interpretive problems, as it is not a static material. Bone is gradually remodelled throughout life, referred to as the 'turnover' of the bone. The remodelling means the composition of the bone analysed is representative of a long expanse of time, rather than a short period before death. This is important to understand when analysing past diets, because it can create an averaging effect. For example the bone of an individual who

died as a young adult will have an isotopic content derived from a mixture of the adolescent and adult diet. As a result, sudden changes in diet are difficult to identify (Tieszen *et al.* 1983).

Different tissues and different bones have different rates of turnover depending on how metabolically active they are (Parfitt 2002, Tieszen *et al.* 1983). Collagen has a relatively slow turnover rate and long half-life. This is supported by Libby *et al.* (1964) who looked at the uptake of ^{14}C in human tissue following the release of ^{14}C into the atmosphere during nuclear testing in the 1960s. They drew the conclusion that virtually no ^{14}C had been incorporated into collagen during a 10 year period after the ^{14}C had been released. Hedges *et al.* (2007) made a large scale study of collagen turnover in femoral bone using the same technique. The results suggested the turnover in the femur was over 10 years and that the rate of turnover varied by age. Turnover during the adolescent years was higher than during adulthood, at a rate of 10-30% per year during the years 10-15. This evidence is substantiated by several other studies which also show a difference in turnover dependent on age (Ubelaker *et al.* 2006, Geyh 2001). Studies of non-human subjects have reached similar conclusions (Thompson and Ballou 1956).

Referring tissue turnover specifically to early life history studies, Fogel *et al.* (1989) showed that new-born infants had the same isotope values as adults, although several studies have since recognised an offset in $\delta^{15}\text{N}$ between mothers and infants (de Luca *et al.* 2012, Beaumont *et al.* 2015, Fuller *et al.* 2006a). Other studies of infant remains have indicated that changes in diet are reflected in the bone within a few months. Herring *et al.* (1998) showed that children as young as 3 months had elevated $\delta^{15}\text{N}$ caused by breastfeeding, while Nitsch *et al.* (2011) showed that a known aged infant of approximately 5 weeks from the Spitalfields assemblage had an elevated $\delta^{15}\text{N}$ value of 16‰.

2.3 Using teeth to Investigate Past Diets and Early Life Histories

Some of the problems associated with the standard bone collagen methodology are minimized by sampling teeth. The techniques which have been developed are discussed in the sections below.

The structure of teeth, in particular the formation of the enamel and dentine are first described, providing the background to the methods.

2.3.1 Tooth Structure

The outer crown of a tooth is composed of enamel, which protects the tooth and provides a durable biting surface for mastication. The dentine develops under the enamel crown, forming the rest of the tooth cap and the roots. Within the dentine is the pulp cavity, where the nerves and blood supply are found (Figure 1).

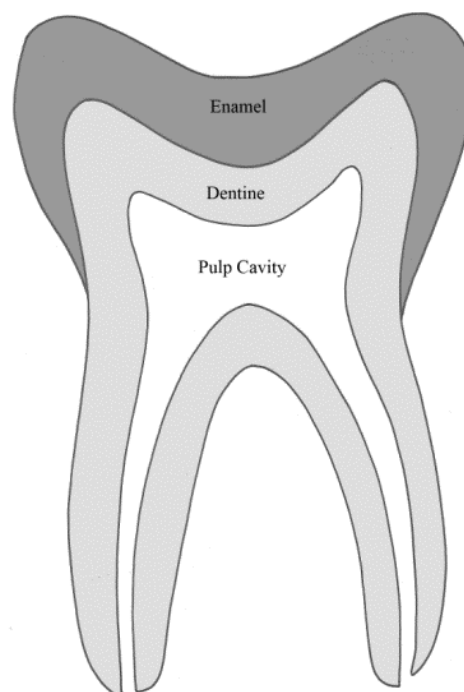


Figure 1. The basic structure of a first molar (M1), showing the position of the enamel, dentine and pulp cavity.

Author's own image, 2014, based on an image from Avery (1976).

2.3.1.1 Enamel

Enamel is formed in a two stage process by enamel creating cells called ameloblasts. The two stages are known as secretion and maturation (Reith and Butcher 1967). During the secretory phase, the matrix is laid down, which is formed of both organic (1/3) and mineral (1/3) components. Crystallites of apatite are laid down within this matrix, which extend throughout. In

the second phase, called maturation, the organic component is removed by the ameloblasts and the crystallites expand, resulting in enamel almost devoid of organic matter. These crystallites are organised into bundles called prisms. Mature enamel is almost entirely mineral and is composed of calcium phosphate minerals which form the structural lattice giving the enamel its strength. Within this lattice are various ions, including incorporated fluorine and carbonate (Boyde 1989, Williams and Elliot 1979).

The formation of the enamel is a complex process. The enamel finishes forming during the maturation stage, but the whole creation process lasts over an extended period of time. Ameloblasts start creating enamel at the tip of the crown, ending at the cervix. The enamel closest to the pulp cavity mineralizes early during the secretory stage, while the enamel closest to the surface mineralizes at the end of the mineralization stage. The waves of mineralization occur in different directions throughout the enamel and mineralize different parts of the enamel to different degrees, resulting in some parts of the enamel being more heavily mineralized than others. At the end of the process the outer layer of enamel is the most heavily mineralized (Suga 1982, Suga 1989).

Developmental structures are present throughout the enamel, which can be viewed under a microscope. Cross striations, which appear as alternate light and dark bands, can be seen on the enamel prisms. These are rhythmic patterns, perhaps caused by variation in enamel production or mineralization (Boyde 1989). Each of these bright and dark bands is representative of a 24 hour period. The other major structural features of the enamel are the striae of Retzius (Retzius 1837), which represent a longer period of development, between 6 to 11 days. Each stria has the same number of cross striations between them, although the number that this is varies by person. It can range from 6-11, but most humans have 7-10 cross striations. This variability occurs between people, but not within an individual (Kawasaki *et al.* 1980, Dean *et al.* 1993). These incremental

features represent the formation of the enamel front and the stages of enamel formation. The striae of Retzius can be seen on the surface of the enamel as troughs, called perikymata.

2.3.1.2 Dentine

Dentine is created by cells called odontoblasts, which lay down collagen as networks of fine fibres, irregularly orientated, in the first stage of dentine development (Takuma 1967). This is the pre-dentine matrix, on which crystallites are seeded. This matrix is first laid down in the crown of the tooth, sometimes called the mantle dentine, after which the matrix is laid down throughout the rest of the tooth (Symons 1967). Unlike the creation of enamel, the organic protein component is not removed in any stage of its formation. After the spherical shaped crystallites have been seeded into the matrix, the crystallites grow out in all directions, in a process called mineralization. This occurs first in the mantle dentine below the cusps of the tooth (Frank and Nalbandian 1989a). The dentine builds up in the tooth in conical stacked layers. In the mature dentine, the organic component is almost entirely collagen and makes up approximately 18% of the dentine (Schmidt and Keil 1971). The rest of the composition is mostly inorganic apatite and water. For an in-depth discussion on dentine formation, refer to Frank and Nalbandian (1989a) and Symons (1967).

Incremental lines are present within the dentine, in a similar way to those found in the enamel. These are called Andresen and von Ebner lines (von Ebner 1902, Andresen 1898), which are thought to be created by variation in the organic composition of the dentine (Dean and Scandrett 1995). Their periodicity corresponds to the cross striations and striae of Retzius found in the enamel, suggesting they are caused by the same phenomenon. The incremental features in the enamel are often easier to view microscopically, as they are patchy in the dentine (Figure 2).

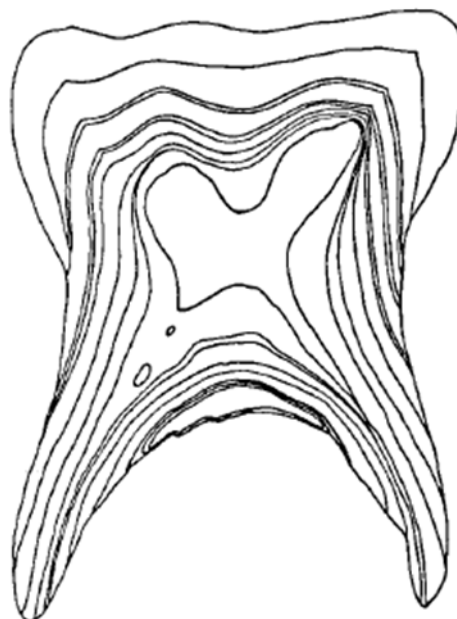


Figure 2. Diagram showing the incremental features on a molar randomly labelled with tetracycline. Not to scale.

(Dean 1985).

Unlike the enamel, the dentine is a living tissue because the odontoblasts do not die after the tooth is created. Dentine is not remodelled like bone, but extra deposits can be laid down throughout the life of an individual. There are three kinds of dentine- primary, secondary and tertiary (Kuttler 1959). Primary dentine, which forms the main bulk of dentine, is laid down during the initial formation process. This is the dentine which is described in the formation process above. Secondary dentine is laid down throughout life around the pulp cavity and root canal, while tertiary dentine is laid down where damage to the tooth occurs. When a tooth experiences attrition or caries, the tubules where the odontoblasts live become exposed and dentine is deposited over the ends of the tubules (Frank and Nalbandian 1989b).

2.3.2 Enamel and Dentine Sampling Strategies

The chemical composition of teeth can be analysed between the teeth of different individuals, between different teeth within the same individual or by a comparison of different regions within a single tooth. These methods have different resolutions and temporal variability. Dentine is less frequently studied, but is fast becoming an important tool in understanding early life histories.

2.3.2.1 Comparisons between teeth

Each tooth develops at a different time, spanning the whole childhood up until adolescence, when the third molar is completed. By isotopically analysing each tooth as a bulk sample, dietary changes occurring during each tooth's formation can be tracked. Wright and Schwarcz (1998) compared the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ in bulk enamel samples between teeth, taken from the cusp to the cemento-enamel junction. Breast milk produced by a woman is enriched in the ^{18}O isotope, which if consumed by an infant should also make their bone mineral enriched in the ^{18}O isotope. The authors found the enamel from the older teeth were more elevated in $\delta^{13}\text{C}$ and lower in $\delta^{18}\text{O}$. They used this to suggest solid foods were being introduced by two years of age, but that breast milk was still being consumed until later. In a study using rib collagen combined with bulk tooth dentine of deciduous second molars, permanent canines and third molars, Richards *et al.* (2002) also identified a breastfeeding signal in individuals from the Medieval Wharram Percy site, a study which would be built on using the more refined incremental sampling described below. Using both dentine and enamel, Dupras and Tocheri (2007) compared the isotopic composition of the dentine and enamel from permanent and deciduous teeth taken from the site of Kellis 2, Dakhleh Oasis in Egypt. Samples were taken in bulk and a comparison between the teeth which formed prior to birth and those which formed after birth showed there was a significant difference in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$. Based on this, it was interpreted that weaning took place by 3 years.

Using a similar technique, but without sampling the whole tooth as a bulk sample, Howcroft *et al.* (2012) took a slice from different deciduous and permanent teeth to track dietary changes in two groups from the island of Öland, Sweden, revealing large inter-population variation in infant feeding practices. Howcroft *et al.* (2014) also used the same technique on a Middle Neolithic Pitted Ware culture from Ajvide on the island of Gotland, showing they were breastfed into the 3rd or 4th year of life.

The bulk sampling method and subsequent comparison between teeth, allows general shifts in diet to be identified, but the wide age range over which each tooth develops makes it difficult to identify when the changes occurred. The time-averaging is so great, that intra-tooth sampling is becoming increasingly important to gain temporal information.

2.3.2.2 Intra-tooth Sampling

Isotopic changes in both enamel and dentine can be studied within a single tooth by taking periodic samples throughout the tissue, sometimes referred to as intra-tooth samples. This works on the principle that the samples represent different time periods during the formation of either the dentine or the enamel. Intra-tooth enamel studies have been more commonly adopted than the equivalent dentine technique. Sharp and Cerling (1998) used incremental enamel sampling on horse teeth to observe changes in meteoric water variation and feeding patterns, while Hoppe *et al.* (1999) sampled enamel throughout the molar of a mastodon to look at migration patterns in the Late Pleistocene. Wiedemann *et al.* (1999) took up to 13 samples per tooth down the crown of Neolithic bovids and equids from Ain Ghazal in Jordan to demonstrate its use for seasonal and climatic studies, while more recently Balasse (2002) looked at isotopic changes in incremental samples of enamel from steers fed on a controlled diet.

Incremental sampling of dentine in comparison has been less widely used to date, but overcomes some major problems associated with sampling enamel. As stated previously, enamel is not formed in a one-step process, which creates a time lag between the secretion and maturation phase. This problem is compounded by the mineralization process, which takes place across several fronts, at different speeds, and to different degrees throughout the enamel (Suga 1989). This creates a complex picture of enamel formation, which potentially blurs the isotopic resolution and makes establishing the timing of dietary transitions more difficult. Balasse (2002) looked at how a change in diet was reflected in the isotopic composition of the enamel of steers. The study found there was a 6-7 month lag in the completion of the enamel. Although it is unclear

how this relates to other species it demonstrates the complex formation process which is also a feature of human enamel formation. Dentine is not associated with these problems, making it an important resource.

The earliest studies using increments of dentine focused on animal teeth to explore and develop the technique. Hobson and Sease (1998) used the dentine of teeth from sea lions to look at changes in the trophic position, while Drucker *et al.* (2001) also looked at seasonal and physiological change in caribou by taking two segments from the root tips. In an experimental study of cattle, Balasse *et al.* (2001) took samples throughout the dentine to identify a change in diet between C3 and C4 foods in a population with a controlled diet. Taking many serial sections of dentine, Kirsanow *et al.* (2008) increased the resolution of the technique and looked at seasonal variation in modern ovicaprids from Mongolia.

The first human early life histories which used the incremental dentine methodology were attempted on individuals from the 10th-16th century site of Wharram Percy, Yorkshire. Deciduous second molars, permanent third molars and canines were sampled throughout each tooth by cutting them into 3 or 4 sections from the crown to the root. These represented different age brackets throughout a person's life. The technique picked up breastfeeding and weaning signals (Fuller *et al.* 2003). The success of the technique and its ability to overcome some of the problems associated with sampling collagen from bone were thus proven. In this study no attempt was made to age the dentine sections by Fuller *et al.* (2003), meaning the timings of the dietary transitions were not addressed.

To increase the resolution, Eerkens *et al.* (2011) took the technique a stage further, sectioning the teeth from six individuals into between 5 and 10 segments. These were individuals from the Marsh Creek site, California, dating to 4300-3100 BP. A difference in childhood diet was subsequently found between males and females (Eerkens and Bartelink 2013). Beaumont *et al.* (2012b) similarly developed the methodology, taking multiple samples of dentine down first and

second molars from 8 individuals. The teeth were selected from remains recovered at the Catholic Lukin Street cemetery in London. While developing the method, the study also sought to identify Irish survivors of the 19th century famine. Recently, Sandberg *et al.* (2014) used the same technique on five Medieval teeth from Kulubnarti, Nubia, which revealed weaning took place between 2-5 years. The method used in this thesis is a modified version of these techniques.

The incremental dentine method has a variety of advantages in assessing early life histories, combating a number of problems which are a feature of the other methods described. Most importantly, the technique allows childhood histories to be established in populations where no children's remains are available. The methodology's ability to assess childhood diet using adult teeth means individuals who survived into adulthood can be studied, bypassing a problem which is present in most weaning studies. This means the data are more representative of the population and atypical feeding patterns, affecting the survival of a person, are less likely to be included in the sample. Children who died young may have suffered from health conditions, such as malnutrition, which would have affected the isotopic signal (Fuller *et al.* 2005).

The methodology benefits from a multiple sample strategy, producing high resolution data which can track diet throughout an individual's early life. This allows potential changes in diet throughout the infancy and childhood of one individual to be identified, rather than using individuals who died at different ages to piece together the influence of age on diet. This makes it an important approach for understanding the early lives of past populations. A review of the incremental dentine methodology can be found in Humphrey (2014) and Tsutaya and Yoneda (2015). While it is a valuable and important methodology, there remain some factors which need to be considered.

Understanding what the strips of dentine are representing and ascribing an age bracket to them is the most serious consideration with any intra-tooth sampling technique. All intra-tooth methods assume the tooth develops from the crown to the root, which is roughly accurate, but does not

account for the complex structural development. Dentine does not form horizontally in strips, as shown by the developmental features- the Von Eber and Andresen lines (von Ebner 1902, Andresen 1898). If horizontal slices are taken down the tooth, the incremental features are roughly followed in the crown, although to obtain a large enough sample for analysis, each time slice represents a group of these features. In the root, these developmental features are deviated from more substantially, meaning the samples are more time averaged. There is potential for the Von Ebner lines to be traced and cut along, but attempts at this have so far failed because of the difficulty in viewing them after demineralisation and problems with attempting to cut accurately around them (Eerkens *et al.* 2011). Even if these incremental features can serve as a map, it is still not possible to analyse each incremental feature, as a mass spectrometer cannot analyse such small quantities of collagen.

Averaging incurred using this methodology has to be placed within the context of the current research and other available options. The incremental dentine method overcomes many of the disadvantages associated with analysing enamel. In addition, rather than one bulk sample being taken from each person's bone, which represents an average of the diet over a number of years leading up until the death of the person, the method produces data which correspond to a more specific range of ages during a person's life. Unlike bone, there is no 'turnover' effect in dentine as the majority of it is not remodelled throughout life, meaning there is no averaging of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ and discrete periods of time are more easily represented. Although remodelling does not occur, secondary and tertiary deposits of dentine can be created throughout life (Kuttler 1959). Screening for teeth likely to have tertiary dentine deposits is relatively straightforward, as teeth with caries or obvious trauma were removed from the samples selected. Factoring in the secondary deposits is more difficult, but selecting younger individuals makes the influence of secondary dentine deposition minimal. The St Saviour's and Zvejnieki samples are mainly biased towards young adult individuals, making the influence of tertiary dentine deposition minimal.

2.4 Stress and Enamel Hypoplasia

Enamel hypoplasia is a term used to describe deficiencies, or the total absence, of enamel on a region of the tooth. During the initial secretory stage of enamel formation the ameloblasts are unable to lay down the protein matrix during a period of ill health or biological stress, which causes an absence of enamel (Sarnat and Schour 1941, Massler *et al.* 1941, Kreshover 1940). After the creation of the enamel, the ameloblasts die which prevents any remodelling of the enamel taking place, thus the defects remain throughout the life of an individual. The position of the hypoplasia can be linked to the age of an individual because the enamel forms from the cusps to the cervix (Hutchinson 1857, Black 1906). The majority of hypoplasia incidences observed are caused by metabolic disturbances, but hereditary hypoplasia and localized trauma are also known to cause defects (Weinmann *et al.* 1945, Aldred *et al.* 2003, Suckling 1980). These are both rare in comparison to the effects of stress and ill health.

Enamel hypoplasia exists in a number of forms, the most commonly studied is linear enamel hypoplasia because of its prevalence and ease with which it can be related to age of occurrence. The reason for the existence of different types of hypoplasia is unclear, but it is thought to be related to the length of time or magnitude of the episode of stress. The various types of defect are commonly categorized using the *Index of Developmental Defects in Enamel*, although other variations of this exist (Commission on Oral Health Research and Epidemiology 1982). In extremely rare cases, hypoplasia can be characteristic of a specific disease, syphilis is one of these diseases (Hutchinson 1857).

Enamel hypoplasia can add to our understanding of past health and infant/childhood experiences, making it an important contribution to early life history studies. Many diseases and episodes of stress are not recorded in the pathology of the skeleton and the predominance of adult remains in most cemeteries makes assessing the health of a population during childhood more difficult. Episodes of childhood stress seen in bone, such as Harris lines, will not be present

during adulthood because bone remodels throughout life (Marshall 1968, Garn and Schwager 1967). Exceptions, such as polio, which can deform the bone, can be identified on adult skeletons, but these do not reflect the full range of illnesses which occurred (Brehm *et al.* 2007). Hypoplasia studies have the advantage that health can be tracked event by event, through a person's life, up to the point when the third molar crown is complete. It is a simple, cheap, non-invasive analysis that can provide important results. As the diet is also tracked using the teeth in the studies made here, this provides an opportunity to match diet and health.

Enamel hypoplasia began to be studied as early as the 1700s, after the initial observation that defects occurred on enamel due to illness. The historical development of enamel hypoplasia research is not covered here, as it has been reported in great detail elsewhere (see Goodman and Rose (1990) for an appraisal). An overview of some of the applications of hypoplasia observations is however discussed, showing the breadth of questions which can be addressed. It has been linked to socio-economic and subsistence strategies, with differences in the incidences of hypoplasia between groups, related to these two factors. Many studies have linked agricultural emergence to increased hypoplasia incidence e.g. Goodman *et al.* (1984), Sciulli (1977), Temple (2010) and Rose *et al.* (1978). Rose *et al.* (1978) found an increase in enamel disturbances in prehistoric Native Americans from the Midwest was associated with the adoption of maize cultivation. Taking an alternative view, Starling and Stock (2007) found the emergence of agriculture was a stressful event in Egyptian and Nubian groups, but intensification lowered the incidence of hypoplasia. This is used as evidence to suggest poor health, caused by ecological or demographic pressures, caused a change in subsistence.

Other events or situations which are stressful or likely to cause ill health have been found to increase the incidence of hypoplasia. This may include slavery, social inequality, poverty or any circumstance which causes malnutrition (Malville 1997, Corruccini *et al.* 1982). Periods of contact or colonization, such as European contact with the Americas (Hutchinson and Larsen 1988),

colonial contact with Amerindians in the Brazilian Amazon (Santos and Coimbra 1999), or post-contact effects on Australian Aborigines (Littleton 2005) are examples of situations where hypoplasia frequency reflects major social change. Higher frequencies of hypoplasia have been connected with a lower life expectancy (Duray 1996). Particular life events, such as weaning, have also been linked to hypoplasia (see Chapter 6). Problems with using hypoplasia to assess stress are discussed in Chapter 3.

2.4.1 Limitations of Enamel Hypoplasia

Enamel hypoplasia remains an important tool in our understanding of early life histories, but problems in its use and interpretation have to be considered. These issues can be split between three main areas.

- 1) Many different methods are used to identify hypoplasia, with different outcomes and accuracies. Different methods are also used to estimate the timing of the hypoplasia.
- 2) There is a lack of standardization in the literature combined with underreporting of the methodologies used to obtain the data. This has made it difficult to compare results across populations.
- 3) Our understanding of what the hypoplasia defects are representing is a significant interpretive problem. Until the processes behind the formation of the enamel are understood it seems likely it will remain unexplained.

2.4.1.1 What does Linear Enamel Hypoplasia Represent?

It is not always clear what an incidence of hypoplasia is representing on a tooth and factors other than stress, such as trauma, genetic susceptibility and long term health conditions are possible causes of these defects, alongside specific short term health problems (von Arx 1993, Bäckman and Holmgren 1988). The method relies on whether a correlation can be identified between the timing of the dietary transition and the timing of hypoplasia. Essentially, 'noise' from other life

events and various other factors have to be eliminated. Although the non-specific nature of hypoplasia is a drawback in some ways, it does mean the general health of a person can be investigated. The fact that biological stress and ill health can cause hypoplasia is not contested and by using a large sample and identifying when, or if, a peak occurs, makes it still possible to consider whether particular life events are a cause of some incidences of hypoplasia.

Hypoplasia is not represented equally throughout the crown of a tooth, making the patterns of hypoplasia more difficult to interpret. This is due to the way the enamel forms and the differences in enamel thickness throughout the tooth crown. Rose (1977) reports the problems associated with the under representation of defects in certain parts of the tooth, with particular periods in the development of the enamel being more prone to disturbance than others. The author suggests this is perhaps due to stages of formation and maturation occurring over different time spans in different parts of the tooth and the possibility that ameloblasts, which form the enamel, in the thinner cervical area are more affected by factors causing hypoplasia. Enamel prism direction and length may also cause the greater representation of defects in the middle and cervical thirds of the crown (Goodman and Armelagos 1985b).

A variety of studies have shown different teeth have variable susceptibilities to hypoplasia, with anterior teeth generally showing a greater number of incidences (El-Najjar *et al.* 1978, Cutress and Suckling 1982). Central incisors and mandibular canines have a higher frequency than other teeth, while anterior teeth are more susceptible than posterior and maxillary teeth are more prone to disturbance than mandibular (Goodman and Armelagos 1985b). This could be caused by differences in the timing of mineralization (Yaeger 1976), or some teeth may be more susceptible because of differences in genetic control or stability in dental development timing (Goodman and Armelagos 1985a).

Lifestyle choices may cause similar interpretative problems concerning the underrepresentation of hypoplasia in some individuals, or in some teeth. In particular, attrition caused by the

consumption of hard or gritty foods mainly affects the cusps due to the action of mastication and can limit the visibility of hypoplasia in the cuspal area (Goodman and Armelagos 1985b). Alongside attrition, other factors can affect whether hypoplasia is seen on the teeth after its creation. Dental calculus, which is less common in the modern developed world due to tooth brushing, can protect the surface of the enamel. Calculus build up tends to occur amongst populations with particular diets and cultural practices (Lieverse 1999). The resultant hard coating of calculus around the teeth can have the effect of protecting the enamel, thus preserving the fine details of the enamel surface and subsequently the hypoplasia.

Calculating the incidence of hypoplasia in adult skeletons within a population can be difficult given that this underrepresents those affected who die young. A lower incidence of hypoplasia makes it appear that the surviving population is healthy, whereas in fact the mortality rate may be higher. For example, comparing the incidence of hypoplasia amongst pre and post-contact people in Peru, it was found that the incidence of hypoplasia decreased with the arrival of the Spanish. It would be expected that, due to their exposure to new diseases hypoplasia incidence would increase. The authors conclude this not an indication they were healthier, but an indication their mortality was higher (Klaus and Tam 2009). Given the known high mortality rate in childhood and infancy during the industrialization of London, it is highly likely hypoplasia is underrepresented in the population.

2.4.1.2 Identification of Hypoplasia

Comparisons of linear hypoplasia incidence between populations are hampered by a lack of standardization in the recording of the defects. In a study of results obtained using different identification methods, Hassett (2012) observed variable outcomes in the identification of hypoplasia, depending on the method used. As might be expected, the scale of observation was a major factor in the data obtained. Defects in cervical regions were more likely to be missed by macroscopic methods and unaided visual methods. Although the author concludes that more

detailed observations can be made with some more intricate methods, it is also conceded that these were more time consuming and they were not suitable for situations where whole populations are studied. While use of the same methodology should provide comparable results, there will be variation in the outcome, as observation of defects is subjective and based on personal opinion. Observational error, experience and differences in eye sight must be considered factors in the results obtained. However, standardization in the recording of hypoplasia is improving and can be defined by recognised standards such as the DDE index (Commission on Oral Health Research and Epidemiology 1982), making them more comparable to other sites.

2.5 Summary

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotopes in collagen can be used to investigate past diet, providing information on a variety of archaeological problems. This includes the identification of changes in agricultural practices such as maize cultivation, investigating the importance of marine foods in the diet and exploring the trophic level animals are feeding from. $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in enamel carbonate can also be used to make inferences about diet and additionally, the intake of water. Information about early life histories can be addressed using the same principles, which allows observations concerning breastfeeding, weaning and childhood diet to be made.

There are a variety of methods used to extract information about early life histories. The most common method uses bone collagen from different aged individuals. The $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values from the bone collagen of these individuals are compared between age groups to track changes in the diet. While important information about infant and childhood feeding patterns have been investigated this way, there remain a number of drawbacks with the technique. The method compares the diet of children who did not survive with adults who did survive. An assumption is made that non-surviving children had a similar diet to those who did survive childhood, which for a number of reasons is not necessarily the reality. There are also many circumstances where

there are no children's remains to study. The second major issue is the turnover of bone collagen, which means $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values reflect an average diet over a number of years. This makes sudden changes in diet difficult to observe.

An alternative to bone collagen is to use collagen from the dentine of teeth and enamel carbonate. Teeth form during infancy and childhood and permanent teeth are retained into adulthood, meaning childhood and infant diet can be studied in individuals who survived and in populations where there are no children's remains available. The sampling of teeth can be done between different teeth, because they develop at different ages, or within one tooth, sometimes called intra-tooth sampling. As teeth develop from the crown to the root, samples taken down the tooth represent different age brackets.

Teeth can be used to assess the health of an individual during childhood. Defects in the enamel, called enamel hypoplasia, can be created during the tooth formation process. These represent incidences of stress or ill health during childhood which are retained into adulthood. An assessment of enamel hypoplasia gives an indication of some early life experiences.

Chapter 3 Methods

Two methodologies were applied to capture temporal changes during the development of the teeth. The first was aimed at tracking changes in diet throughout the early life of each individual using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotopes in the dentine. Samples of dentine were taken incrementally from first molars and a limited number of second molars, which allowed changes in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to be tracked over a number of years of a person's life. All teeth from both case studies were subject to incremental dentine sampling, with the exception of third molars from the St Saviour's almshouse population. The second methodology tracked $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ changes in the enamel carbonate of a sub-sample of first, second and third molars from individuals from St Saviour's.

The final method explored the incidence of enamel hypoplasia on the surface of the enamel, with the aim of providing an indication of the level of stress experienced during infancy and childhood. All first molars from the St Saviour's population were subject to this analysis. The same teeth used for the incremental dentine analysis were also used to assess hypoplasia, allowing for a direct comparison of diet and infant health. The incidence of hypoplasia at Zvejnieki has been studied previously, using a much larger number of samples, so was excluded from this analysis.

3.1 Selection of Samples

Teeth were selected according to a number of criteria, specific to each population. Constraints in selection occurred due to differences in the availability of teeth and compromises had to be made to achieve a suitable sample size. This was affected by differences in the recovery of samples from the excavations, which samples permission could be granted for and issues such as caries rates and attrition. Preference was given to the acquisition of first molars because they develop between 0-8 years old, encompassing a large part of an individual's childhood and their infancy. This includes the period when breastfeeding and weaning would have taken place. Although they form during early life, they are permanent teeth and are retained into adulthood. The samples are therefore representative of those who survived, which makes them ideal teeth to study early

life histories. In the case of the St Saviour's Almshouse, a selection of second and third molars were also available which provided additional information about changes in diet after the age of 8 years, extending the childhood trajectory.

More specific details on how the samples were selected and information about the people the teeth belonged to is given in the background chapters, 4 and 7.

3.2 Method 1: Incremental Dentine Sampling

Before sampling, the teeth were inspected and dental calculus still attached to the teeth was removed with a probe and retained for future research. The teeth were cleaned using aluminium oxide air abrasive to remove adhering dirt, decrease contamination and allow closer inspection of the enamel surface for the presence of small carious lesions. Photographs were taken of each tooth and casts were made of the enamel. The enamel was then removed incrementally in strips (see Method 2). This saved it from destruction, decreased the demineralization time of the dentine, allowed a more even demineralization time across the tooth (the root is not covered by enamel) and a more accurate weight of the resultant collagen from the dentine to be obtained. The tooth was weighed after the enamel was removed to allow the percentage of collagen to be calculated, indicating the level of preservation. This percentage will always be slightly underestimated because of small amounts of remaining enamel on the tooth.

Each tooth, having been stripped of enamel, was mounted in herculite, a type of hard plaster. The herculite powder and water was mixed in approximately the ratio of 1:4. Each tooth was embedded in the herculite, immobilizing the tooth. This provided support during sectioning and decreased the chance of the tooth being damaged by the clamp. The embedded tooth was sectioned using a Buehler wafer diamond tip circular saw. The herculite was removed and one half of the tooth was conserved for future analysis. The remaining half tooth was weighed to allow the percentage of collagen to be calculated after demineralisation and placed in 0.5M HCl, in a refrigerator. The protocol followed the standard laboratory procedure at the Research

Laboratory for Archaeology and History of Art (RLAHA) (Honch 2008). The acid was changed every two days and the tooth remained submerged until it felt soft when probed with a pipette. The demineralization time was highly variable between samples, depending on the preservation. Large variation was seen within each population, as well as between populations.

The tooth halves, which retained their shape after demineralization, were cut into ten incremental samples from the crown to the root using a scalpel, similar to the methods of Eerkens *et al.* (2011) and Beaumont *et al.* (2012b). Five of these samples were evenly spaced throughout the crown, while the remaining five were evenly spaced from the cemento-enamel junction to the root tip. This meant the samples from the crown (encompassing approximately the years 0-3 in the first molars) are representative of a shorter period of time than those from the root (representing approximately the years 3-8 in the first molars) (Figure 4). This was done to achieve a higher level of resolution early on in life, when the most rapid dietary changes take place in the majority of societies. This is also the region where the resolution is greatest, as the incremental features are followed more closely. Age ranges were based on a developmental chart by Massler *et al.* (1941) (Figure 3). Variability in developmental charts exist because of different methods of data collection (Staaf *et al.* 1991). Massler's (1941) chart is one of the more widely accepted.

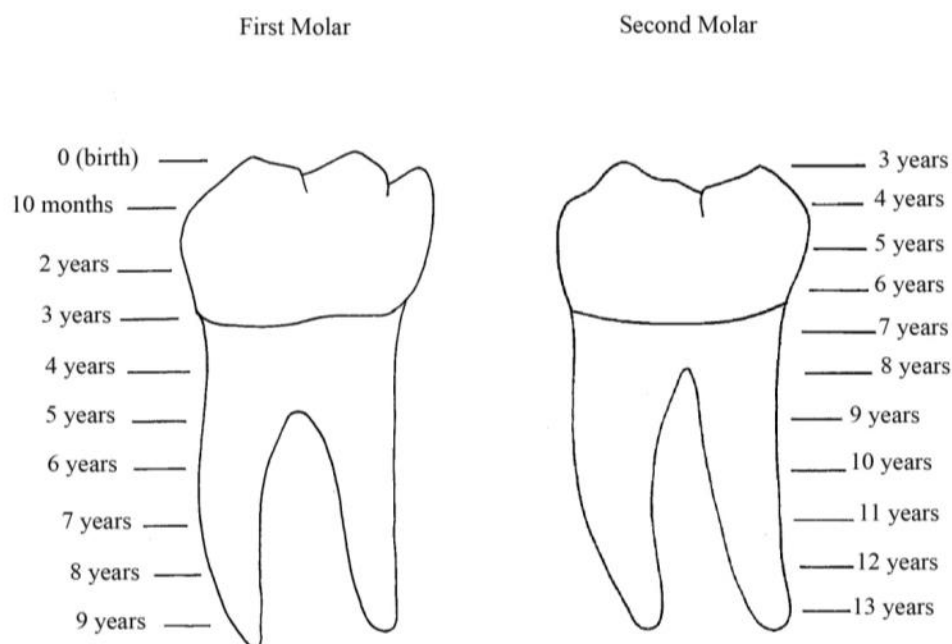


Figure 3. Approximate developmental ages of the first and second molar, redrawn from Massler *et al.* (1941).

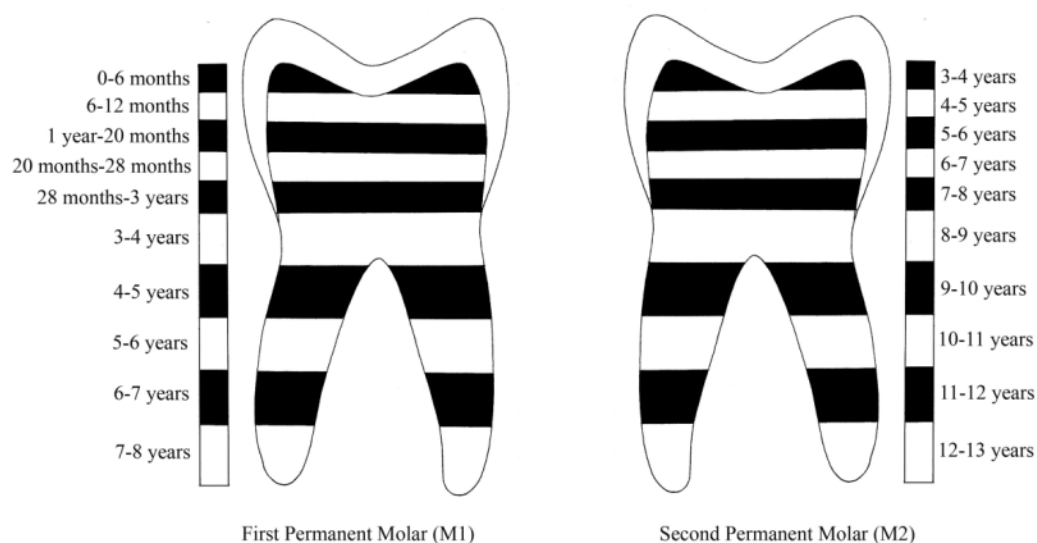


Figure 4. Representation of the incremental time slices taken down the tooth in the first and second molar. The approximate age range represented by each sample is given. From Henderson *et al.* (2014).

The position of the incremental samples is based on the topography of the teeth. For example, in the first molar the 0-6 month sample was removed from the cusps of the tooth, while the 28 month-3 year sample was positioned to line up with the cemento-enamel junction and the 3-4

year sample finished where the roots began. The demineralization of the half tooth prior to segmentation meant the increments could be easily cut and fracturing of the dentine, which can be brittle, was lessened. It also meant a full view of the dentine structure was observable before time slices were taken.

After segmentation, the resulting slices of dentine were rinsed three times in distilled water and placed in test tubes in pH3 water. These were placed on hot blocks at 70°C for two days. After removal, they were cooled, filtered, and frozen. They were then freeze dried and the resulting collagen was weighed into tin capsules.

Samples were run on a continuous flow mass spectrometer (Sercon 20-22) at the Research Laboratory for Archaeology and History of Art, Oxford University. Analytical reproducibility is $\pm 0.1\text{‰}$ and $\pm 0.2\text{‰}$ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ respectively, based on multiple replicates of the internal laboratory standard. The samples in the tin capsules were placed in runs alongside intermittently spaced, well characterised, reference samples of Alanine, IAEA6, USGS40 and in-house standards. These were used to check the quality of the run and to calibrate the results. The $\delta^{13}\text{C}$ was subsequently calibrated using a two point calibration curve.

Figure 5 illustrates the changes in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ which might be expected over the first 8 years of a person's life. The main features are an elevation in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ due to breastfeeding and a decline in $\delta^{13}\text{C}$, followed by a decline in $\delta^{15}\text{N}$, as other foods supplement the diet and weaning occurs. During childhood, the $\delta^{15}\text{N}$ is relatively low, elevating slightly later in childhood. The $\delta^{13}\text{C}$ remains fairly constant throughout childhood, with a slight but insubstantial trend towards lowering.

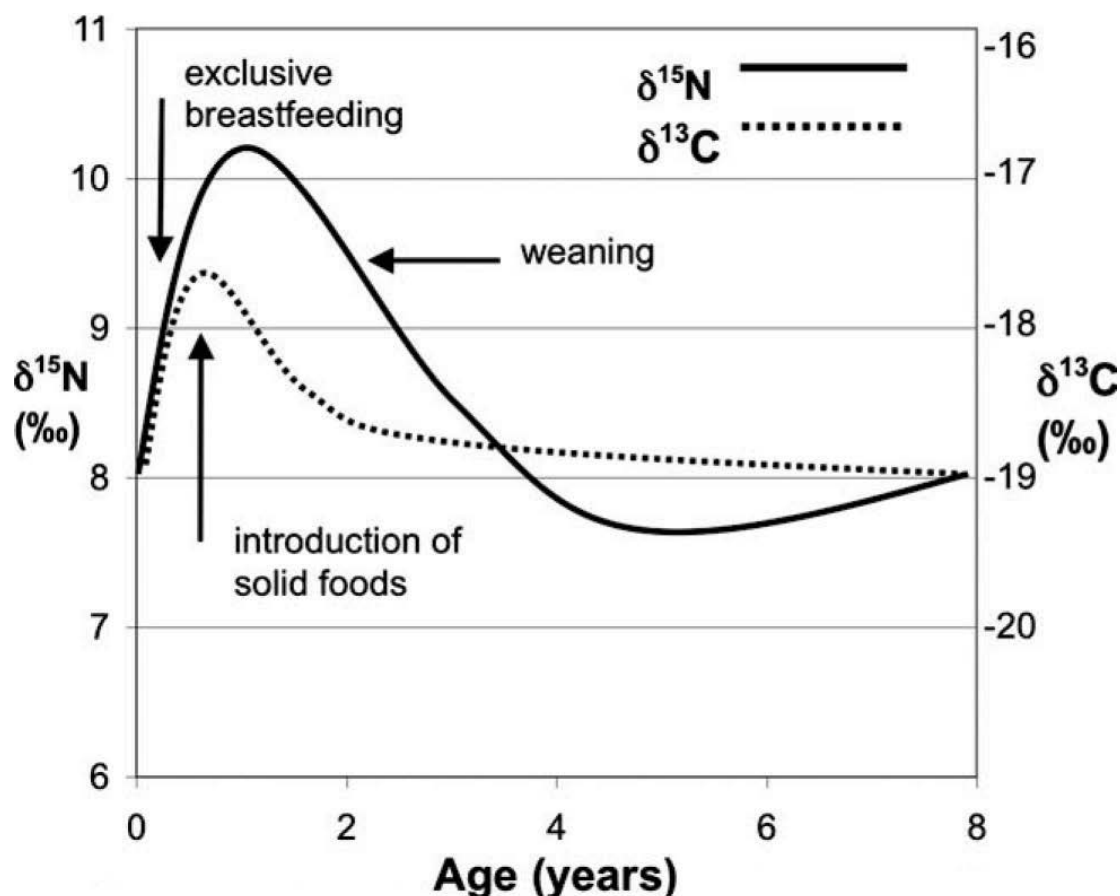


Figure 5. A model showing changes in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ often observed during infancy and childhood. Taken from Nitsch *et al.* (2011). Based on data from Schurr (1998), Fuller *et al.* (2006a) and Waters-Rist and Katzenberg (2010).

3.2.1 A Note on the Comparability of the Data

Males and females were assigned the same age brackets from Massler's (1941) chart, despite some evidence that male and female teeth have slightly different developmental times because of steroid hormones and sexual maturity (Lewis and Garn 1960). In the earliest stages of tooth development there is evidence that males and females show similar rates of development. Later, females show slightly more advanced tooth formation than males. These observations are based on a study of French-Canadian children from a single ethnic group (Demirjian and Levesque 1980). The differences are small enough that they have not been taken into account in this study. The timing of early dietary change, specifically the breastfeeding and weaning period, would be unaffected as the differences manifest later in the tooth development.

Another consideration is stress, which can affect the developmental rate of tissues in the body; for example stature (Floud and Wachter 1982), but while it has been shown tooth eruption can be severely affected by these factors, tooth development is one of the least affected tissues in the body (Smith 1991, Elamin and Liversidge 2013). In a comparison of tooth development in Danish children from 1913 and 1965, results show that although physical development was more advanced in the later cohort, tooth development remained the same, giving hope to intra-population comparisons (Helm 1969). Similarly, in a study of severely malnutrition North Sudanese children, it was also found that the formation of the teeth was not affected (Elamin and Liversidge 2013). No attempt is therefore made to factor this into the analysis, as despite suffering different stress levels, the St Saviour's and Zvejnieki populations should be comparable.

Race should also not influence the comparability of the data. Fanning and Moorrees (1969) compared the formation of teeth in Caucasoid and Australian aborigines, reporting that formation times in most teeth were similar except the third molar. This tooth's development was delayed by 3-4 years in the Caucasoid group compared to the aboriginal group. Third molar teeth included in the post-medieval dietary study here are not reported as a specific age bracket to take into account this problem. The third molar is also the tooth which is most likely to show substantial developmental variation, not just between racial groups but also within a racial group (Mincer *et al.* 1993), sometimes causing the complete absence or non-eruption of the third molar (Nanda 1954, Björk *et al.* 1956, Hillson 1996). The teeth developing before the third molar, including the first and second molar, have greater uniformity in the timing of development (Fanning and Moorrees 1969). This means there is greater accuracy in assessing the timing of life history events from these earlier years. Given that more rapid changes in diet occur during these years, including breastfeeding and weaning, major discrepancies in timing are generally avoided.

3.3 Method 2: Incremental Enamel Sampling

A sub-sample of St Saviour's teeth were selected for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ analysis of the enamel. After the cleaning process described above, 5 equally spaced strips of enamel were hand drilled from each tooth before the dentine was demineralized. These strips were removed incrementally, from the crown to the cemento-enamel junction. The samples were taken from approximately the same location on the crown as the increments of dentine and correspond to the same strips of enamel used to record the linear enamel hypoplasia described below. This is represented in Figure 6. The enamel strips were aged according to Massler's (1941) developmental chart, the same chart used to age the dentine samples.

The powdered enamel carbonate samples were sent to the laboratory at the University of Bradford for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ analysis in a Thermo Finnigan Delta V Advantage mass spectrometer equipped with a Gasbench II. Samples were run with the international standards CO-1 (Calcite) and NBS19 together with the internal enamel standard, Bos Enamel Standard (BES). Analytical precision was better than 0.1‰ for both $^{13}\text{C}/^{12}\text{C}$ and $^{18}\text{O}/^{16}\text{O}$.

There are several problems associated with sampling enamel incrementally. The two-step formation process of enamel results in a delay between the initial secretion of the enamel and the end of the process when it becomes mineralized. As mineralization takes place to different degrees in different directions throughout the enamel, this has the potential to affect the age that the samples reflect (Suga 1982). This known problem has not been possible to counteract in this study, meaning the incremental samples may not be fully representative of the age brackets ascribed. A full discussion of this is made in the results section.

3.4 Method 3: Enamel Hypoplasia

This method was used to record and analyse the enamel hypoplasia. Enamel hypoplasia is a defect in the enamel and an indicator of physiological stress, described in more detail in Chapter 2. Like the dentine, the enamel forms at a known rate and a specific tooth can be targeted to

observe stress during a particular part of childhood or infancy (Hillson 1996). All first molars from St Saviour's Almshouse which were analysed according to Method 1 were also studied for hypoplasia.

After cleaning and before the enamel was removed, latex casts were taken of the teeth, allowing a record of the enamel surface to be made prior to destruction. This also created a means to aid identification of enamel hypoplasia. Liquid latex was painted onto the surface of the cleaned teeth using an acrylic brush. Experiments showed building up five layers of latex and allowing it to dry between applications produced a cast which could be easily removed, retained its shape and gave an accurate impression of the crown's surface. In experimentation, various dyes were added to the liquid latex as an aid to achieving detail under a microscope, as suggested by Hillson (1992). The available dyes did not yield better results and so the technique was subsequently abandoned. After the casts had dried and were removed, they were placed under a dissecting microscope, backlit and photographed. The images were then adjusted using Photoshop and the surface detail examined.

Enamel hypoplasia was identified visually using the latex casts with the aid of a dissecting microscope, and recorded according to the Epidemiological Index of Developmental Defects of Enamel (DDE Index) (Commission on Oral Health Research and Epidemiology 1982). This index is used as a standard for defining enamel hypoplasia. The casts produce a permanent record of the enamel surface prior to destruction. Comparisons were made between the teeth and the casts before the teeth were destroyed to ensure accuracy. This tested for problems which could occur due to the flexibility of the mould structure. The slight flexibility of the mould made it possible to remove from the enamel surface without damage and the loss of fidelity in the shape of the cast was deemed to be minor enough that it would not affect the age bracket than any defect was ascribed to.

The casting method is a compromise solution. It is more time consuming to create casts than simple observations by eye, but due to the destruction of the teeth, a latex record of the tooth's crown was considered an important record. These casts also allowed hypoplasia results to be rechecked or other examinations to be made after the crown had been destroyed. Because these casts could be examined easily under a microscope, with appropriate lighting, it is likely a greater number of defects were identified compared to visual analysis of the crown. This is something which was considered when looking at the incidences in comparison to other sites.

The crown was measured into five sections horizontally, from the cusps to the cemento-enamel junction, as shown in Figure 6. The number of incidences of linear hypoplasia was recorded for each section. The sections of enamel were aged using the same developmental chart used for the dentine (Massler *et al.* 1941). Where it was unclear whether a defect was hypoplasia or otherwise, a visual inspection of the tooth was made and a fingernail or probe was used to decide whether a ridge in the enamel was present. To be considered linear hypoplasia, the line had to project across the surface of the crown. Any lines which were unclear were excluded. Incidences of hypoplasia on the boundary of the sections were recorded as being present in the section containing the majority of the defect.

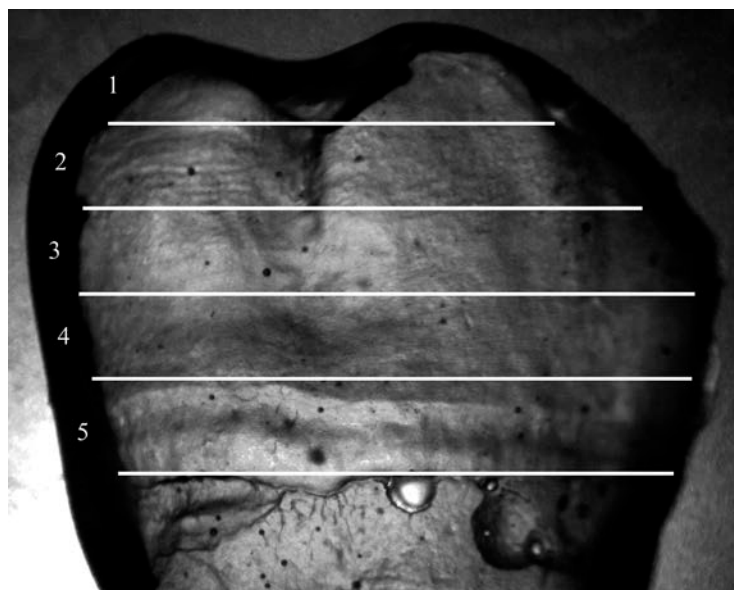


Figure 6. Image showing how the position of the linear hypoplasia is recorded and where the incremental enamel strips were taken from. Approximate ages assigned to each region are: Section 1= 0-6 months, Section 2= 6-12 months, Section 3= 1 year-20 months, Section 4=20 months-28 months, Section 5=28 months-3 years.

The $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ results from the incremental dentine analysis (Method 1) and the results of the timing of the hypoplasia (Method 3) were compared in the St Saviour's Almshouse population. The aim was to look at the relationship between diet and stress, specifically if dietary change due to weaning causes hypoplasia. The results are reported in Chapter 6. There is a small difference between the development of the dentine and the enamel, with dentine beginning to form just before the enamel (Hillson 2005). This has not been taken into account here because it is minor and as age ranges are given rather than precise ages the difference should be factored out. Using the same teeth to explore both hypoplasia and dietary analysis means even if development of the tooth is slightly delayed and under aging is taking place, both the hypoplasia and dietary analysis will be equally affected. This means the two can still be compared relative to each other.

3.5 Summary

Three methods were used to explore early life histories. In Method 1 the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope composition of incremental strips of dentine was measured. 10 samples were taken from first molars and a limited number from second molars. These samples were taken horizontally

down the tooth, from the crown to the root, following the direction of tooth formation. As the dentine does not remodel, these samples represent the diet during the tooth's formation. Each segment was aged according to the developmental chart by Massler *et al.* (1941). In the first molars this allowed diet to be tracked over the first 8 years of a person's life. Method 2, which was only applied to a sub-sample of St Saviour's teeth, analysed the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ composition of incremental strips of enamel. These were taken from the same regions as the incremental strips of dentine and aged according to the same developmental chart.

In Method 3, hypoplasia is studied by painting liquid latex on to the crown of each tooth, which once dry produced a removable latex cast. These were studied under a microscope and scored for hypoplasia. The position of the hypoplasia was recorded to allow dietary change and health to be considered in relation to each other.

Part One

An Industrial UK Working Class Population (c.1730-1860)



An 1808 illustration of the almshouses and associated burial ground on Park Street, Southwark. Illustration by George Smith, curated by the London Metropolitan Archives.

Chapter 4 St Saviour's Almshouse, Southwark

4.1 Introduction

The social and economic changes which occurred as a consequence of the industrial revolution caused one of the major upheavals in human history. In the United Kingdom this occurred during the 18th and 19th centuries, where the effects were far reaching. The catalyst was an amalgamation of technological and agricultural innovation, population growth, capital formation and increased engagement in world trade (Hudson 1992). Unlike many major transitions, the industrialisation of the UK is a recent event in human history and historical records exist testifying to the socioeconomic impact. Major impacts on human health are recorded within these historical accounts and can be seen today in developing countries experiencing the industrial transition. Remaining questions, personal experiences and the impact of industrialisation on specific groups within societies can be addressed using the archaeological record. The combination of a recent large scale transition which can be historically accounted for, combined with the known catastrophic impact it had on the health of the population, makes it an important case study when looking at early life histories. A dual study of infant diet and health in Southwark, a region of London which experienced the full effects of the industrial revolution, is made in the following chapters. The study considers both site specific questions relating to the people sampled from Southwark and broader implications concerning the impact of the industrial revolution on children.

Background information on the St Saviour's Burial Ground site is given in this chapter, providing the context on which the following chapters draw. A brief description of the effects of industrialization on the local area is provided, followed by the effects this had on the early lives of the children who lived during this turbulent period. This is followed by a more detailed account of the St Saviour's Almshouses and the burial ground, a site which was in use during this period, and

on which the analysis is based. The human remains from this site in Southwark formed the sample for exploring industrial early life histories.

4.2 The Impact of Industrialisation in Southwark, London

Social changes experienced in this era can be partially attributed to the migration and resettlement of people to areas where work was becoming available in the cities. As a consequence, industrial regions became more densely populated and overcrowded, exacerbating dirty conditions and facilitating the spread of disease in a society which lacked the necessary understanding and health care to deal with the consequences (Brickley *et al.* 1999). The south London area of Southwark was the epitome of these harsh conditions. Between 1700 and 1831 the population rose from 35,000 to 85,000, an increase which is indicative of the scale of migration by those in search of work (Reilly 1998). The incidence of disease was high in this region, with outbreaks of a variety of infections killing large numbers of people. In 1832 cholera took the lives of 10% of the Southwark population (Boast 1997). One of these cholera epidemics was attributed to the flushing of sewage into the River Thames, from which the inhabitants drank. The spread of typhus and typhoid peaked because of the crowded conditions, with the former becoming known as 'jail fever' because of its association with crowded institutions (Luckin 1984). Other infectious and potentially life limiting diseases included smallpox, diphtheria and scarlet fever (Howe 1997). Predictably, life expectancy was shorter in London than in the rest of England and Wales (Woods 1984) and it has been suggested that without migration into the city, population levels would not have been maintainable (Storey 1992).

The high prevalence of disease and ill health was amplified by the limited availability of nutritional foods, which would have left the local population disadvantaged and ill-equipped to cope with other biological pressures. The effects of local industry would similarly have caused health to suffer, in addition to contagious disease transmission, as air pollution exacerbated the already difficult environmental conditions (Lewis 2002a). Employment opportunities were the main

attraction of London for many and in working class Southwark, men and women found employment in the inns, glass works, brewers, vinegar works and the leather industry (Reilly 1998, Museum of London Archaeology Service 2003). A description of Southwark by Dodd (1843), in which the tall chimneys and clouds of smoke are described, paints a picture of the industrial nature of the area. Immigration by those seeking work in these local industries caused a shortage of housing across the city. Cramped, poor quality housing was thrown up in response to the population increase, which would come to define the modern day slum (Howson 2008).

The author Charles Dickens in his works of fiction attempted to capture the poverty of the Southwark area in his book *Little Dorrit*. He wrote this passage about the area:

‘They walked back through the miserable muddy streets, among the poor, mean shops, and were jostled by the crowds of dirty hucksters usual to a poor neighbourhood. There was nothing, by the short way, that was pleasant to any of the five senses’ (Dickens 1857).

While every period, including the modern day, is associated with particular health conditions, there is little doubt that people who lived during this era in places such as London were under obvious pressure from their changing environment. The historical resources reflect the high mortality rates and disease prevalence, reflected also in the osteological information available. While adults clearly suffered, their children were not always able to cope effectively.

4.3 Early Life in the Industrial Era

Infants and children would have been vulnerable to the impact of the industrial revolution because of their inherent susceptibility to disease due to their immature immune systems. Lewis and Gowland (2007) found environmental factors caused a high number of neonatal deaths associated with urbanisation. Similarly, Williams and Galley (1995) compared the mortality of infants from rural and urban settings in the Victorian period, concluding that infants in urban environments were eight times more likely to die from diarrhoeal diseases than those from rural

environments. Other illnesses, including measles, scarlet fever and respiratory disease were also significantly higher in an urban setting, demonstrating a divide in health and mortality between contemporary groups living in different areas.

Whilst a child's survival can depend on the environment it is brought up in, it is also partially predetermined by the mother's state of health before and after birth. The poor health of a mother is reflected in the health of her unborn baby, and can be seen in the prevalence of enamel defects on the child's deciduous teeth, which form *in utero*. Lewis (2002b) found that hypoplasia on deciduous teeth was more common in industrial populations, which contributed to the author concluding industrialization had a significant negative impact on child health. The findings suggest that mothers in urban populations were less healthy than mothers from other backgrounds, which agrees with the general principle that adults in urban environments suffered greater incidences of disease and higher mortality in urban environments. Maternal health in the urban environment was worse than other environments due to employment in industry. Williams and Galley (1995) suggest a 10% increase in premature births which occurred in urban settings was caused by the employment of women in the textile industry. This reflects a change in women's roles and shifts in the structure of the family, from extended rural families to small urban family units (Jelliffe and Jelliffe 1978).

Later childhood appears to have been similarly bleak, as shown by the high mortality rates, high incidence of disease and osteological indications, such as height. A difference in height between middle and working class children was apparent throughout the Victorian era, demonstrating the divide in nutritional wellbeing between rich and poor (Floud and Wachter 1982). Changes in the health and welfare of children would not improve until the early 1900s, when various policies regarding child welfare the poverty came into being. This was combined with changes in medical care, better standards of living and a decrease in the size of families (Jordan 1993). Social pressure to make changes in these areas was the product of increasing concern and publicity over

the plight of the poor. Part of this fight for welfare extended to the labour of children. Children were employed in sweat shops in the clothing, lace-making and straw-plaiting industry, mines, mills and various other trades from the age of 5 years up (Frost 2009). Some of these occupations resulted in a variety of illnesses and deaths. It was not until 1870 that policies regarding child welfare and poverty came into being which dictated that all children under the age of 10 should be schooled, a policy which was not universally popular, or practiced, by working class families who relied on the income from their older children (Hibbert 1975).

Historical documentation suggests a series of shifts throughout the post-medieval period in infant feeding strategies practiced by mothers and carers, which would have influenced the survival of children throughout the period. During the 1700s in the UK it became fashionable to hand feed infants rather than breastfeed them, a practice which seems to have taken place amongst both wealthy individuals and orphans. Infant foods considered to be suitable, and sometimes preferable, substitutes to breast milk include two foodstuffs- 'pap' (bread soaked in butter or milk) or 'panada' (cereals cooked in broth). These foods would not have provided infants with the appropriate nutrients or immunological protection they required, causing an increased incidence of rickets and scurvy in industrial populations (Lewis 2002a). Without the knowledge or ability to adequately sterilize feeders and feeding implements, many infants had their lives cut short by such practices (Stevens *et al.* 2009). In London during the 1740s there were an estimated 450 deaths per 1000 live births, a figure which dropped gradually throughout the 18th century as infant feeding fashions changed. During the later post-medieval period, the chances of a mother breastfeeding and bringing up her own baby, rather than employing a wet nurse, appear to increase. This is recognised by a decline in infant mortality throughout the period, probably due to both an increased incidence of breastfeeding and advances in midwifery (Levene 2005).

Animals' milk was one alternative that has been used widely in post-medieval contexts. In post-medieval France, asses were sometimes used in orphanages, a practice which is likely to have

been common to many other populations, particularly in such situations (Wickes 1953c). Such a practice would have depended on the availability of an animal that was lactating, potentially limiting the number of infants being supported by this food source. Due to a lack of sterilization of the milk and teat, which children were sometimes fed directly from, reliance on animal milk was a risky venture because of the potential for pathogens to be transmitted to an infant. For children who were not put to the teat of an animal, feeding equipment would have been used to facilitate animal milk provision, meaning the choices some carers made was reliant on available material culture. Material culture associated with infant feeding from the post-medieval period still exists, including bottles, spoons and other devices.

Foods likely to have been consumed during the weaning transition before the introduction of adult foods include broths, beef tea, diluted cow's milk, pre-chewed meat, bread, rusks, cereals, pulses and fruit, although the evidence for the diet at this stage of childhood is sparse (Fildes 1986, Wickes 1953a). More prosperous parents may have also provided their children with boiled vegetables and milk puddings, part of a limited repertoire of foods considered suitable (Hibbert 1975). A lack of vegetables in the diet or the stewing of vegetables would have left children without the nutrition they required.

There are gaps in the historical accounts, with variation within the community unaccounted for and short lived trends undoubtedly passed over. Predictions of infant feeding strategies based on mortality rates are complicated by a variety of factors that affect mortality rates and the non-recording of some infants' deaths (Humphrey *et al.* 2012). Inevitably the early life experiences of some children during this era are missing, with childhood experiences more commonly recorded from the affluent parts of society. This includes advice on children's diets provided by doctors, which would have reached a limited and probably predominantly upper class audience. To add to the difficulty of interpreting the resources, accounts do not necessarily agree with each other, providing further doubt about how well practiced the advice was (Fildes 1986, Fildes 1995). While

there are difficulties assessing the relevance and importance of historical sources concerning infant feeding practices, information on childhood diet is almost completely missing (Fildes 1986).

Biological techniques provide a vital tool where other sources are unavailable and two post-medieval isotopic studies have been published with the aim of identifying the early life histories of these people. Nitsch *et al.* (2011) used known age human remains from Spitalfields, a middle class east London assemblage, to address infant feeding strategies practiced throughout the period of the crypt's use (the 18th and 19th centuries). The considerable body of information known about the assemblage, including the occupations, age and sex of many individuals makes this study an important insight into post-medieval practices and an interesting comparison to those analysed here from south London. By analysing $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ from the bone collagen of different aged individuals, the authors were able to show there was variability in breastfeeding longevity within the Spitalfields population, suggesting practices were not uniform. There also appears to have been a change over time, with a longer duration of breastfeeding occurring during the 19th century than the 18th century, correlated with a decline in the silk industry and a decline in prosperity. In general, breast milk intake in most children dropped by one year of age and was completely removed from the diet by the age of two years. No difference was noted between the sexes.

In a study of less privileged post-medieval individuals from the Catholic Lukin Street cemetery in the east of London, Beaumont *et al.* (2012b) demonstrated the importance of the incremental dentine technique to track early life histories. These individuals probably suffered nutritional hardship and might have been survivors of the Irish famine who came to London. The nutritional deficiencies these people experienced suggests they might have more in common with those from Southwark discussed here, rather than those from Spitalfields described by Nitsch *et al.* (2011), although the possibility that they are immigrants means their early life histories may differ from those who grew up in London. Isotope results from the five first molars analysed suggest

variable early life experiences, with only one individual showing an obvious elevation in $\delta^{15}\text{N}$ in the first dentine increment, suggesting that this individual was breastfed (Beaumont *et al.* 2012b). Analysis of the isotopic composition of the bones of a larger number of individuals also suggests variable infant feeding strategies (Beaumont *et al.* 2012a).

4.4 St Saviour's Almshouse Burial Ground, Park Street, London

The tooth material analysed here is from a burial ground located on Park Street, Southwark, in the south of London (Figure 7 and Figure 8). The burial ground was excavated by the Museum of London Archaeological Service, as part of a redevelopment programme by Network Rail. The excavation included a burial ground known by several names, including '*College Yard*' and '*St Saviour's Almshouse Burial Ground*' (Figure 9). The burial ground was opened in 1730, after the closure of St Saviour's churchyard, and was finally closed in the 1850s. In the 1860s it was purchased by Charing Cross Railway Co. and the area was subject to redevelopment. During this period there had been increasing concern over human internment within the city limits. Burial grounds were full, but due to a lack of alternatives and the desire to have loved ones buried locally, bodies continued to be buried in ground which was saturated. This resulted in shallow graves, stacking of bodies and burial grounds which were health hazards, some accounts describing protruding human remains and earth which oozed foul odours. The redevelopment of the St Saviour's Almshouse Burial Ground involved the removal of some of the human remains to Brookwood and Nunhead cemeteries. Brookwood was created as an alternative to burial within the city, a large cemetery which could satisfy the needs of the city and remove the problems caused by city burial.

The construction of railway arches followed the removal of the human remains (Bard 2008), while some burials remaining in the area, which became the builder's yard and Borough market, were undisturbed. A total of 331 individuals were recovered from the recent excavations at the almshouse site, although many of the skeletons were not excavated in full because they were

beyond the remit of the excavation area (Teague *et al.* 2013). Osteological work was completed by Oxford Archaeology and the skeletal remains have since been reburied.



Figure 7. The site of the burial ground today, showing the railway arches which were erected in 1860. Borough market, under which the St Saviour's Almshouse Burial Ground extended, still functions and is situated left of the photograph. Author's own photograph 2013.

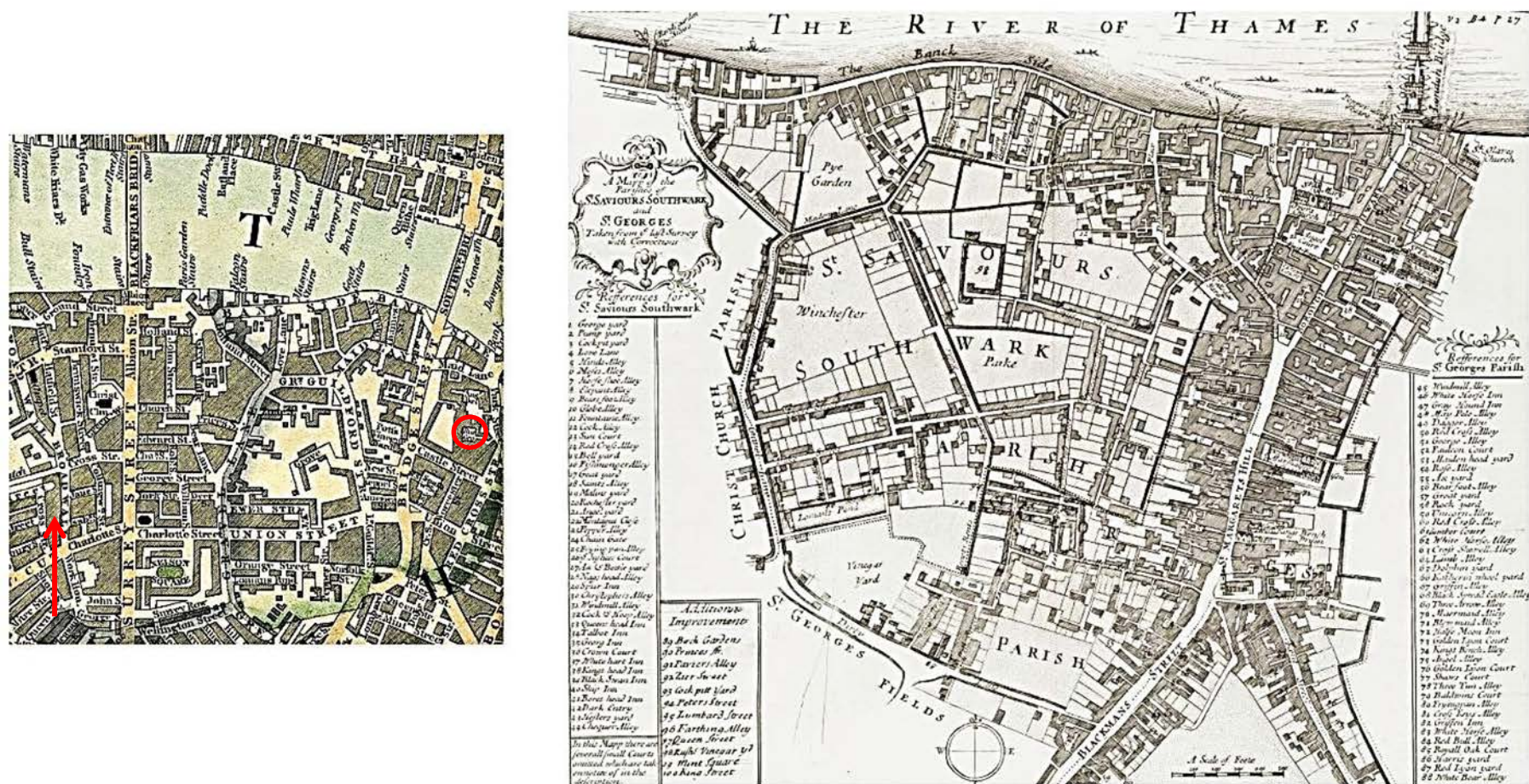


Figure 8. Location of St Saviour's almshouses. The 1851 map on the left shows the location of the burial ground circled in red. It is divided into half square miles (Cross 1850). The 1820 map to the right shows the location of St Saviour's parish in Southwark (Pigot c.1820).

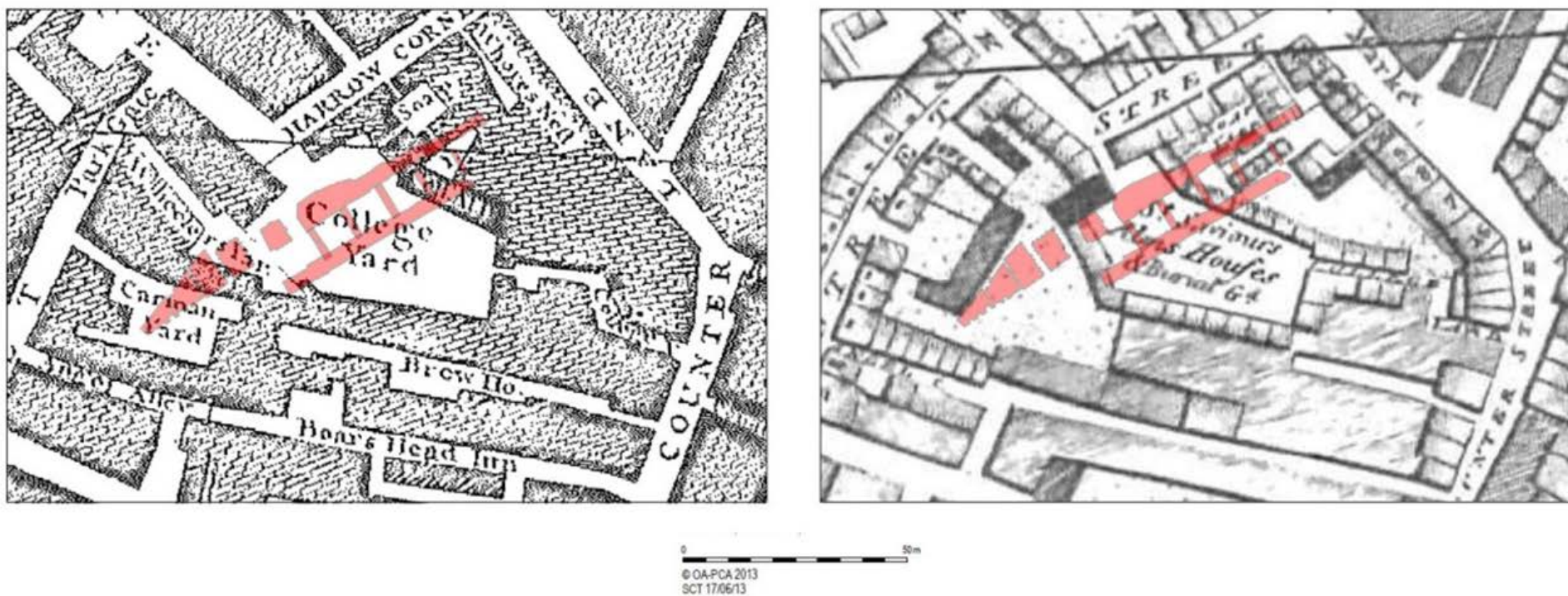


Figure 9. The area of excavation shown on two maps, (Rocque 1746) (left) (Horwood 1799-1819) (right). The area excavated is overlaid in red (Teague *et al.* 2013). The burial ground is named as 'College Yard' or 'St Saviours Almshouse Burial Ground'.

Park Street is situated in what was the parish of St Saviour, forming one of the seven burial grounds available within the parish (Brickley *et al.* 1999). This St Saviour's Almshouse Burial Ground is one of the lesser known in the Southwark area and historical documentation is more limited than for some of the more major burial grounds. It is overshadowed by its better known neighbouring burial ground, Cross Bones, which continues to receive public attention because of its association with medieval prostitutes. St Saviour's Burial Ground was associated with an almshouse, implying the Park Street plot is a likely burial ground for the poor and destitute of the parish (Holmes 1897). This almshouse was originally erected by Thomas Cure, the buildings were later added to by Henry Jackson (1685), Henry Young (1694) and Henry Spratt (1709), before being fully redeveloped in 1831. Some of the stages of this development are illustrated. In five of these images the burial ground is depicted in front of the almshouses, a later addition to the area in 1730 (see Appendix A).

The age distribution of those buried in the plot is biased towards young adults, with fewer children and older adults than would be expected from a post-medieval London population. The London Bills of Mortality during this period record the high incidence of infant mortality, with 40% of deaths occurring in those under five years (Roberts and Cox 2003). The demographic profile of the St Saviour's Almshouse burial ground does not follow this pattern, as 69% of individuals recovered at the St Saviour's Almshouse Burial Ground are placed in the age range of 18-25 or 26-35 (Teague *et al.* 2013). Other burial grounds in the local area display demography more in line with those expected. Cross Bones, a burial ground in close proximity to St Saviour's Almshouse burial ground and from the same period, includes a large number of children, as would be expected (Brickley *et al.* 1999). The reason for the omission of young children at the Almshouse Burial Ground is unclear, but could point towards a catastrophic event, where an incident or specific disease killed large numbers of young adults. Given a lack of documentation of this supposed event, it is more likely young adults were buried here for cultural reasons, or at least preferentially buried in this part of the graveyard.

The national census records, the earliest dating to 1841, record those living in the St Saviour's almshouses and include information on the age and sex of the inhabitants. The 1841, 1851 and 1861 censuses all show a similar demographic bias towards older individuals, the greatest proportion of individuals were aged between 70 and 80 years and there was a bias towards female inhabitants over males, reflecting the demography of those who were considered most in need. Figure 10, an example of the census records, and Figure 12, a page from the candidate selection book, illustrate this bias. Few children are recorded as residents of the almshouses, which may in part explain the lack of children's remains in the burial ground, but the high incidence of young adults does not fit with the demography of the almshouses. While it is likely those living at St Saviour's Almshouse Burial Ground were buried in this plot, other individuals from the local area must also be represented in the assemblage. A list of burial fees is given in Figure 11, which lists the burial options in St Saviour's parish, along with fees specifically for children's burial services. This shows there was no constraint in the burial of children in this plot, although cultural preferences may still have remained.

The burial fees shown in Figure 11 also suggest the St Saviour's Almshouse Burial Ground is not the cheapest in the St Saviour's parish, but nor was it an expensive one for affluent people. The strict social order in the Victorian era meant the most elite burial locations were always plots in close proximity to the parish church, the most expensive location being inside the church and crypt. The St Saviour's Almshouse Burial Ground, being positioned away from the parish church and located by almshouses, in a less salubrious area, indicate that those buried here were probably mostly the community's poorer inhabitants. It would appear from the illustrations however that some individuals had gravestones, something which paupers reliant on the parish would not have been able to afford. Gravestones may have been a late feature of this burial place and the images clearly do not show there to be hundreds of headstones, suggesting the majority of individuals were in unmarked graves.

Parish or Township of <i>St Saviour</i>		Ecclesiastical District of <i>St Saviour</i>		Super Borough of <i>Southwark</i>		Ward of <i>St Saviour</i>		Where Born	
No. of House	Name of Street, Place, or Road, and Name or No. of House	Name and Surname of each Person who abode in the house, on the Night of the 30th March, 1851	Relation to Head of Family	Condition	Age of	Sex	Rank, Profession, or Occupation	Where Born	
								Male	Female
108	1 Cure's College Almshouse Park St	James Burdett	Head	Widow	75		Almsman (Householder)	St Saviour's Almshouse	
109	2	Elizabeth Smith	Inmate	W	75		Almswoman (Monthly Pension)	St Saviour's Almshouse	
110	3	Jane Unwin	Inmate	W	66		Do (Schoolmistress)	St Saviour's Almshouse	
111	4	Elizabeth Sutton	Inmate	W	57		Do (Schoolmistress)	St Saviour's Almshouse	
		James Wharton	Inmate	M	72		Almsman (Box Maker)	St Saviour's Almshouse	
		Jane Do	Wife	M	70			St Saviour's Almshouse	
		Elizabeth Do	Daughter	W	44			St Saviour's Almshouse	
		William Do	Son	W	8			St Saviour's Almshouse	
112	5	Mary Frank	Inmate	W	70		Almswoman (Pensioner)	St Saviour's Almshouse	
113	6	Mary Doran	Inmate	W	70		Do (Pensioner)	St Saviour's Almshouse	
		Margaret Do	Daughter	W	26		Do (Pensioner)	St Saviour's Almshouse	
114	7	Rebecca Mercer	Inmate	W	69		Almswoman (Pensioner)	St Saviour's Almshouse	
115	8	Benjamin Thompson	Do	M	77		Almsman (Pensioner)	St Saviour's Almshouse	
	One House Uninhabited								
116	9	Maria Elizabeth	Inmate	W	66		Almswoman (Schoolmistress)	St Saviour's Almshouse	
117	10	Samuel Thomas	Inmate	M	71		Almsman (Butcher)	St Saviour's Almshouse	
		Harriet Do	Daughter	W	44		Housekeeper	St Saviour's Almshouse	
		Ann Do	Do	W	44			St Saviour's Almshouse	
Total of Persons...					51				

10 11 B

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Figure 10. One of the census record sheets from 1851, listing the inhabitants living in the St Saviour's Almshouses, referred to as Cure's college almshouses in this record. Downloaded from www.ancestry.co.uk.

<i>Defunct Service, in the Church, or in the Church-Yard.</i>			
	Old Table, 1709.	Present Receipt.	New Table, 1792.
	£. s. d.	£. s. d.	£. s. d.
Minister in addition	—	0 10 0	0 5 0
Clerk, ditto	—	0 1 6	0 1 0
Sexton, ditto	—	0 0 0	0 2 0
The sexton, for this additional fee, to open the pews at funerals, and preserve order in the church; also to relinquish a late charge for tressels, and 1s. 10d. for laying down the body in the ground.			
<i>In Bull or Green Church-Yard, Man or Woman.</i>			
Minister	—	0 2 4	0 2 6
Clerk	—	0 1 0	0 1 6
Register	—	0 0 4	0 0 4
Sexton and conductor	—	0 1 0	0 2 0
Bill and duty	—	0 0 2	0 0 5
<i>A Child in Bull or Green Church-Yard.</i>			
Minister	—	0 1 8	0 2 0
Clerk	—	0 0 8	0 1 0
Register	—	0 0 4	0 0 4
Sexton and conductor	—	0 0 10	0 2 0
Bill and duty	—	0 0 2	0 0 5
<i>College Yard, Man or Woman.</i>			
Minister	—	0 2 0	0 2 6
Clerk	—	0 0 8	0 1 6
Register	—	0 0 4	0 0 4
Sexton and conductor	—	0 1 0	0 2 0
Bill and duty	—	0 0 2	0 0 5
<i>A Child, in College Yard.</i>			
Minister	—	0 1 6	0 2 0
Clerk	—	0 0 8	0 1 0
Register	—	0 0 4	0 0 4
Sexton and conductor	—	0 0 10	0 2 0
Bill and duty	—	0 0 2	0 0 5

	Old Table, 1709.	Present Receipt.	New Table, 1792.
	£. s. d.	£. s. d.	£. s. d.
<i>In the Choir or under the Pews thereof, for every person</i>	3 0 0	3 0 0	3 0 0
<i>In the New Vault.</i>			
Man or woman	—	1 10 0	1 10 0
Under 14 years	—	0 15 0	0 15 0
Under 7 years	—	0 15 0	0 10 0
<i>Bull, or Green Church-Yard.</i>			
Man or woman	—	0 5 0	0 10 0
Under 14 years	—	0 2 6	0 10 0
Under 7 years	—	0 1 8	0 5 0
<i>College-Yard.</i>			
Man or woman	—	0 5 0	0 7 6
Under 14 years	—	0 1 4	0 7 6
Under 7 years	—	0 0 8	0 3 6
<i>St. Saviour's Old Burying-Ground.</i>			
Man or woman	—	0 1 4	0 2 6
Under 14 years	—	0 0 8	0 2 6
Under 7 years	—	0 0 4	0 1 6
<i>St. Saviour's New Burying-Ground.</i>			
Man or woman	—	—	0 1 0
Under 14 years	—	—	0 1 0
Under 7 years	—	—	0 0 3

Every person being a parishioner, although buried in a private place, or in any other parish, shall pay the duties of this parish as follows:
If buried in the church, shall pay the least of our church duties; and so in all other kind of sepulchre.

Figure 11. (Left) List of service costs for different burial plots available in Southwark. The cost of a child's service in College Yard is provided, indicating children's burials were accepted here. (Right) List of the cost of burial at some of the local Southwark burial sites, including College Yard (Concanen and Morgan 1795).

4.4.1.1 Health

The individuals represented in the assemblage are likely to have experienced nutritional hardship and biological stress during their lives. This makes them excellent subjects to explore the relationship between infant diet and stress. A full osteological report is currently being compiled by Oxford Archaeology, but a number of features of this assemblage relating directly to this research should be discussed. Diseases linked to nutritional deprivation including scurvy, rickets, cribra orbitalia and porotic hyperostosis were all noted as present (Teague *et al.* 2013). Scurvy, a disease caused by a lack of vitamin C, was diagnosed for several individuals, including individual 885, whose early history is analysed in the coming chapters. Rickets, a disease which causes poor mineralization of bone and deformities, often caused by a lack of vitamin D, was present. 7 adults showed signs for healed rickets, while 6 juveniles showed signs of active rickets. The disease is often associated with industrialization due to limited UV light, a major contributor to the body's vitamin D requirements. This means it is both a nutritional and environmental problem. Cribra orbitalia is identified by porosities in the frontal bone which forms the roof of the orbital foramen. The cause is debated, but there is an argument that it results from iron deficiency anaemia, in turn caused by disease and poor diet (Walker *et al.* 2009, Wapler *et al.* 2004).

The evidence for nutritional hardship is supported by the small stature of the population in comparison with other post-medieval groups. While height is influenced by a variety of factors, including genetics, it is also strongly related to health and environment during childhood. Based on a sample of 44 males and 30 females, long bone measurements from those recovered show males were on average 5'6 (1.68 meters) and females were on average 5'2 (1.57 metres). The small stature of these individuals is a strong indication that growth was retarded by a lack of appropriate nutrients and poor living conditions (Floud and Wachter 1982). In general, height during this era was retarded compared to modern western European populations and children would have appeared to be immature compared to their contemporaries today because of delayed development.

Caries in adult dentitions affected a large proportion of the population (77.2% of all skeletons with teeth). Carious lesions were not universal and only affected 14% of all teeth. This figure is not notably high when compared to other populations, but does reflect a diet with a frequent intake of carbohydrates and sugars. Dental calculus was present on the dentition, which could point towards a diet high in protein and/or carbohydrates, along with poor dental hygiene (Teague *et al.* 2013). The exact cause of calculus within a population however remains unclear, as it relates not only to diet but also to a variety of other factors including age, ethnic origin and systemic disease (Lieverse 1999, White 1997). Over-interpretation of its presence must therefore be cautioned against.

A full understanding of children's ailments is not possible with this assemblage because few children's remains are available at this site. One feature which is possible to discuss is the childhood dentition, although this is based on a limited number of samples. Out of 44 children who had dentitions, 21 of these showed signs of caries (Teague *et al.* 2013). It is not possible to draw meaningful comparisons with other populations because juvenile dentition often goes unreported. What can be noted however, is that as caries is more prevalent in societies with high sugar and carbohydrate diets, such foods were clearly not absent from childrens' diets.

4.5 Selected Samples from St Saviour's Almshouse Burial Ground

Analysis in the proceeding chapters is based on the samples described here. First molars (M1s) were initially selected from the St Saviour's Almshouse Burial Ground assemblage. Their selection was based on a number of criteria. Due to the possible deposition of tertiary dentine deposits, teeth exhibiting caries were excluded. Each remaining tooth was provided with a score based on an attrition chart (Brothwell 1981). Only those which had limited attrition, where the dentine had not been exposed in the crown, were selected. Aside from excluding those which were more likely to have secondary dentine deposits, the selection of these teeth also ensured a full age range from birth to 8 years old was available. The number of first molars totalled forty two. Six

suitable second molars (M2s) and ten third molars (M3s) from the same individuals were also available. The M2s represent approximately the years 3 to 13, whereas the M3s finish developing in the late teenage or early adult years. Development of the M3 is the most variable in its rate and timing of completion and is notable for its complete absence in some individuals, so a more exact age range is not cited (Mincer *et al.* 1993).

To gain a large sample size with healthy teeth, it was not possible to preferentially select either mandibular or maxillary molars. This would have been advantageous because there is a slight difference in eruption time between the molars in the maxilla and mandible, with mandibular teeth erupting earlier (Eskeli *et al.* 1999). This difference in timing is small enough and the incremental samples have a large enough range, that interpretation should not be hampered by this discrepancy.

Analysis was carried out according to the methods outlined in Chapter 3.

4.6 Summary

The industrial revolution in London was a particularly difficult period in terms of health and the survival of adults and children. A combination of unhygienic, cramped living conditions, industrial workplaces which lacked health and safety standards as well as poor nutrition and sanitation resulted in the shortening of many lives. The intrinsic vulnerability of children made them particularly susceptible to environmental and nutritional problems. Health problems related to diet were exacerbated by the provision of bad quality infant foods, such as pap and panada, which in turn was a consequence of the unavailability of some healthier alternatives and a lack of education concerning infant care. Fads in breastfeeding patterns throughout the post-medieval era, including a period when breast milk was not considered suitable for infants, adds to the picture of infant and childhood deprivation.

The St Saviour's Almshouse Burial Ground dates from this industrial era and is an important site for our understanding of infant and childhood experiences during this period for working class individuals. The osteological analysis suggests that these individuals suffered from stress caused by nutritional and environmental factors, as shown by their below average height and pathology such as scurvy and rickets. The humans interred at this site will be explored in the following chapters, to build up a picture of infant and childhood experiences. 42 first molars, 6 second molars and 10 third molars were selected to investigate the early life histories of these people.

Chapter 5 Post-Medieval Early Life Histories

This chapter tracks diet using $\delta^{15}\text{N}$, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ stable isotopes for a number of individuals buried in the St Saviour's Almshouse burial ground. The study explores the weaning age, breastfeeding duration and childhood diet of these people, including how childhood diet compares to the adult diet. The St Saviour's Almshouse burial ground was utilized over an extended period of time, during which there is evidence for a number of fashions and shifts in infant feeding patterns. This includes a period when dry feeding was practiced by some mothers. The study considers where these people fit within this broad post-medieval context and also sheds light on topics which are not conveyed sufficiently by historical records, thus providing a better understanding of early life histories in the post-medieval period. The methodology followed is given in Chapter 3.

5.1 Class and Infant Experiences During the Post-Medieval Era, London

While some of the upper class infant feeding strategies are potentially identifiable historically, along with other specific groups such as those in orphanages, it is unknown how the middle and working class inhabitants of London compare in their infant feeding strategies. There is a preconceived, yet untested, notion that the working class are more likely to have deprived early lives because of a lack of available nutrients in the diet and their poor environmental conditions. A child from a working class background surviving long enough to eat solid foods would have had less access to suitable uncontaminated foods, whereas the rich would have been able to pick foods they deemed desirable. Whether this food was suitable or not is debatable. The pressure on mothers from low socio-economic industrial backgrounds to return to work following an infant's birth, restricting the ability of mothers to choose an infant feeding strategy, could similarly have proved a disadvantage for lower socio-economic families. A pregnant woman's health would undoubtedly be affected by her environment and if those from poorer industrial backgrounds suffered worse health, this would further support the notion that infants from working class backgrounds might have significantly more health problems than those from

privileged backgrounds. A lack of a mother's access to education and medical knowledge could have worsened an already dire situation.

Speculating about the effects of difficult circumstances faced by some infants does not take account of the possibility that mothers from detrimental environments may deliberately attempt to negate the effects of their environment. One way of doing this would be to practice extended breastfeeding to buffer their children. Although these mothers might not have understood the full biological benefits of breast milk, there are accounts that weak or sickly infants are breastfed for longer in such circumstances, implying advantages may have been known to them (Simondon *et al.* 2001). There is a further possibility that some mothers would have extended breastfeeding to delay a further pregnancy, particularly if they were unable to afford more children. If this is the case, it is possible lower class infants would benefit from their more modestly resourced upbringing. While the selection of an appropriate infant feeding strategy may have been possible for some women, it is also likely that many mothers would have practiced an infant feeding strategy based on personal circumstances and necessity.

These conjectures about the impact of wealth and class on early life histories are the foundations for a series of questions explored using the St Saviour's Almshouse Burial Ground assemblage. This working class population can be compared with the results from the more affluent post-medieval site of Spitalfields, analysed by Nitsch *et al.* (2011) and the working class Lukin Street population, published by Beaumont *et al.* (2012a) and (2012b). A summary of the questions follows:

- How variable were infant feeding patterns between the classes? Did working class mothers attempt to buffer their children from an industrial environment with a high incidence of disease and low nutrition by practicing different infant feeding strategies, such as extended breastfeeding? Alternatively, due to differences in lifestyles, were the

working class mothers forced to adopt feeding strategies such as the early introduction of solid foods?

5.2 Variability within the St. Saviour's Almshouse Burial Ground Community

Leaving aside differences in wealth and class, there are variables within this population which provide some valuable clues to address social differences within post-medieval London. A greater variety of early diets could indicate diverse cultural practices, life experiences and beliefs, indicative of immigration or social differentiation. Immigrants may retain infant feeding practices from their cultural background, ignoring the traditions and practices from their new environment. Given there was known to be a high level of migration into the area, it is possible this could be reflected in a high degree of variability in infant feeding strategies.

Distinctions in the treatment of male and female infants can also manifest itself in dietary studies, although there is little historical information to suggest sex-related variation in infant and childhood feeding regimes. Differences in the mortality of male and female infants are however thought to have occurred (Humphrey *et al.* 2012), implying that some cultural trends may have influenced their respective health. Male infants have an increased chance of early death because of their physiological make-up (Naeye *et al.* 1971), but during various periods throughout the post-medieval period, there is an excess of either female or male mortality (Humphrey *et al.* 2012). This could signify a cultural bias favouring one of the sexes. A summary of the questions about variability in the diet follows:

- How homogenous was the infant feeding strategy within this population? What could this be indicative of?
- Was there a difference in the diet between males and females?

5.3 Selected Samples

Of the forty two first molar samples which were chosen, sixteen were identified as female and fourteen as male. These were sexed by the osteological unit at Oxford Archaeology, using pelves and crania. Identification was made according to Buikstra and Ubelaker (1994) and Schwartz (1995). A list of individuals sampled and the teeth analysed from each individual are given in Table 1. Six second molars and ten third molars were also selected from the same individuals. No bone was available to study from this population.

Table 1. List of all individuals sampled in this study, including information on age and sex.

Individual	Age (years)	Sex	Teeth Sampled
603	13-17	Female	M1, M2
607	36-45	Female	M1
629	18-25	Female	M1
659	>18	Male	M1
661	18-25	Male	M1
667	18-25	Female	M1, M2
681	13-17	Unknown	M1
709	18-25	Male	M1, M2, M3
767	13-17	Male	M1
785	26-35	Male	M1, M2, M3
799	>18	Female	M1, M3
801	13-17	Unknown	M1
809	18-25	Male	M1, M3
813	13-17	Unknown	M1
823	18-25	Female	M1
843	13-17	Unknown	M1
885	>18	Female	M1
889	26-35	Female	M1, M2, M3
895	6-12	Unknown	M1
921	>18	Female	M1, M3
949	6-12	Unknown	M1
959	>45	Male	M1
962	13-17	Unknown	M1
2079	18-25	Male	M1
2097	6-12	Unknown	M1
2127	36-45	Unknown	M1
2151	>18	Female	M1
2199	36-45	Female	M1
2272	6-12	Unknown	M1
2350	18-25	Male	M1, M2, M3
2362	18-25	Female	M1, M3
2406	36-45	Female	M1, M3
2408	13-17	Male	M1
2417	18-25	Female	M1
2423	36-45	Female	M1
3011	18-25	Male	M1, M3
3065	13-17	Female	M1
4005	18-25	Female	M1
4044	13-17	Unknown	M1
4050	>18	Male	M1
4052	18-25	Male	M1
4084	13-17	Male	M1

5.4 Dentine Results

The average yield of collagen was 12.9%, reflecting good preservation. All samples had C:N ratios within the acceptable range of 2.9 and 3.6 (DeNiro 1985) with the exception of the 0-6 month

samples from individual 2417 and 799. These had C:N ratios of 13.6 and 7.2 respectively. These teeth were omitted from subsequent data analysis as the high value obtained from them is an indicator of contamination or poor preservation which was visually unidentifiable. The full results can be found in Appendix B. The viable data were subsequently pooled by age class and presented as a box and whiskers plot (Figure 13). This allowed a comparison of the entire cohort. The data for each individual were then plotted separately as scatterplots (Figure 14). Scatterplots were also created for individuals with first, second and third molars to represent these longer term projections (Figure 15).

These data show the average $\delta^{15}\text{N}$ value for each dentine section during the earliest sample of 0-6 months was $13.6 \pm 1.9\text{‰}$ with a range of 8.2-17.3‰. This average was the peak value obtained from the life trajectories and was also the section which had the greatest variability between individuals. The individual with the lowest $\delta^{15}\text{N}$ value is likely to represent an individual who was not breastfed, while the highest values are strong indicators that breastfeeding was taking place during this period of their lives. A step-wise decline in $\delta^{15}\text{N}$ is observed after this 0-6 month peak, with each subsequent segment becoming increasingly less elevated in $\delta^{15}\text{N}$. At around 3-4 years the average $\delta^{15}\text{N}$ is $11.4 \pm 1.3\text{‰}$. These average results suggest a breastfeeding signal within the population, with the early supplementation of non-breast milk products at or before 6 months of age. Variability in breastfeeding practices between individuals is indicated by the range of $\delta^{15}\text{N}$ values.

After a decline in $\delta^{15}\text{N}$ during childhood, the $\delta^{15}\text{N}$ increases steadily during the later childhood and teenage years from approximately 8-9 years (Figure 15). This is represented by the second and third molars. As with the breastfeeding signal, there is some variability between individuals, with 889 and 709 showing less of a trend towards elevating $\delta^{15}\text{N}$ in adulthood than the others. In general, at an undetermined point, $\delta^{15}\text{N}$ enters the adult range of $13.3 \pm 0.5\text{‰}$ in the ten third molars. These are taken as the mean 'adult' value, although without bone available this age

assignment has to be viewed with caution. The third molars develop during puberty when physiological changes could be influencing the isotope values and the adolescent diet could vary from later adulthood.

There is little apparent variation in the $\delta^{13}\text{C}$ values over the entire period using this method. For the 0-6 months segment, the average $\delta^{13}\text{C}$ value is $-18.69 \pm 1\text{‰}$, ranging from -16.8‰ to -21.2‰ . Limited change is shown over the rest of the childhood and all subsequent sections had a combined mean of $-18.64 \pm 0.84\text{‰}$, ranging between -16.5 and -21.4‰ . The M3 average value of $-18.6 \pm 0.5\text{‰}$ does not represent a notable dietary difference from childhood to adulthood. While there is no change over time, there is a significant difference in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ between the males and females (Figure 16 and Figure 17), with males on average having less negative $\delta^{13}\text{C}$ values. A General Linear Model (GLM) was used to test for the effects of age and sex on $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ simultaneously using the software QED Statistics (Pisces Conservation Ltd) (Table 2). No significant age effect was found for $\delta^{13}\text{C}$ ($p=0.961$ at a 95% significance level), unlike the $\delta^{15}\text{N}$ which shows a highly significant age effect ($p=0.000$ at a 95% significance level). The $\delta^{13}\text{C}$ showed a statistically significant difference between the sexes throughout the first 8 years of life ($p=0.000$), as did the $\delta^{15}\text{N}$ ($p=0.02$). There were too few M2s and M3s to make a viable study of differences between the sexes after the age of 8 years.

Table 2. Results of the General Linear Model statistical analysis.

	Source	DF1	DF2	Inc. SS	Adj. SS	MS	F	Prob
$\delta^{15}\text{N}$ output								
	Sex	1	270	9.307	9.307	9.307	5.581	0.019
	Age	9	270	153.401	152.509	16.945	10.163	9.005E-014
	Age/Sex Interaction	9	270	3.615	3.615	0.402	0.241	0.988
	Error	270		450.201		1.667		
	Total	289		616.524				
$\delta^{13}\text{C}$ output								
	Sex	1	270	11.222	11.222	11.222	17.327	4.236E-005
	Age	9	270	1.952	1.992	0.221	0.342	0.960
	Age/Sex	9	270	2.820	2.820	0.313	0.484	0.885

Interaction			
Error	270	174.866	0.648
Total	289	190.86	

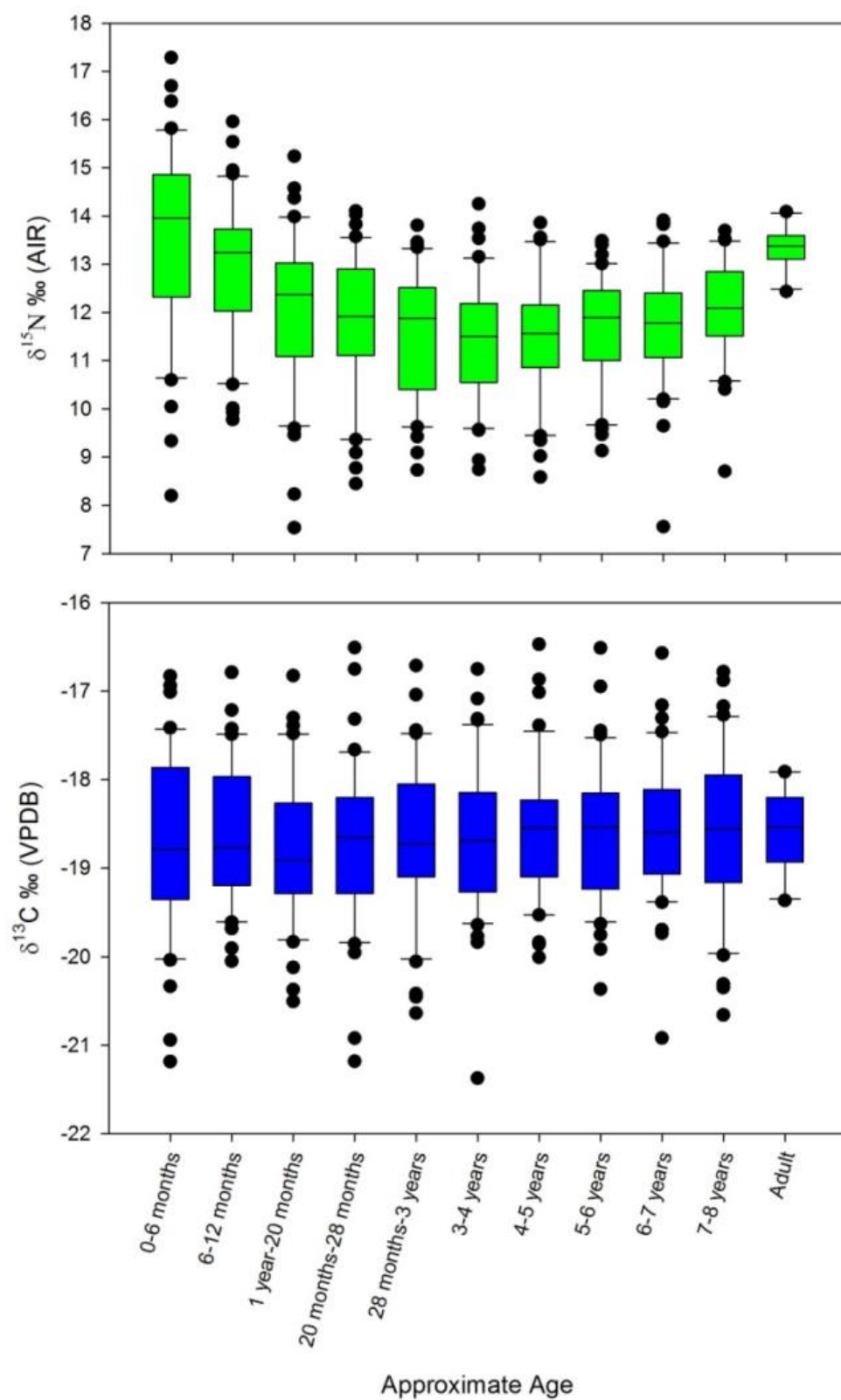


Figure 13. Box and whiskers plots depicting the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ results for all forty individuals sampled. The results show the isotopic changes over the first eight years of life for these individuals.

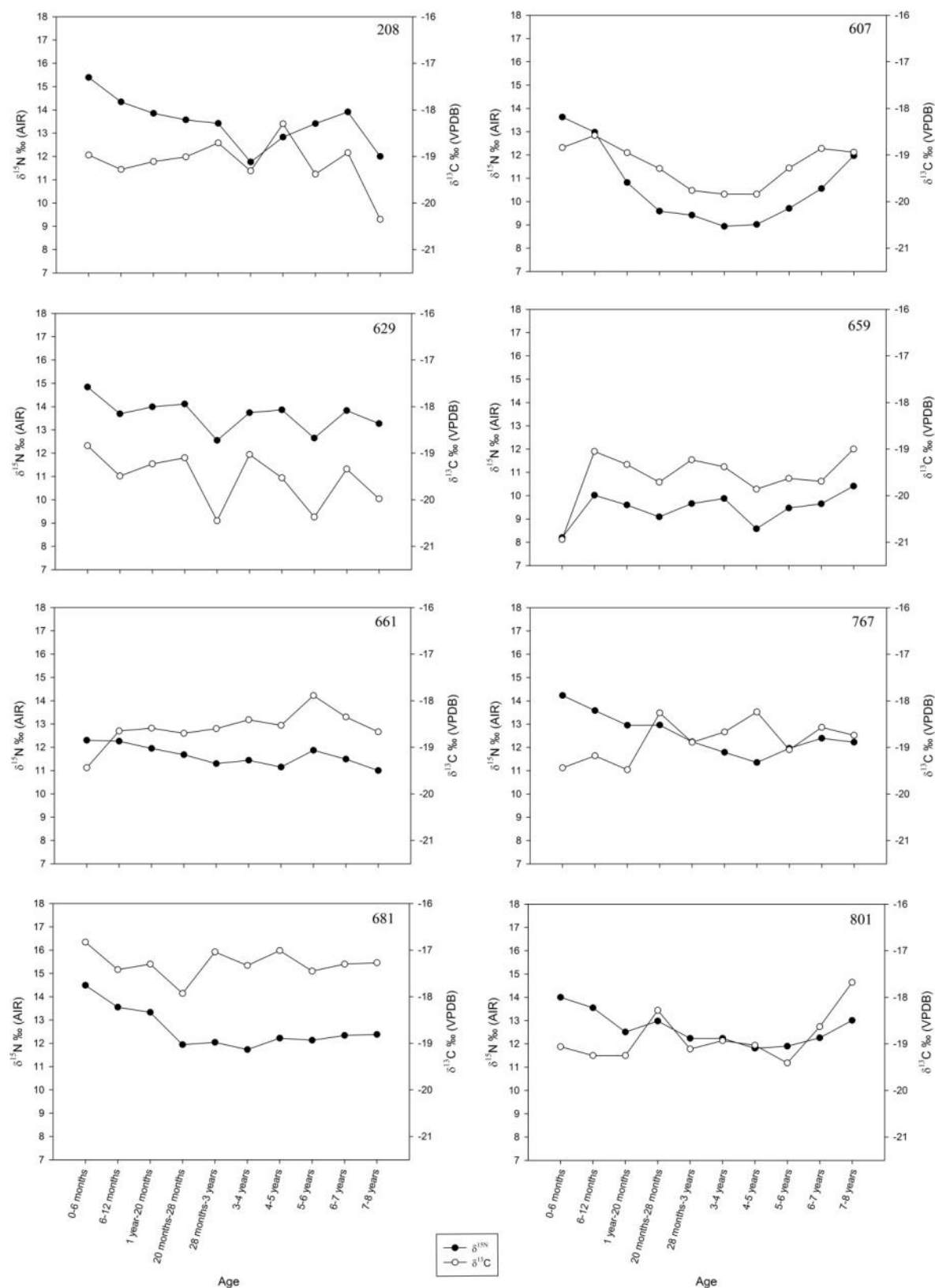


Figure 14. Graphs showing the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ over the first 8 years of life for each individual based on incremental nitrogen and carbon isotope analyses of the first molars. The number of the individual is given in the top right of each graph.

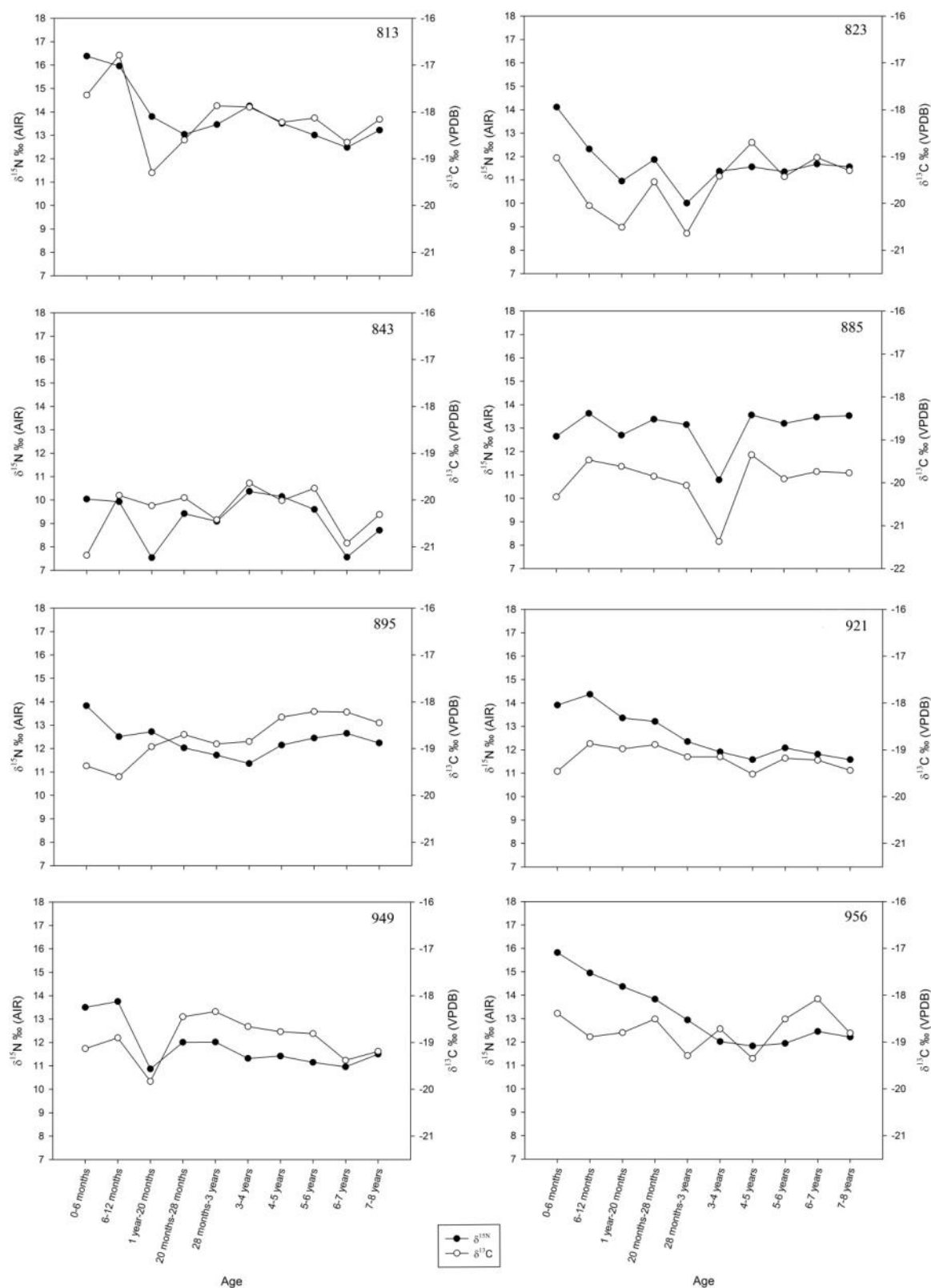


Figure 14 (continued). Graphs showing the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ over the first 8 years of life for each individual based on incremental nitrogen and carbon isotope analyses of the first molars. The number of the individual is given in the top right of each graph.

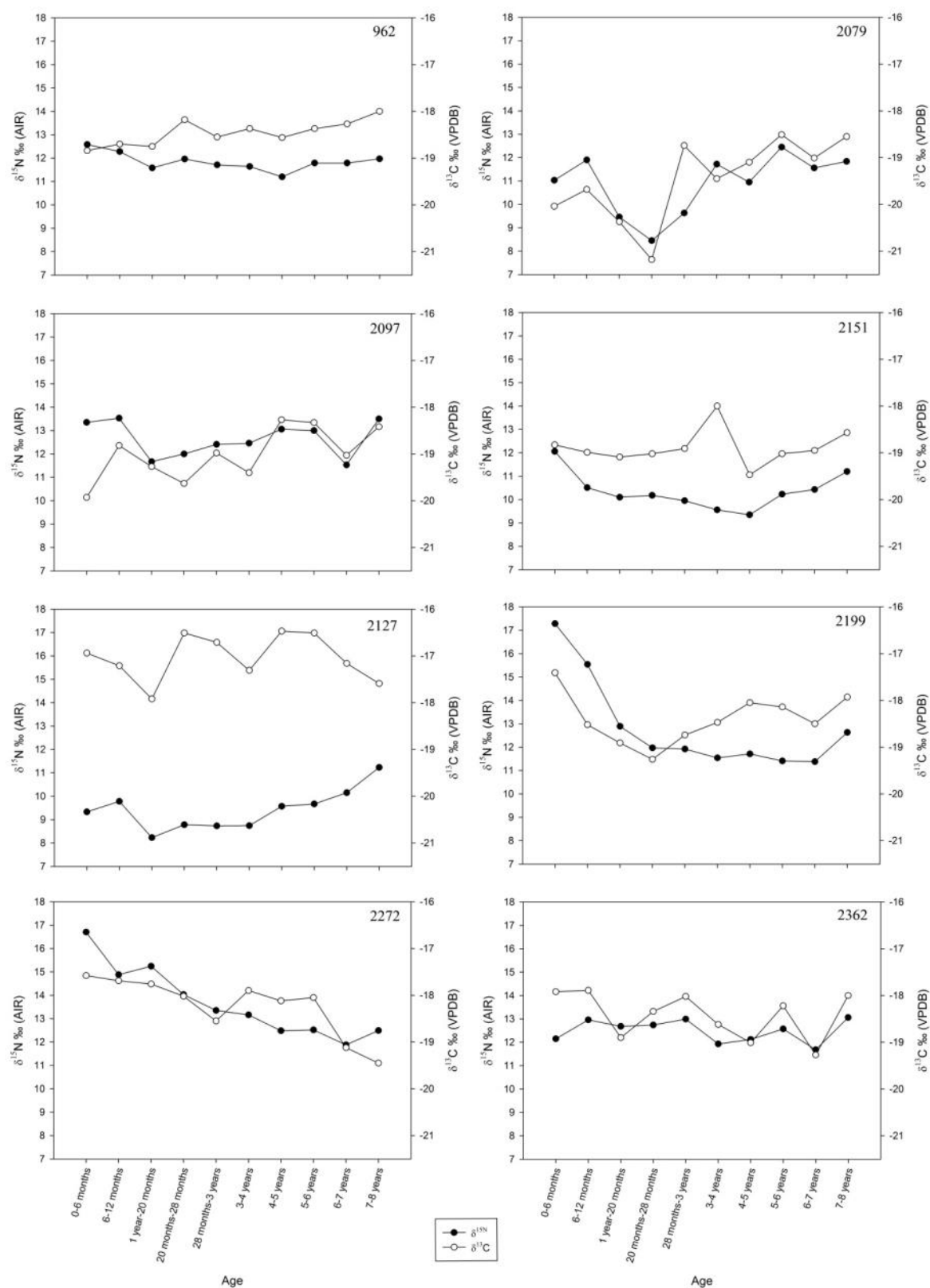


Figure 14 (continued). Graphs showing the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ over the first 8 years of life for each individual based on incremental nitrogen and carbon isotope analyses of the first molars. The number of the individual is given in the top right of each graph.

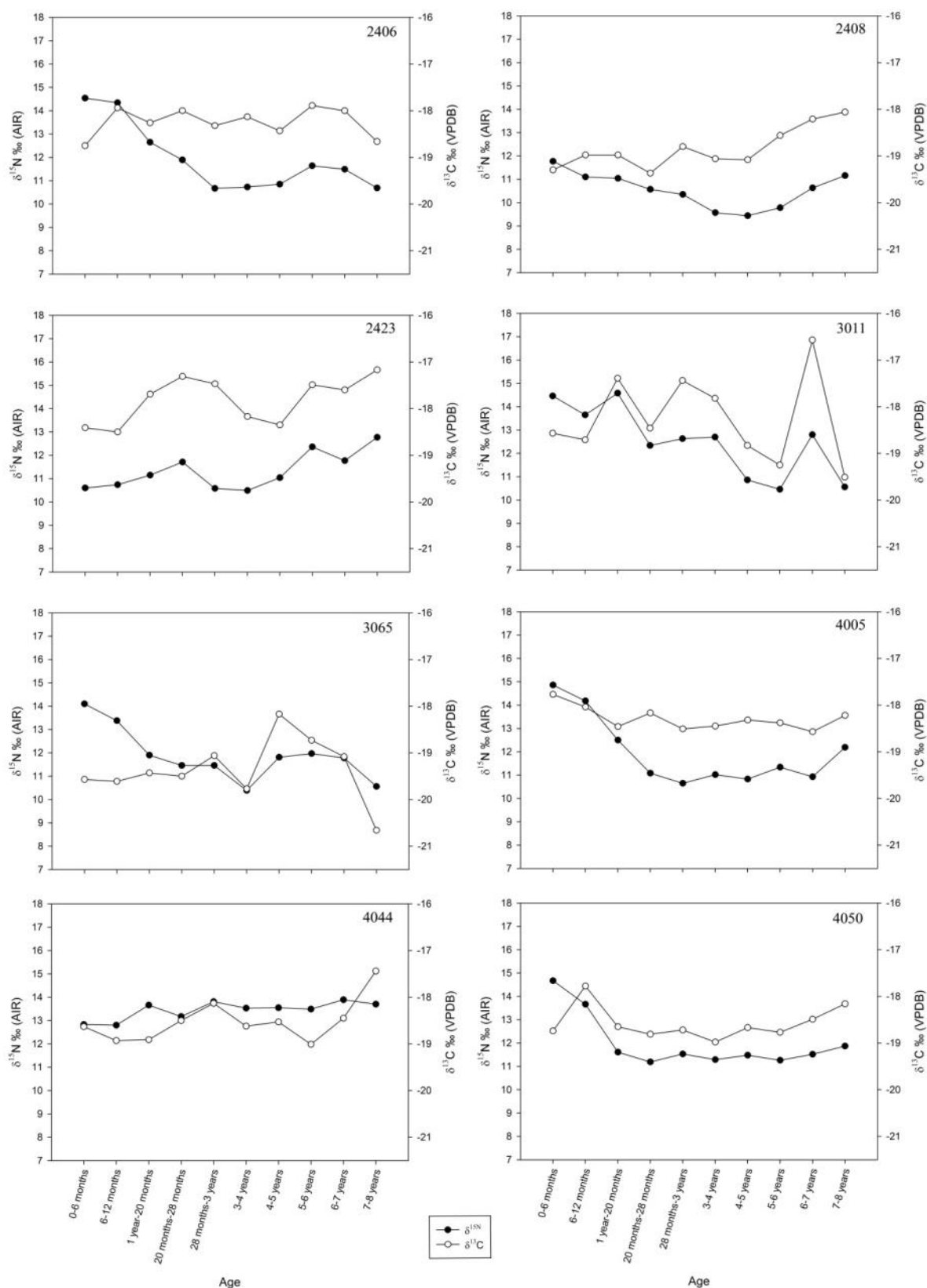


Figure 14 (continued). Graphs showing the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ over the first 8 years of life for each individual based on incremental nitrogen and carbon isotope analyses of the first molars. The number of the individual is given in the top right of each graph.

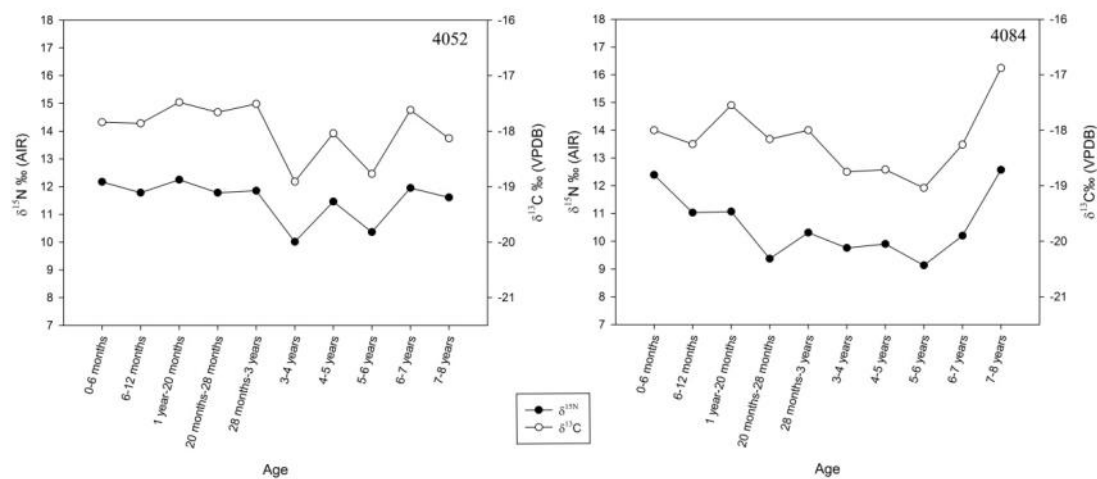


Figure 14 (continued). Graphs showing the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ over the first 8 years of life for each individual based on incremental nitrogen and carbon isotope analyses of the first molars. The number of the individual is given in the top right of each graph.

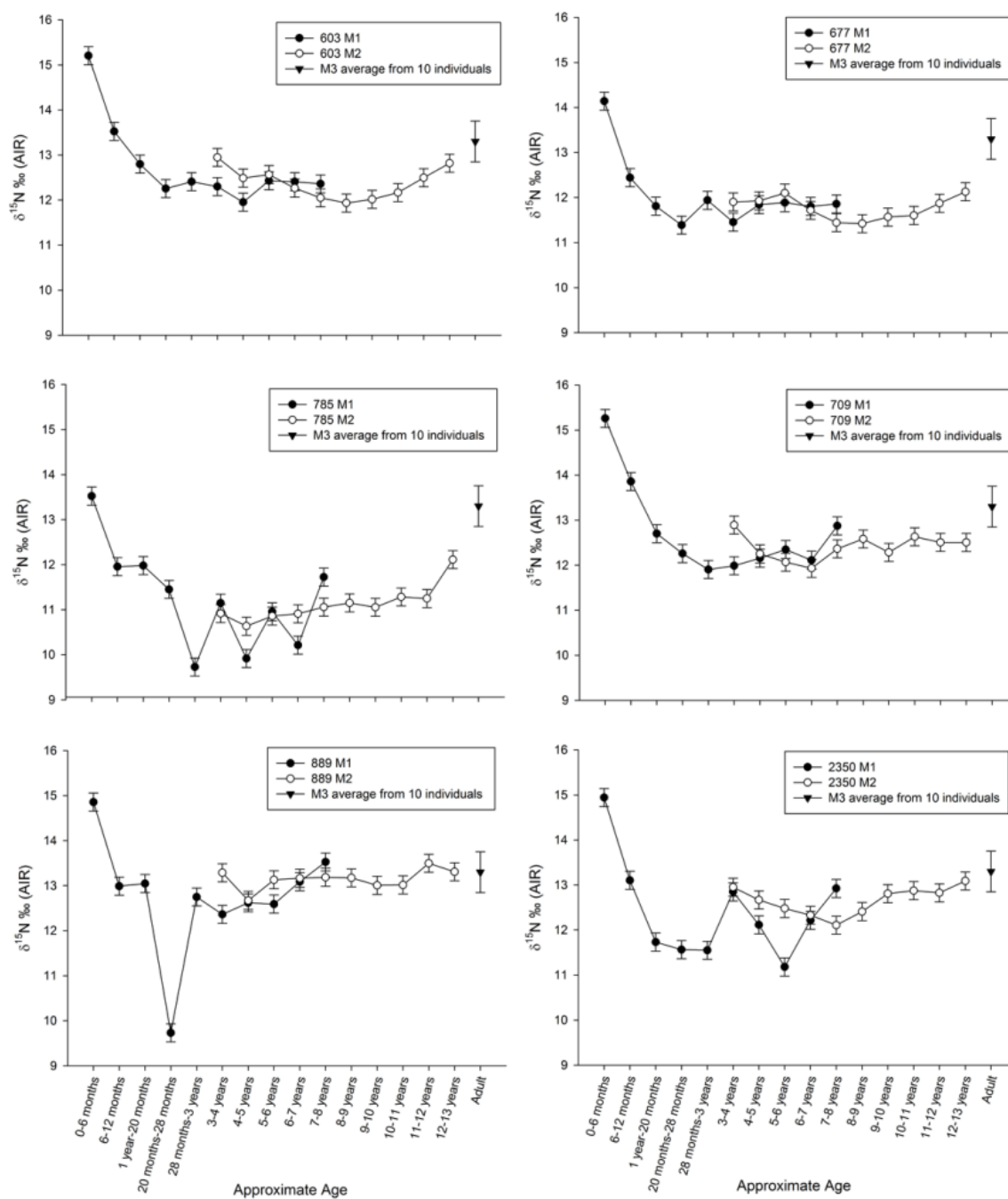


Figure 15. Graphs showing the change in $\delta^{15}\text{N}$ during six individual's lives. Results from the first and second molars are shown, representing approximately the years 0-13. Error bars on these plots represent the analytical error. The average M3 adult value also is given on each graph. The error bars on this adult value represent the standard deviation. The low $\delta^{15}\text{N}$ value on the fourth segment for individual 889 should be treated with caution as although the C:N ratio is within the correct range, the result is significantly different to suggest it may be inaccurate.

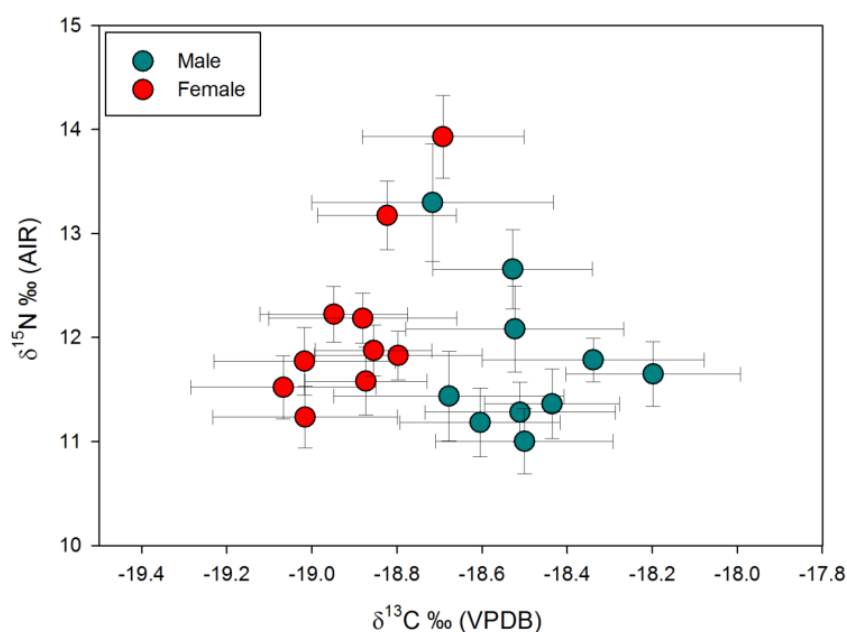


Figure 16. Scatterplot showing the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ value of each incremental sample from the first molars of all sexed individuals, each point representing a different tooth segment and therefore age bracket. The average values for the males and females have been plotted separately to show the difference between the two (10 plots for the females and 10 for the males). Error bars represent standard error. Statistical analysis is given in Table 2.

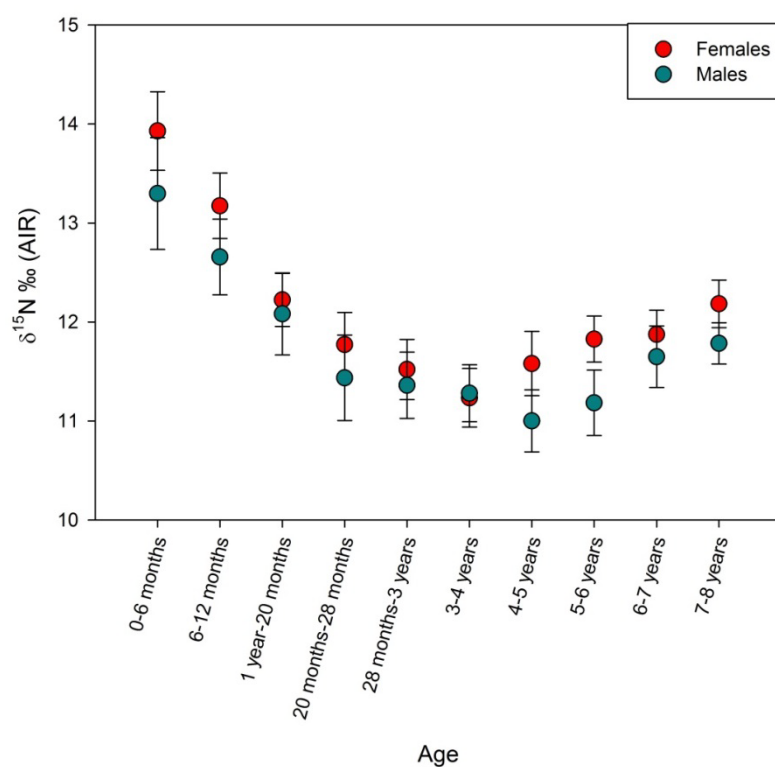


Figure 17. Graph showing the sequential difference in $\delta^{15}\text{N}$ between males and females.

5.5 General Patterns and Interpretation of the Dentine Results

5.5.1 General Patterns in $\delta^{15}\text{N}$

The elevated $\delta^{15}\text{N}$ in the 0-6 month age bracket is a strong indicator of a breastfeeding signal, caused by the consumption of the ^{15}N enriched breast milk by the majority of the forty individuals. A small amount of dentine in this segment forming before birth may also represent pre-birth dietary and physiological isotope values, which have been shown to sometimes be enriched in ^{15}N (Beaumont *et al.* 2015). There is a high degree of variability between individuals, particularly within this age bracket, which indicates there were different child care regimes being practiced within the population. Adult variability is much lower, suggesting that the infant variability is not caused solely by a high degree of variability in the diet of mothers/carers. This may have been caused by the unavailability of breast milk or deliberate, variable, choices made by the parents or carers. After the 0-6 month elevation, the subsequent decline in $\delta^{15}\text{N}$ values for the next age range of 6-12 months suggests breastfeeding declines at or before the age of 6 months. Reduced breast milk consumption by 6 months of age is similar to many modern western European weaning patterns, as it is around this age that health care practitioners recommend solid foods should be replacing breast milk.

The indication is that some individuals from the St Saviour's Almshouse Burial Ground assemblage were not breastfed. This statement is made on the grounds that some individuals show a lack of elevation in $\delta^{15}\text{N}$ during the first segments, which represent the age categories when breastfeeding might be expected. Given that the baseline maternal $\delta^{15}\text{N}$ may be variable, and in some cases low, it is possible that some infants with low $\delta^{15}\text{N}$ in the early age brackets could still have been breastfed. Although some individuals are ambiguous, it is estimated that around 17% of the sample were not breastfed. The absence of breastfeeding in some individuals may be explained by the high rate of mortality experienced by women giving birth, in combination with work requirements and other preferences. Figure 18 shows the sequential $\delta^{15}\text{N}$ signal from three

individuals, 2199, 709 and 2127, demonstrating the variability in individual life histories within the assemblage. Individuals 2199 and 709 are both interpreted as individuals who were breastfed up to 6 months, after which the contribution of breast milk declined. Individual 2127 has low $\delta^{15}\text{N}$ early in life, indicative of an individual who was not breastfed and was possibly consuming lower trophic level foods. Interestingly, this individual does show an elevation in $\delta^{15}\text{N}$ towards adulthood, in common with the patterns seen in the other individuals.

Given the apparent lack of adequate nutrition suitable for infants, it is surprising that some of these individuals clearly survived into adulthood. Without the availability of children's remains to study, it is difficult to estimate the proportion of non-breastfed infants who survived amongst the St Saviour's Almshouse population. Fildes (1986) reports some historical estimates of mortality amongst non-breastfed infants, suggesting between 67-86% of infants without breast milk died in infancy. It is unknown how this percentage was estimated, but given that it is similar to mortality rates amongst non-breastfed infants in developing countries today, it is likely these figures were based on a reliable resource.

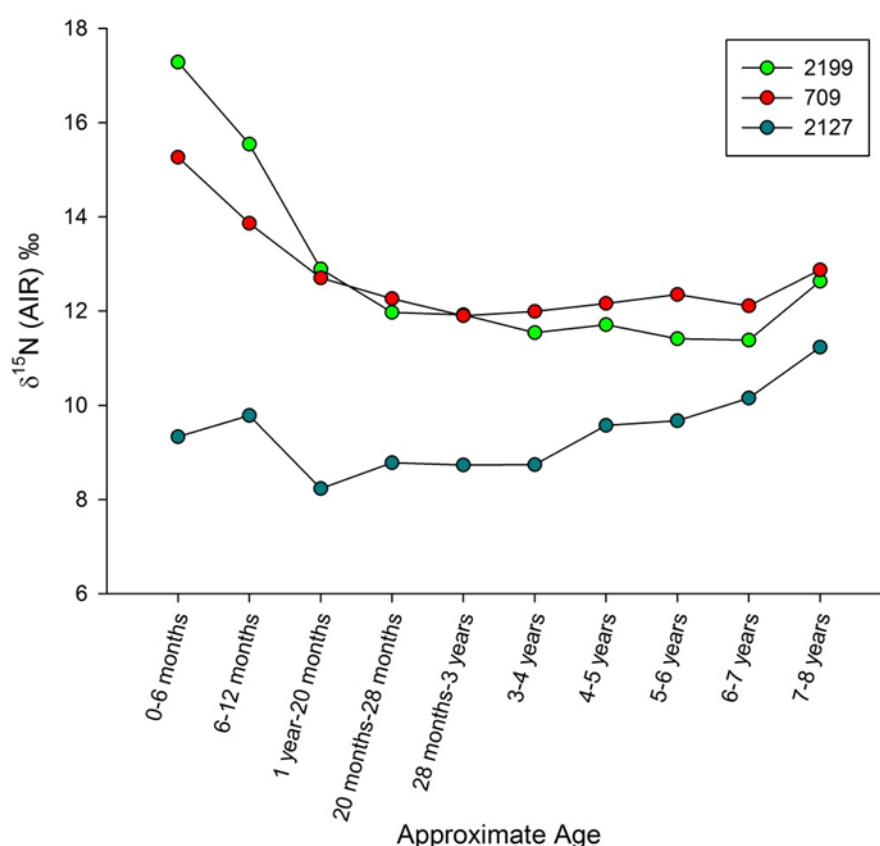


Figure 18. An example of the $\delta^{15}\text{N}$ variability within the assemblage. Individuals 2199 and 709 both show an elevated $\delta^{15}\text{N}$ value in the 0-6 month bracket, while individual 2127 does not show this elevation early in life.

Throughout childhood there is a gradual decrease in the $\delta^{15}\text{N}$, until around the age of 8-9 years, when the $\delta^{15}\text{N}$ gradually begins to elevate again into adulthood. In all individuals, the $\delta^{15}\text{N}$ is more elevated in adulthood than it is during childhood. It is difficult to ascertain the timing or variability of this $\delta^{15}\text{N}$ drop because of the limited number of second and third molar samples available and the variability in the development of the third molar, but a number of features can be discussed. The decline in $\delta^{15}\text{N}$, to a value below that of adults, could be representing either a dietary or physiological change during this period of life, both of which are discussed as possibilities.

A childhood diet with a lower trophic level protein intake to the adult diet would seem a reasonable explanation for the results. There may have been cultural reasons why some foods were restricted to children, or adults may have been provided with higher trophic level foods due

to social status. Although this is a feasible explanation, there is little historical evidence to back up this theory, and given the availability of fish in the region (predominantly herring and eels), it is unlikely a shortage of high trophic level foods occurred (Freeman 1989, Atkins 2007). Additionally, this pattern has been seen in a variety of other populations from different locations and environs e.g. Eerkens *et al.* (2011).

A more likely explanation for the childhood decline is that the isotope values are signalling a period of rapid growth as the child develops. During this time a child may not differentiate between the nitrogen isotopes as effectively as an adult, essentially taking what it needs from the body pool without discriminating. As protein synthesis slows down and growth decelerates, the body is able to differentiate effectively again and the $\delta^{15}\text{N}$ values obtained are more likely to be representative of the diet (Schurr 1998). As the mechanisms of fractionation in this process are not fully understood, it is difficult to be specific about the way the body differentiates. It is clear however that although the findings may be exacerbated by nutritional deficiencies, this pattern is seen in other populations and in other animals (Reitsema and Muir 2015).

Schurr (1998) was the first to recognise the significance of the decline in $\delta^{15}\text{N}$ during childhood. The population in question was a prehistoric (1300-1450 AD) site known as Angel, in the lower Ohio valley. The methodology involved the selection of bone fragments from aged individuals to reconstruct the weaning patterns. Individuals sampled for dentine incrementally in the studies by Eerkens *et al.* (2011) and Beaumont *et al.* (2012b) show the same trend. Since the initial suggestion that growth rate could affect stable isotopes, several studies considering the effects of growth have been made. Trueman *et al.* (2006) found there was a relationship between growth and isotope values in salmon, while a human study on the effects of pregnancy on stable isotopes found nitrogen isotope values decreased during growth (Fuller *et al.* 2004).

After the childhood decline in $\delta^{15}\text{N}$, the adult values are high enough within this population to be noteworthy. In the post-medieval period fish and meat are known to have formed part of the

adult diet and fish played an important part in the diet of the less wealthy. One author wrote that the smell of herring was associated with the smell of poverty (Freeman 1989). Amongst post-medieval London populations in general, the adults have high $\delta^{15}\text{N}$ values which could be indicative of a major contribution of high trophic level foods to the diet. This is shown by the Lukin Street and Spitalfields populations (Nitsch *et al.* 2011, Beaumont *et al.* 2012a). Another likely reason for this elevation is the heavy manuring of crops which were consumed by humans (Bogaard *et al.* 2007). Historical sources suggest human excrement was collected and used as a fertilizer, which in sufficient quantities would have elevated the $\delta^{15}\text{N}$ significantly (Picard 2005). While both of these are equally likely, the $\delta^{13}\text{C}$ does indicate that some marine foods were being consumed by the St Saviour's population, giving foundations to this hypothesis.

5.5.2 General Patterns in $\delta^{13}\text{C}$

As stated in the results, the average $\delta^{13}\text{C}$ of the adults, as inferred from the third molars, was $-18.5 \pm 0.5\text{‰}$ and the children had a similar $\delta^{13}\text{C}$ value of $-18.6 \pm 0.8\text{‰}$. This is just a little high for an ordinary C3 diet that one might have expected for Londoners (Figure 16), but it is similar to the results obtained from the other two major studies. At Spitalfields, the average of the adults was $-18.8 \pm 0.5\text{‰}$, a value which was not attributed to the consumption of C4 foods (Nitsch *et al.* 2010). The similarity of the $\delta^{13}\text{C}$ values from the middle class Spitalfields population and the lower class St Saviour's population suggests the values are not related to class. At Lukin Street, the average of all individuals was $-19.1 \pm 0.7\text{‰}$, including children and some individuals who were clearly immigrants. The high $\delta^{13}\text{C}$ may represent the consumption of some marine foods. The results suggest that this is the range of $\delta^{13}\text{C}$ to be expected from post-medieval London populations. Although most individuals fall within a similar range at St Saviour's, individual 2127 is ^{13}C enriched while the ^{15}N is depleted compared to the rest of the population. The most likely explanation is that the data represent evidence for the input of some C4 food. This is unusual for a Londoner and may suggest this person was an immigrant.

While the $\delta^{15}\text{N}$ points to major changes throughout life, the $\delta^{13}\text{C}$ shows few significant changes, remaining fairly constant throughout infancy, childhood and adulthood (Figure 13). This lack of overall variation is recognised statistically by the General Linear Model. It is significant because it does not follow the predicted 1‰ elevation in $\delta^{13}\text{C}$ which occurs in tandem with the $\delta^{15}\text{N}$ elevation, associated with breastfeeding. A range of isotopic weaning studies show a $\delta^{13}\text{C}$ breastfeeding elevation (Dupras and Tocheri 2007, Prowse *et al.* 2008, Fuller *et al.* 2006a, Richards *et al.* 2002), but equally, a number reflect a similar $\delta^{13}\text{C}$ 'plateau' (Waters-Rist *et al.* 2011, Howcroft *et al.* 2012, Beaumont *et al.* 2012a, Howcroft *et al.* 2014). This difference between populations could be caused by the varying composition of the mother's milk, which is affected partially by feeding practices. The proportion of fatty acids in the mother's milk changes according to the frequency of suckling, duration of breast milk production because the composition of the milk adapts to the infant's changing nutritional needs, the intensity of nursing, as well as general variation between women (Quandt 1995). It is possible that some of these factors influence the elevation seen in some populations, or as is the case here, a lack of elevation in the $\delta^{13}\text{C}$. In combination with these variables, the $\delta^{13}\text{C}$ may be influenced in life by non-milk additions to the diet, sometimes introduced before they become a vital and sustaining source of nutrition. This sometimes occurs when mothers offer food to the infant to taste, which does not form a significant dietary component. It could also be the case that individuals at St Saviour's were recycling fat stores in the body, which would give more negative $\delta^{13}\text{C}$ values. This is discussed in greater detail in Chapter 9.

5.6 A Sex Linked Difference in Stable Isotopes

The General Linear Model shows there is a significant difference in the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ between males and females. The quantitative difference in $\delta^{15}\text{N}$ between males and females is small, the average male value being 11.8‰ and female value 12.1‰. Females have statistically higher $\delta^{15}\text{N}$ than males, but the average difference is less than 0.5‰, indicating this difference is minor.

Error! Reference source not found. gives the results from the General Linear Model and Table 3 shows the differences in $\delta^{15}\text{N}$ for males and females in relation to age. It suggests there were larger differences during some age brackets than others. The mean in $\delta^{13}\text{C}$ between males and females is more obvious, as shown by Figure 16. These results could be indicative of males and females consuming a different diet from each other during the years 0-8, with females consuming marginally higher trophic level foods than males.

Table 3. A comparison of average $\delta^{15}\text{N}$ values in relation to sex throughout the first 8 years of life.

	Age										
Sex	0-6 mos	6-12 mos	1 year-20 mos	20-28 mos	28 mos-3 years	3-4 years	4-5 years	5-6 years	6-7 years	7-8 years	Mean $\delta^{15}\text{N}$
Female	13.9	13.2	12.2	11.8	11.5	11.2	11.6	11.8	11.9	12.2	12.1
Male	13.3	12.7	12.1	11.4	11.4	11.3	11.0	11.2	11.7	11.8	11.8
Difference	0.6	0.5	0.1	0.4	0.1	0.1	0.6	0.6	0.2	0.4	0.3
Mean $\delta^{15}\text{N}$	13.6	12.9	12.2	11.6	11.4	11.3	11.3	11.5	11.8	12.0	

Although a difference in diet is plausible, there is no direct evidence for diet in the literature. There is a brief glimpse of a sex linked bias in weaning time before the post-medieval period, as some physicians recommended boys were weaned 6-12 months later than girls (Jones 1579). Similarly, Fildes (1995) reports girls in some regions of France were weaned at 1 year and boys at 2 years. These sources relate only to the weaning period and not the rest of the childhood. They also do not relate directly to post-medieval industrial London.

Sex-related difference in mortality might be one way to explore the effects of differences in male/female nutrition and health. However the problem is that there are multiple influences on mortality patterns, including the environment. Problems with using mortality records include circumstances where the sex of individuals is not recorded and difficulties which occur because of the ways in which mortality rates are estimated. Nevertheless, evidence relating to the post-medieval site of Spitalfields in London shows variation in the mortality of male and females throughout the era, with oscillations between the enhanced survival of one sex over the other at

various intervals. This could be caused by a greater nutritional investment in one sex over the other (Humphrey *et al.* 2012).

An alternative explanation is that the isotopes reflect a physiological difference between the sexes. In infancy, males are more likely to suffer from periods of stress or ill health than females and have a higher rate of mortality, even in the developed world (Naeye *et al.* 1971). Genetically, males are more susceptible to illnesses such as respiratory problems, diarrhoea and are more likely to die from SIDS (sudden infant death syndrome) (Mage and Donner 2004). Females on the other hand are physiologically able to cope better with their environment, essentially buffering themselves from detrimental conditions (Bouman *et al.* 2005). The enamel hypoplasia results (deficits in the enamel often caused by illness) concur with this idea. The difference in the incidence of enamel hypoplasia between males and females at St Saviour's Almshouse Burial Ground is significant up to the age of 5, with 7.7% of male teeth showing defects and 3.9% of female teeth showing defects. A chi-squared test shows this is statistically significant ($p=0.001$). This suggests males were suffering more health problems than females in early life. This is important because stress can potentially lead to metabolic and digestive changes.

No bone could be obtained from the St Saviour's Almshouse Burial Ground individuals before reburial, which means an investigation of male/female isotopic differences in adults could be not made. In general it has proved very difficult to detect male-female isotopic differences in most homogenous populations. It was also not possible to assess health and nutritional status using height estimates because so many of the individuals selected did not have surviving lower limb bones.

5.7 Identification of Early Life Histories in Relation to Class

The St Saviour's Almshouse Burial Ground assemblage shows a large degree of $\delta^{15}\text{N}$ variability between individuals, suggesting different infant feeding practices were taking place. This variability is also reflected in the Spitalfields assemblage (Nitsch *et al.* 2011) and the Lukin street

population (Beaumont *et al.* 2012a), demonstrating a range of feeding practices could be a general feature of post-medieval populations. The backgrounds of those inhumed in the Spitalfields crypt are better known than St Saviour's Almshouse because documents for named individuals and their occupations are available on census and death records. The information this provides, combined with the burial context of the individuals, suggests these people were middle class. A tentative suggestion could be made that class did not define the variability of childrearing strategies within each population, although other large scale isotopic studies would help to establish this. While general variability in infant feeding patterns is a common feature of both populations, Nitsch *et al.* (2011) found no significant isotopic difference between males and females. This is in contrast to the significant difference between males and females at St Saviour's Almshouse Burial Ground. Future work will establish if there is a link between the stable isotopes of boys and girls in relation to class.

5.7.1 Comparing Working Class and Middle Class Infant Feeding Patterns

A preliminary visual inspection of the graphs (Figure 19 and Figure 20) indicates that both the St Saviour's and Spitalfields datasets show a decline in $\delta^{15}\text{N}$ with increasing age. This decline ends before the age of 4 years, after which the $\delta^{15}\text{N}$ flattens out before the childhood and teenage $\delta^{15}\text{N}$ decline occurs. Only data up to the age of 8 years are included in this comparison due to the limited dataset beyond 8 years from the St Saviour's Almshouse Burial Ground. To compare the breastfeeding and weaning strategies between the two datasets statistically, the regression lines from age 0 to less than 4 years were compared to test for any difference between the two datasets. The regression lines can vary in 2 ways; (1) the slope (rate of decline in $\delta^{15}\text{N}$), may vary between the two datasets and (2) the mean level may vary between the datasets. An analysis of covariance (ANCOVA) was used to compare the two regression lines. The source material (tooth or bone) is used as a categorical factor in the analysis. If there is a significant interaction between age and source then this indicates that the regressions differ in slope. A significant source effect with no significant interaction shows that the covariate has the same effect for all levels of the

categorical factor. This means that the two regression lines have the same slope, but have a different mean level. In other words, they are parallel lines. The two models are as follows:

Model 1 (slopes different) $\delta^{15}\text{N} = \text{age} + \text{source} + \text{age} * \text{source}$

Model 2 (slopes the same) Nitrogen isotopes = age + source

Note that both these models assume that source and age can both affect the $\delta^{15}\text{N}$. Model 1 assumes that the source affects the rate at which it changes with age (slope) whereas Model 2 assumes that source affects the level independent of age. The analysis was undertaken using the `aov` and `lm` functions in R. The ANCOVA with the interaction term shows that the age: source interaction was not significant ($p=0.904$). This indicates the two regression lines do not differ in slope (Table 4).

Table 4. The ANCOVA results showing the age: source interaction is not significant.

	Df	Sum	Mean	F Value	Prob (>F)
Age	1	192	192.05	87.367	2e-16
Source	1	140.3	140.31	63.829	3.13e-14
Age: Source	1	0.0	0.03	0.015	0.904
Residuals	293	644.1	2.2		

The ANCOVA without the interaction term gave the results shown in Table 5. Both age and source (bone or tooth) are both highly significant. This indicates that there must be a difference in the mean levels of $\delta^{15}\text{N}$ between the two datasets. To finally check that a model without an interaction term is not required the two models above were compared. The models are not significantly different ($p=0.9041$) so we use the simpler Model 2 which does not have an interaction term (Table 6). In other words, the slopes are assumed to be the same.

Table 5. The ANCOVA results without the interaction term.

	Df	Sum	Mean	F Value	Prob (>F)
Age	1	192.0	192.05	87.66	< 2e-16
Source	1	140.3	140.31	64.04	2.84e-14
Residuals	294	644.1	2.19		

Model 1: $\delta^{15}\text{N} \sim \text{age} * \text{source}$

Model 2: $\delta^{15}\text{N} \sim \text{age} + \text{source}$

Table 6. Analysis of variance table.

	Res Df	RSS	Df	Sum of Sq	F	Prob (>F)
1	293	644.06				
2	294	644.10	-1	-0.031955	0.0145	0.9041

The regression lines were then fitted to each dataset (Table 7). For the Spitalfields data we have the following results:

Table 7. Regression line data for Spitalfields.

Residuals				
Min	1Q	Median	3Q	Max
-1.8558	-0.7225	-0.1625	0.6843	2.2708

Table 8. Table showing age has a significant effect on $\delta^{15}\text{N}$.

Coefficients	Estimated std	Error	T value	Prob (>t)
Intercept	15.2560	0.2699	56.523	2e-16
Age	-0.6667	0.1571	-4.244	0.000115

Age has a highly significant effect on $\delta^{15}\text{N}$ ($p=0$ approx) (Table 8). Note that at age zero (intercept) $\delta^{15}\text{N} = 13.3$ with a standard error of 0.18.

It is concluded that the two sources differ in nitrogen isotope composition with the level higher in the bone samples at age 0 (15.3 vs 13.3‰).

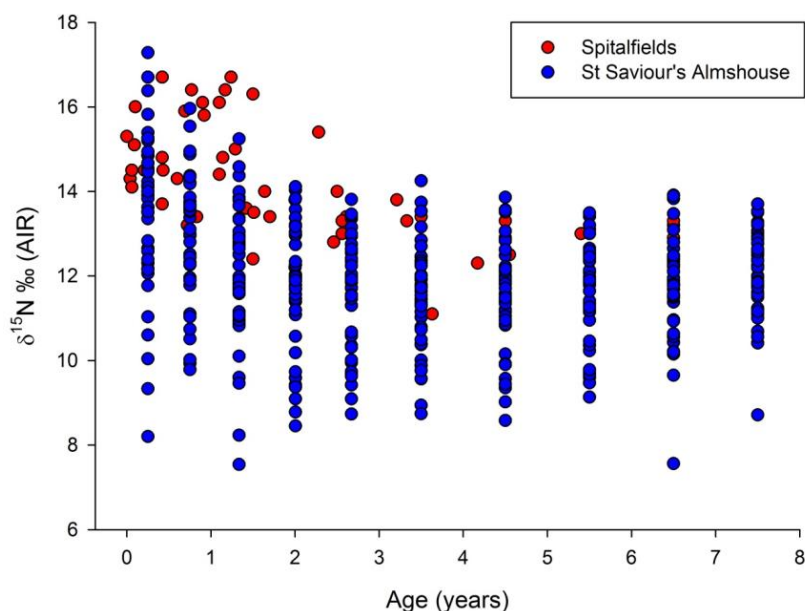


Figure 19. A comparison of $\delta^{15}\text{N}$ throughout the first 8 years for individuals from Spitalfields and St Saviour's Almshouse Burial Ground.

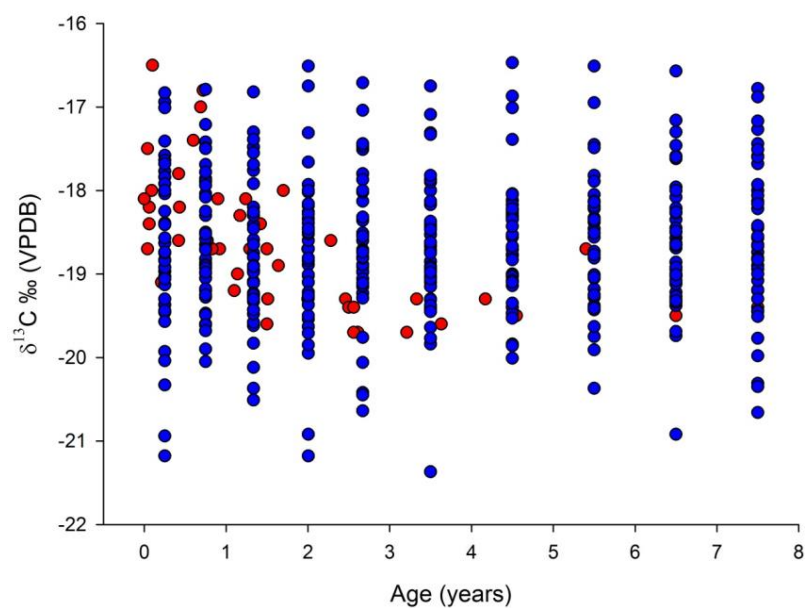


Figure 20. Comparison of $\delta^{13}\text{C}$ over the first 8 years of life from Spitalfields and St Saviour's Almshouse Burial Ground.

Figure 22, Figure 23 and Figure 23 compare the childhood $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ from Lukin Street with the St Saviour's population. Looking at these graphs it appears that there is little difference in $\delta^{13}\text{C}$ between the two populations, but that the Lukin Street population has higher $\delta^{15}\text{N}$. A General Linear Model was used to test the following 2 models:

$$\delta^{13}\text{C} = \text{Age} + \text{Site}$$

$$\delta^{15}\text{N} = \text{Age} + \text{Site}$$

The analysis was undertaken using the `lm` function in R. The data were arranged with two locality codes 1= St. Saviour's, 2= Lukin Street. Age is treated as a continuous variable and site as a factor with two values. Data for ages > 6 years were excluded from the analysis so that both localities covered the same age range.

Table 9. Analysis of variance for $\delta^{13}\text{C}$.

	Df	Sum	Mean	F Value	Prob (>F)
Age	1	0.183	0.18313	0.2548	0.61406
Site	1	2.773	2.77252	3.8570	0.05032
Residuals	355	255.183	0.71882		

The results in Table 9 show there is no significant age or locality effect, although there is almost a significant difference in $\delta^{13}\text{C}$ between the sites.

Table 10. Analysis of variance for $\delta^{15}\text{N}$.

	Df	Sum	Mean	F Value	Prob (>F)
Age	1	135.22	135.217	60.566	7.847e-14
Site	1	55.25	55.253	24.749	1.019e-06
Residuals	355	792.55	2.233		

The results in Table 10 shows the $\delta^{15}\text{N}$ varies significantly with both age and locality.

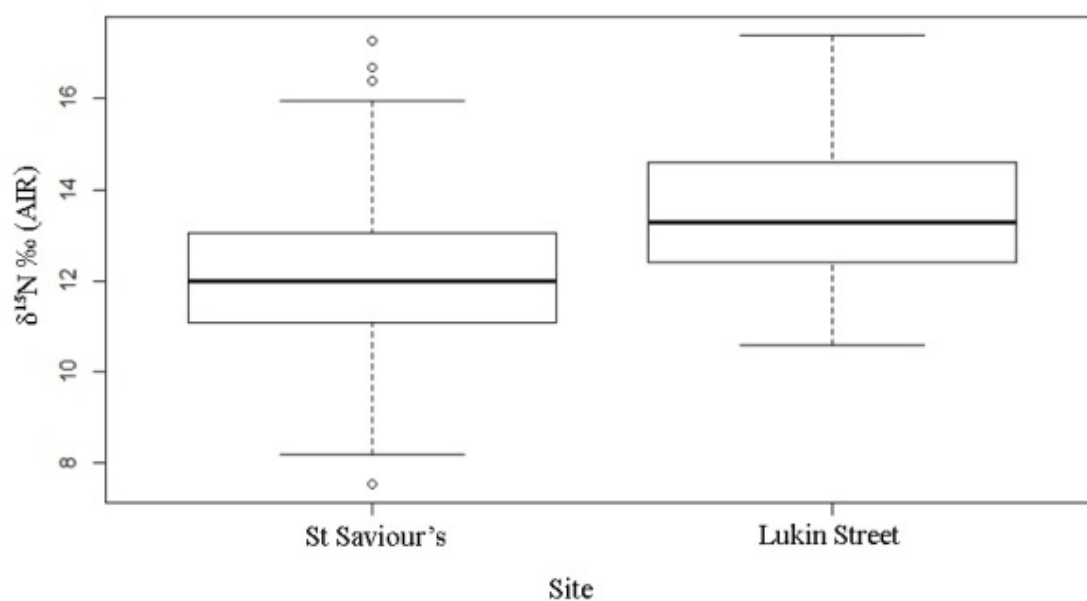


Figure 21. Boxplot showing the difference in $\delta^{15}\text{N}$ between St Saviour's and Lukin Street.

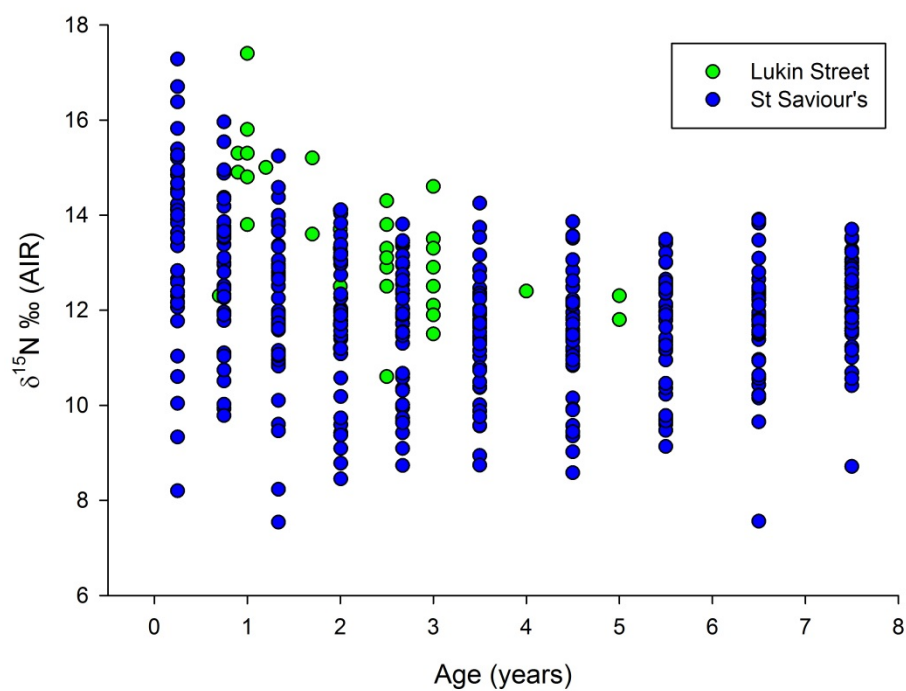


Figure 22. A comparison of $\delta^{15}\text{N}$ throughout the first 8 years for individuals from Lukin Street and St Saviour's Almshouse Burial Ground.

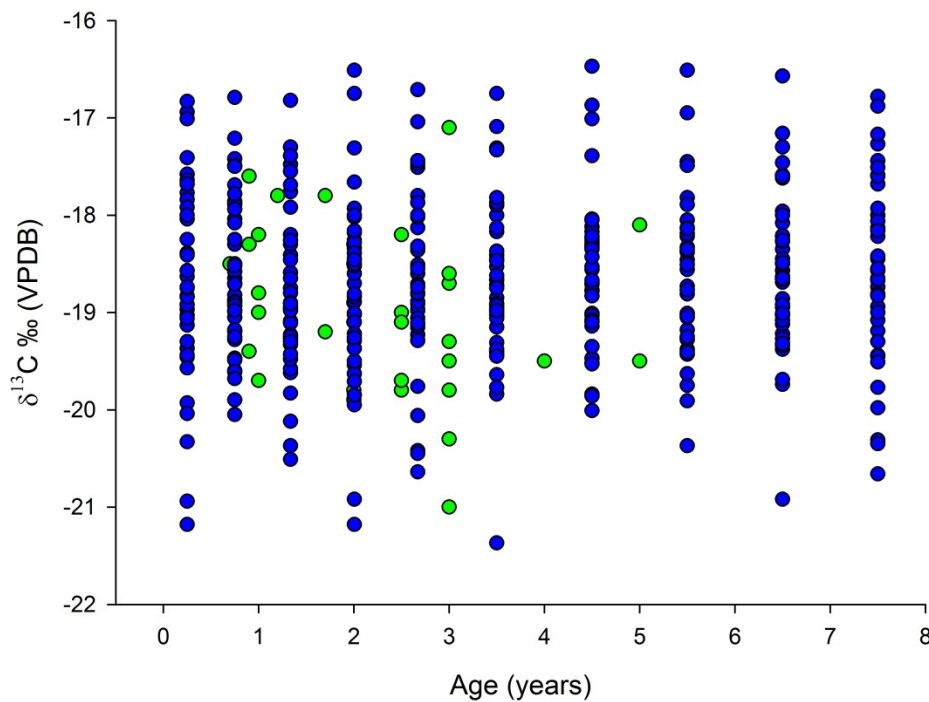


Figure 23. Comparison of $\delta^{13}\text{C}$ over the first 8 years of life from Lukin Street and St Saviour's Almshouse Burial Ground.

5.7.1.1 Discussion

Based on the $\delta^{15}\text{N}$, it appears that breastfeeding and weaning patterns were similar between the populations. There is no evidence that the working class St Saviour's mothers and carers were attempting to buffer their children against their harsh living conditions by extended breastfeeding. This could imply these mothers were not aware of the impact of breast milk or they were not able to breastfeed for longer even if they desired to, perhaps because of the need to work. Alternatively, they were following a uniform custom dictated by fashion, medical knowledge or public opinion which resulted in the two groups rearing their children in similar ways.

Leaving aside class and status, it might have been expected that infant feeding patterns would have differed between the St Saviour's and Spitalfields/Lukin Street populations because the latter two represent individuals who did not survive into adulthood. In the first study to specifically address differences in feeding patterns between survivors and non-survivors Sandberg

et al. (2014) found there was a difference in a Medieval Nubian population. In this group, survivors were weaned earlier than non-survivors. Beaumont *et al.* (2015) also considered differences in diet between survivors and non-survivors across several populations, concluding that non-survivors had a more variable diet than survivors. The similarity between St Saviour's and Spitalfields/Lukin Street might suggest that the deaths of infants and children at these latter two sites was unrelated to their feeding regimes or that their feeding patterns were not deliberately manipulated for the benefit of a sick infant.

The high $\delta^{15}\text{N}$ values at St Saviour's Almshouse Burial Ground might hint at a high trophic level food source, which is similar, but not as high as, the $\delta^{15}\text{N}$ exhibited by the Spitalfields or Lukin Street populations (Nitsch *et al.* 2010, Beaumont *et al.* 2012a). This is interesting as there is some indication that there is a small offset for $\delta^{15}\text{N}$ between bone and dentine, with dentine often having higher $\delta^{15}\text{N}$ than the bone in the same individual. This is perhaps due to the continual formation of dentine during times when bone has stopped growing due to stress (Beaumont *et al.* 2015, Elamin and Liversidge 2013). Elevated $\delta^{15}\text{N}$ seems to be a general feature of post-medieval London individuals and may be related to diet and environment. All groups might have had diets high in animal protein and fats, but without faunal remains to analyse, it is unclear where humans fit in the trophic system. There is a possibility that the difference in $\delta^{15}\text{N}$ between the Spitalfields and St Saviour's populations is caused by analytical differences in mass spectrometry. Both sets of samples were run at RLHA (Research Laboratory for Archaeology and History of Art) at the University of Oxford, but on different mass spectrometers. This could account for small differences, but it seems unlikely that this is the main cause of a statistically significant difference in $\delta^{15}\text{N}$.

Assuming that the difference in $\delta^{15}\text{N}$ is representative of a dietary difference, the following hypothesis is proposed. Higher $\delta^{15}\text{N}$ values for Spitalfields individuals could be explained by the consumption of slightly greater quantities of high trophic level protein compared to the working

class St Saviour's individuals. It would appear however, given the historical documentation and the high $\delta^{15}\text{N}$ values during adulthood of many St Saviour's individuals, that animal protein was not solely a foodstuff of the upper classes (Freeman 1989). This is also reflected in the high $\delta^{15}\text{N}$ values at Lukin Street, which are lower than Spitalfields but higher than St Saviour's. A summary of the comparison between the three post-medieval London sites is given in Table 11.

Much of this chapter has been published prior to the completion of this thesis (Henderson *et al.* 2014). This paper can be found in Appendix D.

Table 11. A summary comparison of the three post-medieval sites.

Site	Isotopic Variability	Sex difference	$\delta^{15}\text{N}$
Spitalfields	High	No	More elevated than St Saviour's and Lukin Street.
St Saviour's	High	Yes	Least elevated out of all three sites.
Lukin Street	High	No	More elevated than St Saviour's, less elevated than Spitalfields.

5.8 Incremental Enamel Analysis

14 individuals were selected from the St Saviour's samples included in the dentine analysis. 4 individuals with first, second and third molars were randomly selected from those which had all three molars, while the rest were randomly selected from the whole sample. At the time of analysis, the results from the incremental dentine samples were unavailable, otherwise selection would have included individual 2127 with a possible C4 signal. Table 12 lists all the samples subject to $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ analysis, which included 14 first molars, 6 second molars and 4 third molars. They were analysed according to the methodology outlined in Chapter 3. The full results are listed in Appendix C.

Table 12. List of individuals and teeth selected for analysis of the enamel.

Individual	Teeth Analysed
661	M1
709	M1, M2, M3
785	M1, M2, M3
799	M1
809	M1
889	M1, M2, M3
2079	M1
2350	M1, M2, M3
2417	M1
3065	M1
603	M1, M2
659	M1
2272	M1
677	M2

5.8.1 Results

The results are shown in Figure 24 and in Appendix C. There is a general trend of progressive $\delta^{13}\text{C}$ elevation throughout the first molar. The average $\delta^{13}\text{C}$ value at 0-6 months is $-13.4 \pm 0.7\text{‰}$, and $-12.7 \pm 0.7\text{‰}$ at 28 months-3 years. This occurs in almost every first molar selected, with the exception of 659. As the trajectory continues in the second molars, there is a pattern of gradual ^{13}C depletion, becoming most depleted at the age of 4-5 years, when the $\delta^{13}\text{C}$ averages $-12.9 \pm 0.2\text{‰}$. The $\delta^{13}\text{C}$ then steadily elevates again for the rest of the second molar sequence. A more pronounced drop in $\delta^{13}\text{C}$ is notable at the age of 8-9 years, the beginning of the third molar sequence. The $\delta^{13}\text{C}$ averages $-13.3 \pm 0.2\text{‰}$ in this age bracket. The four individuals which represent the subsequent age brackets in the third molar mostly show a small, gradual, elevation in $\delta^{13}\text{C}$ with the exception of individual 785. In summary, the results shown in Figure 24 indicate the $\delta^{13}\text{C}$ peaks and troughs three times during the first 13 years of life.

The $\delta^{18}\text{O}$ is relatively constant throughout the first and second molar, averaging $-5.5 \pm 0.6\text{‰}$ in the first age bracket of the first molar, representing the age of 0-6 months, and $-5.5 \pm 0.7\text{‰}$ at the

start of the second molar, representing the age bracket of 3-4 years. Towards the end of the second molar sequence the $\delta^{18}\text{O}$ elevates slightly, although not significantly, reaching an average of $-5.2 \pm 0.7\%$ at 7-8 years. The third molar $\delta^{18}\text{O}$ is comparatively low, all age segments averaging $-6.3 \pm 0.5\%$. There is a slight elevation towards the final age bracket.

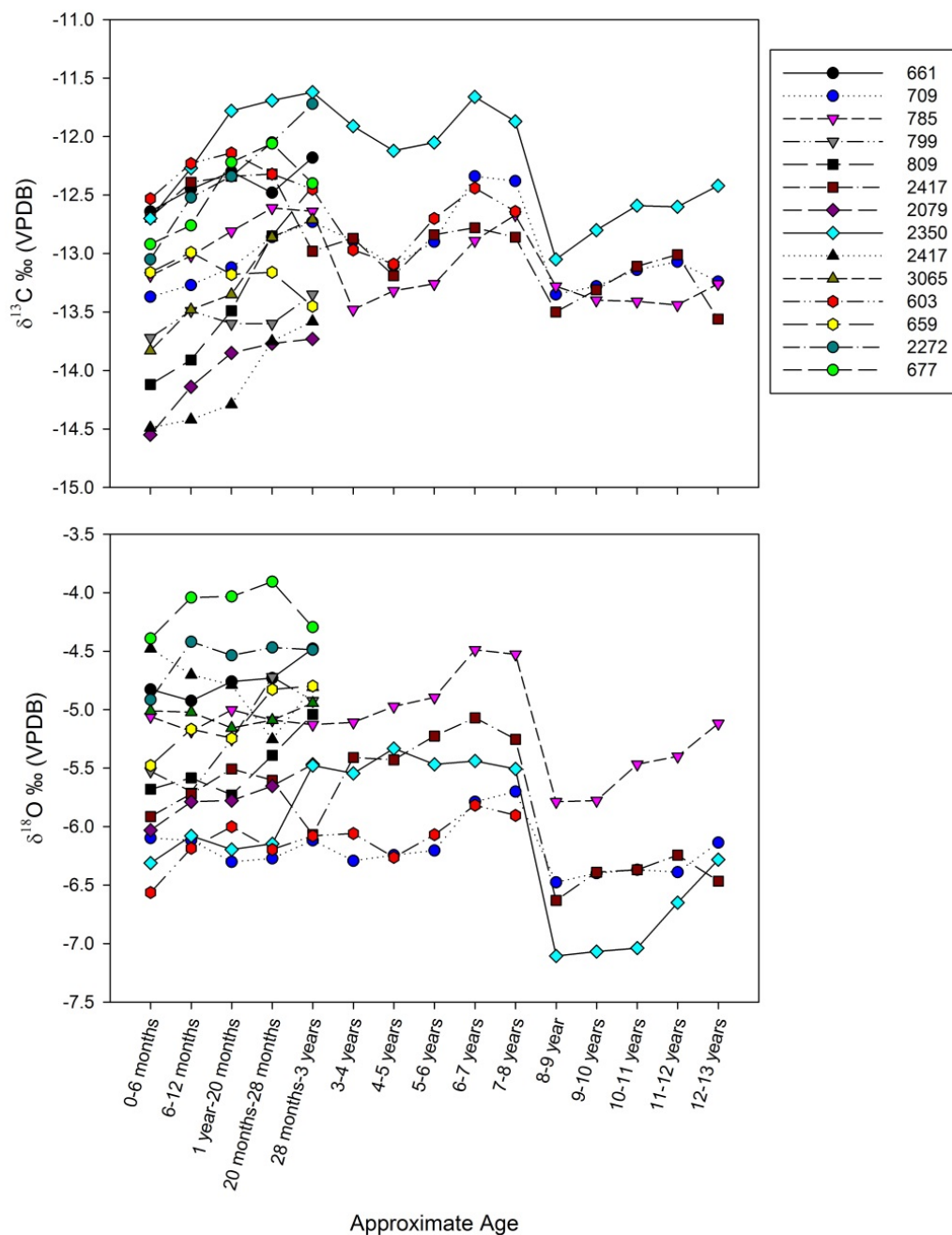


Figure 24. $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ enamel results from the first, second and third molars of 14 individuals from St Saviour's almshouse.

5.8.2 Discussion

In general, there is a large amount of variability between individuals in both the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. The $\delta^{18}\text{O}$ ranges from -3.9 to -7.1‰ and the $\delta^{13}\text{C}$ from -11.6 to -14.6‰. This intra-population variability was also observed in the analysis of the dentine. Relating the range of enamel $\delta^{13}\text{C}$ to the $\delta^{13}\text{C}$ values obtained in the dentine analysis, it is clear that the $\delta^{13}\text{C}$ in the enamel is slightly lower. This is partly a consequence of the cyclic pattern of the $\delta^{13}\text{C}$ in the enamel, although the third molars are also lower in $\delta^{13}\text{C}$. These analyses were performed on the carbonate fraction, so there are few direct comparisons as most other analyses for $\delta^{18}\text{O}$ are performed on the phosphate fraction. However, given that the offset with the carbonate is around 9‰, it appears that the $\delta^{18}\text{O}$ is what might be expected for this population compared to other archaeological sites (Evans *et al.* 2006, Hemer *et al.* 2013, Hughes *et al.* 2014). These London values are also comparable to known values in England (Darling *et al.* 2013), which is unsurprising given that $\delta^{18}\text{O}$ is most heavily influenced by rainfall and modified by diet and drinking habits in humans (Evans *et al.* 2012).

Given the breastfeeding and weaning signal which was observed in the isotopic composition of the dentine, it would be expected there might be an elevation in $\delta^{18}\text{O}$ or $\delta^{13}\text{C}$ in the enamel during the same period. A progressive elevation does occur in the $\delta^{13}\text{C}$, but it does not peak until 28 months-3 years, which is the time when breast milk should be replaced by other foods rather than introduced. The lack of $\delta^{13}\text{C}$ elevation in enamel which could be attributed to breastfeeding is also shown by the $\delta^{13}\text{C}$ in the dentine (see above). It was suggested this could be caused by breastfeeding practices, such as frequency and length of suckling or the early introduction of other foods to infants. These factors would also affect the $\delta^{13}\text{C}$ in the enamel, making this dietary period difficult to distinguish.

There is no change in $\delta^{18}\text{O}$ which is consistent with a breastfeeding signal in any of the selected individuals, which is surprising given that this has been seen elsewhere (Wright and Schwarcz

1998). The signal might be obliterated given the generally short breastfeeding interval for these individuals. The $\delta^{15}\text{N}$ results in Figure 14 clearly show some of the individuals included in this analysis were consuming breast milk in infancy. Two of the most obvious are individuals 3065 and 2272, neither of which shows a change in $\delta^{18}\text{O}$ during the same period. The alternative explanation for the lack of change in $\delta^{18}\text{O}$ is that its use as a tool for observing breastfeeding patterns has been overestimated.

After the peak in $\delta^{13}\text{C}$ the subsequent drop, followed by a repeated elevation suggests there is a reason for the pattern. The pattern of peaks and troughs occurs over years, rather than months, indicating a long term cause. The low $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values at the age of 8-9 years is substantial and the sudden jump indicates the age brackets ascribed to the third molar sequence starts too young. The timing of third molar development is the most variable tooth, making it more difficult to predict the age brackets represented compared to the first and second molars (Levesque *et al.* 1981). The latter two teeth, in contrast, show a more natural sequence between the two, suggesting that the timing of these is more accurate. Despite this problem, the lower $\delta^{18}\text{O}$ in the third molar could imply a different diet or water source during adolescence and adulthood compared to childhood. The large variability between teeth also illustrates we should be cautious when drawing conclusions using only one tooth per individual in other studies.

Even with the difficulty of aging the samples, the $\delta^{13}\text{C}$ pattern cannot be related to discrepancies associated with aging the samples, as the patterns are shown within a tooth. This is particularly clear with the second molar, as the $\delta^{13}\text{C}$ lowers and elevates within this one tooth. It is notable, that while there is variability in the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$, all individuals with first, second and third molars show the same pattern, suggesting there is a common cause.

The results can be compared to a study of highland Guatemala by Wright (2013). Sequential enamel sampling showed a gradual decline in $\delta^{13}\text{C}$ between successive teeth. This was interpreted as a decline in breast milk and the effects of increased maize consumption. It was concluded that

changes in $\delta^{18}\text{O}$ were consistent with seasonality and the decreasing contribution of breast milk. There is little indication C4 foods were consumed by the St Saviour's population, with the exception of individual 2127 who was not included in the enamel analysis. This makes this aspect of the comparison obsolete. However, the interpretation given by Wright (2013) is that the $\delta^{13}\text{C}$ is more heavily influenced by the consumption of foods other than breast milk. $\delta^{13}\text{C}$ elevation caused by breast milk consumption is minor enough that even small amounts of other foods may mask this dietary period.

There is a possibility the sampling method could be affecting the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ results in the St Saviour's study. Different parts of the enamel are mineralized to different degrees and at different times (Suga 1982). In a study using an intra-tooth method of sampling enamel in bovids, similar to that used in this study, Zazzo *et al.* (2005) found there was a large variation in $\delta^{13}\text{C}$ within a sample. This means the isotopic composition of each sample is representing a longer period than previously thought. They suggest that sampling the enamel towards the enamel-dentine junction lessens the dampening effect caused by the mineralization process. Avoiding the enamel closest to the surface was not possible in this study because the method favoured taking a greater number of intra-tooth samples. To achieve a large enough sample for analysis, the enamel was taken from different depths towards the enamel-dentine junction on the crown. Enamel closest to the cemento-enamel junction is thin, meaning the enamel sample was drilled off throughout the whole depth of the enamel. This means these samples represent enamel mineralized at different times and to different degrees. Samples of enamel from the thicker regions, such as the middle of the crown, were taken from nearer the surface, as a large enough sample could be achieved without penetrating the enamel closest to the dentine. These samples would have been mineralized later and more heavily than the other samples.

5.9 Summary

$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ analysis of incremental dentine samples from the first molars of 42 individuals buried in the St Saviours almshouse burial ground reveal the contribution of breast milk declined at or before 6 months of age for the majority of individuals. This clearly suggests the 18th century trend of dry feeding infants with foods such as pap and panada from birth had either ended, or was less widely used than previously thought. While the majority of individuals show a breast milk isotopic signature early in life, variability in infant feeding practices is shown by a lack of elevated $\delta^{15}\text{N}$ in some individuals, suggesting some of these people were not breastfed. This could be the result of a high death rate amongst mothers, the need for mothers to return to work following the birth, or cultural factors.

$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ from the more limited number of second and third molars provide information on the later childhood trajectory into adulthood. Results from these second molars suggest children aged up to around 8 years had lower $\delta^{15}\text{N}$ values than those of adults. This could be caused by accelerated growth rates during this period, resulting in greater nitrogen requirements and reduced fractionation. The third molar results reflect a more elevated $\delta^{15}\text{N}$ value, which is similar to the adult values obtained by Nitsch *et al.* (2011) and Beaumont *et al.* (2012a). This elevation could be the result of a reliance on high trophic level foods, such as fish, or could be a consequence of the heavy use of manure on crops. In this population the $\delta^{13}\text{C}$ shows limited variability and does not reflect a breastfeeding signal, where a small elevation of 1‰ might be expected. While many populations analysed do display this elevation, St Saviour's is not alone in showing limited variation. This could be the result of different maternal diets, or the frequency and duration of suckling.

A small but statistically significant sex difference in stable isotopes for males and females during their childhood is observed. This could be the result of a dietary difference between males and females or could be a physiological response to stress, with females coping better than males.

The elevated incidence of stress shown by the males in the form of linear enamel hypoplasia could be a physical manifestation of this.

A comparison of the results obtained from St Saviour's with the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results from the middle class Spitalfields and working class Lukin Street populations suggests a similar pattern of breastfeeding longevity and variability. This might suggest that class was not a major factor in the likelihood that a mother would breastfeed during this era in London. While all populations had elevated $\delta^{15}\text{N}$, the more elevated $\delta^{15}\text{N}$ in the Spitalfields population might be a consequence of greater meat and fish consumption amongst these people. The difficulty of comparing results from survivors with non-survivors is a difficult issue which needs to be addressed in a separate study.

$\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ results from the incremental enamel analysis show no pattern which could obviously be attributed to infant feeding strategies. The cyclic elevation and decline of the $\delta^{13}\text{C}$ suggests the cause may be related to the sampling strategy.

Chapter 6 Hypoplasia, Health and Diet

In this chapter the results from two methodologies are combined to explore whether hypoplasia and dietary change, over the transition from breast milk to solid foods, are correlated. The theory that weaning causes hypoplasia is frequently quoted but it has been difficult to test directly. A synopsis of the studies exploring this relationship is provided, which gives the background to the current debate. The results from St Saviour's Almshouse Burial Ground are used to consider whether this population shows a correlation between hypoplasia and weaning.

The hypoplasia results are subsequently considered in relation to sex and class. In Chapter 5, a difference in hypoplasia prevalence between males and females in the St Saviour's Almshouse burial ground is reported. It suggests males were suffering more stress than females during their early lives, a pattern which is explored further here. The general effects of industrialization on children is considered, including how hypoplasia incidence at St Saviour's Almshouse compares to other post-medieval sites around London, how class and wealth may have influenced early childhood experiences and what variation in early life experiences within the population could mean.

6.1 Hypoplasia and Weaning Time

The cause of most incidences of enamel hypoplasia is unknown unless a medical record is available (Hillson 1996). A possible exception to this rule is hypoplasia which occurs due to stress associated with the withdrawal of breast milk and weaning in childhood (Rose 1977). This is potentially a stressful time because immunologically protective breast milk is withdrawn at the same time as potentially contaminated foods are introduced to a child. If weaning is related to hypoplasia, observing these defects could be used to identify when this childhood dietary transition occurred by simply looking for the age when hypoplasia peaks within a population. As hypoplasia assessment normally takes the form of an easy, inexpensive, visual analysis of the

teeth, it could avoid the use of more costly isotopic analysis to predict infant feeding patterns. The relationship however remains disputed.

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ composition of the incremental dentine samples is compared to the timing of linear enamel hypoplasia to assess whether dietary change and stress is related in the St Saviour's burial ground population. This case study provided a large enough sample for the relationship to be considered and is a well contextualised, historical site from an industrial UK population, a group which has not been previously subject to research concerning weaning patterns and hypoplasia incidence.

6.1.1 The Debate in the Literature

The early literature indicates a possible link between weaning and hypoplasia, forming the basis for the current investigation. In a study of modern enamel hypoplasia verses hypoplasia in a prehistoric population, Rose (1977) reported differences in the part of the tooth showing hypoplasia. While the modern group in the study suffered from defects predominantly in the cuspal part of the enamel, the prehistoric group suffered from hypoplasia in the cervical part of the enamel. This difference was attributed to cultural variations, stemming from differences in weaning age and nutrition. In a similar study, Goodman *et al.* (1984) compared peak frequencies of hypoplasia between Pre-Mississippian and Mississippian populations from Dickson Mound, Illinois. The hypoplasia peak in the Mississippian period occurred 0.5 years earlier than the Pre-Mississippian period. It was concluded this was caused by an earlier and sharper weaning period during the Mississippian period as a consequence of an increase in the production and consumption of maize.

A later study compared hypoplasia peaks in a 19th century industrial era poorhouse cemetery from New York with hypoplasia peaks from other populations (Lanphear 1990). The peak incidence occurred in the poorhouse population between 3.5-4 years in the canines and 2.5-3 years in the central incisors, an age believed to coincide with the weaning period. This contrasted

with the peak in prehistoric populations which occurred around 2-6 years and a peak in industrial modern populations at around 0-3 years, variations which are interpreted as reflecting differences in infant feeding practices (Lanphear 1990).

To understand when childhood dietary changes would have been occurring in each population, historical references reporting infant diet have been compared to the peak age of hypoplasia. Corruccini *et al.* (1985) considered the formation of hypoplasia in 17th-19th century Caribbean slaves, which peaked at 3-4 years, an age which is later than many records in other populations. The authors suggest this was caused by the late weaning of these children, at an age of 2-3 years. In a review of the same population, Jacobi *et al.* (1992) drew the conclusion that the timing of hypoplasia was due to weaning stress, but that the underlying cause of the serious lesions was due to disease, specifically syphilis. In a further historic study, Moggi-Cecchi *et al.* (1994) interpreted the peak in hypoplasia for a 19th century population from Florence, which occurred between 1.5 and 3.5 years, as consistent with a weaning of age of between 12-18 months. They considered the width of the hypoplasia and used this to suggest the patterns reflected the time when supplementary foods were added to the diet.

Studies of hypoplasia incidence in modern populations provide an important source of information, as infant feeding practices can be recorded and problems such as tooth attrition are in some instances less significant. A study of Mexican children showed a peak occurred during the 12-36 month period, an earlier time than is often reported in archaeological populations. It was concluded that this early peak is caused by weaning, although the authors concede that work in the future will help to clarify this relationship (Goodman *et al.* 1987). Similar results from Jordanian individuals showed a correlation between weaning and peak hypoplasia (Alcorn and Goodman 1985).

The incidence and timing of hypoplasia in animals has provided further clues about the relationship between life events and stress. Dobney and Ervynck (2000) compared the hypoplasia

results from different assemblages of domestic pig, showing the peaks were similar to each other in all populations. The peak occurrence on the first molar was attributed to birth and weaning. Peaks on teeth developing subsequently were attributed to stress caused by malnutrition during winter months. The authors base the weaning event caused by hypoplasia on an assumption that weaning amongst domestic pigs occurred in month 3 or 4, a timing based on the weaning patterns amongst wild boar.

A study of the timing of hypoplasia and differences in wild and captive giraffe showed hypoplasia did not occur in wild animals, but captive animals display peaks at three periods, the earliest of which is attributed to weaning stress. The authors conclude the reason this peak does not occur in wild animals is due to weaning taking place later in captive animals (wild giraffe can wean at 1 month old, while captive animals may wean up to 1 year old). This variability makes it difficult to correlate the weaning and hypoplasia events (Franz-Odenaal 2004). This problem was rectified in another study comparing hypoplasia to weaning age, where oxygen isotopes were used to determine when weaning took place amongst the Pleistocene giraffae, *Sivatherium hendeyi*. A correlation between the two was found (Franz-Odenaal *et al.* 2003).

In the only study which compares dietary stable isotopes with hypoplasia in humans, Sandberg *et al.* (2014) examined the timing of hypoplasia in five individuals from the Medieval Nubian site of Kulubnarti. The results were considered relative to the early life history stable isotope projections. The five individuals showed a similar infant feeding pattern to each other, with weaning ceasing between 2 and 5 years of age. 4 out of 5 individuals had incidences of hypoplasia which coincided with the decline in $\delta^{15}\text{N}$. It was concluded there was a positive correlation between the timing of weaning and hypoplasia in these medieval Nubian individuals.

While the association between weaning and hypoplasia has been partially accepted or in many cases assumed, aside from the study by Sandberg *et al.* (2014) there have been few attempts to test the hypothesis. At an early stage of the debate, Buikstra and Cook (1980) stated there was

not enough evidence to yet conclude clusters of hypoplasia are the result of cultural factors. They cautioned that hypoplasia patterns are not fully understood and emphasized the population specific nature of these defects (see Chapter 2). The idea that hypoplasia is highly variable by population is supported by the range of results obtained from different assemblages across post-medieval London presented later in this chapter. Katzenberg *et al.* (1996), in their review of the debate, make the point that the study by Buikstra and Cook (1980) has been frequently misquoted in support of the relationship between hypoplasia peak and weaning time.

Since the initial cautions on the use of hypoplasia, a number of studies have emerged which do not support the hypothesis that weaning causes hypoplasia. Many of these use the same methodologies as those which support the hypothesis. Wood (1996) examined an 18th century frontier American population, which had low levels of hypoplasia before 1.5 years and a peak at the age of 2.5-3 years up to 4-4.5 years. The author believes this is too late to be caused by weaning and disease is a more likely cause. The low incidence prior to 1.5 years is suggested to be caused by attrition or the enamel's lower susceptibility to hypoplasia in this region.

In a study which specifically addresses the hypoplasia-weaning debate, Blakey *et al.* (1994) assessed the enamel hypoplasia of African American slaves from Maryland and Virginia, USA, who were known to have suffered a high incidence of stress. Historical sources showed these people weaned their children between 9-12 months, while the peak in hypoplasia occurred in the population between 0.5-3.75 years, a period which is notably later than the weaning age. In this case, an assumption is made that the historical information is accurate and that it applies to the population they tested. The paper states that the 9-12 month weaning period was historically known *from other plantations*, a potentially misleading source of information.

In a similar study, hypoplasia incidence from a black slave population in South Carolina showed males suffered from stress slightly earlier than females, peaking at 2-3 years and at 3.5-4.5 years respectively (Rathbun 1987). In line with the study of black slaves by Blakey *et al.* (1994), a

weaning age of 1 year was predicted for these people based on historical records (Steckel 1979). The hypoplasia peaks are attributed to increased exposure to parasites and infections, or weaning stress. The authors of these two similar case studies have chosen different explanations for the peaks in hypoplasia, despite historical information pointing towards a similar weaning strategy.

6.2 Central Problems in the Debate

Faunal studies have provided some useful examples supporting the association between hypoplasia and weaning. Their major drawback however is that they are not directly comparable to humans, who may receive medical intervention during periods of ill health, decreasing the incidence or severity of hypoplasia. Humans are capable of creating breast milk substitutes, unlike wild animals, which are almost certain to die if breast milk cannot be provided. The seasonal breeding patterns of many animals is also a key difference, as they are capable of reproducing all year round. Many mammals give birth to their young at specific times of the year, meaning their young will be affected by external stresses, such as seasonal change, at the same age. Peaks in hypoplasia within an animal population are more likely to be related to these external factors compared to humans, who would be stressed at different ages depending on the time of year a child is born.

The intrinsic problem with both the animal and human studies is that it is difficult to establish when weaning took place. Humans have the disadvantage that both social and biological reasons will determine the patterns in infant feeding, which means without controlled studies or methods which accurately determine infant feeding, defining the association between weaning and stress is often arbitrary. The lack of consensus across studies might be related to highly variable infant feeding regimes (and in turn the populations analysed) or to the methods used to determine the relationship. The criteria which is used to define how hypoplasia relates to weaning is frequently overlooking in the publications. Some studies report a peak incidence of hypoplasia as a direct cause of weaning (i.e. a child is weaned at 2 years and the peak incidence of hypoplasia occurs at 2 years), while others cite weaning as a non-direct cause of hypoplasia (i.e. a child is weaned at 2

years and the peak incidence of hypoplasia forms at 3 years). Although they may be caused by the same underlying dietary change, the first is the short term effect and the other the long term effect of the weaning strategy. While the long term effects of the weaning strategy could produce a peak in hypoplasia after the main dietary transition has occurred, without a direct correlation it is impossible to test.

6.3 St Saviour's Almshouse Burial Ground

The present study uses all the M1 teeth which were analysed using stable isotopes and assessed for enamel hypoplasia, as described in Chapter 3. The original selection criteria excluded individuals with carious lesions and those with serious attrition. Only first molars were included in this study because their developmental age covered the period when breastfeeding and weaning took place.

This burial ground is an important site to test the weaning and hypoplasia relationship for several reasons.

1. The method does not rely solely on weaning information from historical sources, a potentially problematic resource, particularly when generalizations are applied across populations.
2. No assumptions about weaning age are made, as infant feeding is established through scientific means using carbon and nitrogen stable isotopes.
3. The population has a reasonably high incidence of hypoplasia on the teeth, making the study viable.
4. Incremental isotope results show weaning began at or before the 0-6 month period in this population. This is preferable, as the major dietary change does not occur around the age of 2 years, when a high incidence of hypoplasia is often recorded. This minimises the chance that a correlation would be coincidental.

5. It is likely weaning was a stressful event in this period due to poverty and nutritional hardship. Historical evidence suggests pap and panada, bread based foods, would have formed a major component of the weaning diet. The exclusion of fresh fruit and vegetables would have been nutritionally devastating. This poor weaning diet is reflected in the high rate of infant mortality experienced during the industrial transition. These pieces of evidence indicate that children from this population would be stressed by the introduction of weaning foods to a greater degree than populations with a more appropriate weaning diet.
6. The samples have been preselected to only include those which show limited attrition and no caries.

Several non-breastfed individuals are included in the analysis. These are individuals 659, 661, 885, 962, 2127, 2362, 2423, 4044 and 4052. Their identification is based on a lack of $\delta^{15}\text{N}$ elevation during the early stages of life. They have not been excluded as they make up only a small proportion of the whole population (17% or less) and in some cases breast milk provision is ambiguous. These individuals were also considered separately, to see how hypoplasia affected non-breastfed children.

6.4 The Results from St Saviour's Almshouse Burial Ground

The results in Table 13 and Figure 25 show the incidence of hypoplasia was lowest in the first segment, aged at approximately 0-6 months. This section produced only 3 incidences of hypoplasia in total. After this low initial prevalence, the number of defects increased sequentially, until the number of incidences peaked during the 20-28 month age bracket. The number of incidences totalled 15 during this period. The final segment with 11 incidences showed a drop in hypoplasia, corresponding to stress occurring at approximately 28 months-3 years. 15 individuals showed no incidence of hypoplasia. Out of the non-breastfed infants, 6 individuals showed no

incidences of hypoplasia, while individual 4052 has one incidence at 0-6 months, 4044 has an incidence at 6-12 months and 661 has hypoplasia at the age of 20-28 months.

The $\delta^{15}\text{N}$ results have been discussed in full in Chapter 5. A childhood peak in $\delta^{15}\text{N}$ occurs in the first age bracket of 0-6 months, dropping after this age. This has been interpreted as a breastfeeding signal, followed at or before 6 months, by a decline in the contribution of breast milk and the introduction of weaning foods. It is unclear what these weaning foods are, but historical evidence suggests pap and panada are likely to have contributed to the diet (Fildes 1986, Wickes 1953b). A dip in childhood $\delta^{15}\text{N}$ could point towards the consumption of lower trophic level foods compared to adulthood, but could equally reflect the physiology of children.

Figure 25 compares the timing of the hypoplasia and the time when weaning occurred. Images of the enamel casts can be found in Appendix E. The peak in hypoplasia occurs at a later time (20-28 months) than the first introduction of solid foods and the initial reduction in breast milk (after 6 months of age).

Table 13. The position of hypoplasia on each tooth selected for analysis.

Individual	1st section	2nd section	3rd section	4th section	5th section
603	1				2
607			1		
629				1	1
659					
661				1	
677			1		
681		1	1		1
709		1		1	1
767					
785				1	1
799				1	
801				1	
809		1	1	2	1
813					
823	1			1	
843				1	
885					
889					
895			1		1
921					
949					
956			1		
962					
2079			1		
2097				1	
2127					
2151				1	
2199			1		
2272					
2350				1	
2362					
2406					
2408					1
2417					
2423					
3011				1	1
3065			1		
4005					
4044			1		
4050		1			
4052	1				
4084		1	1	1	1
TOTAL	3	5	11	15	11

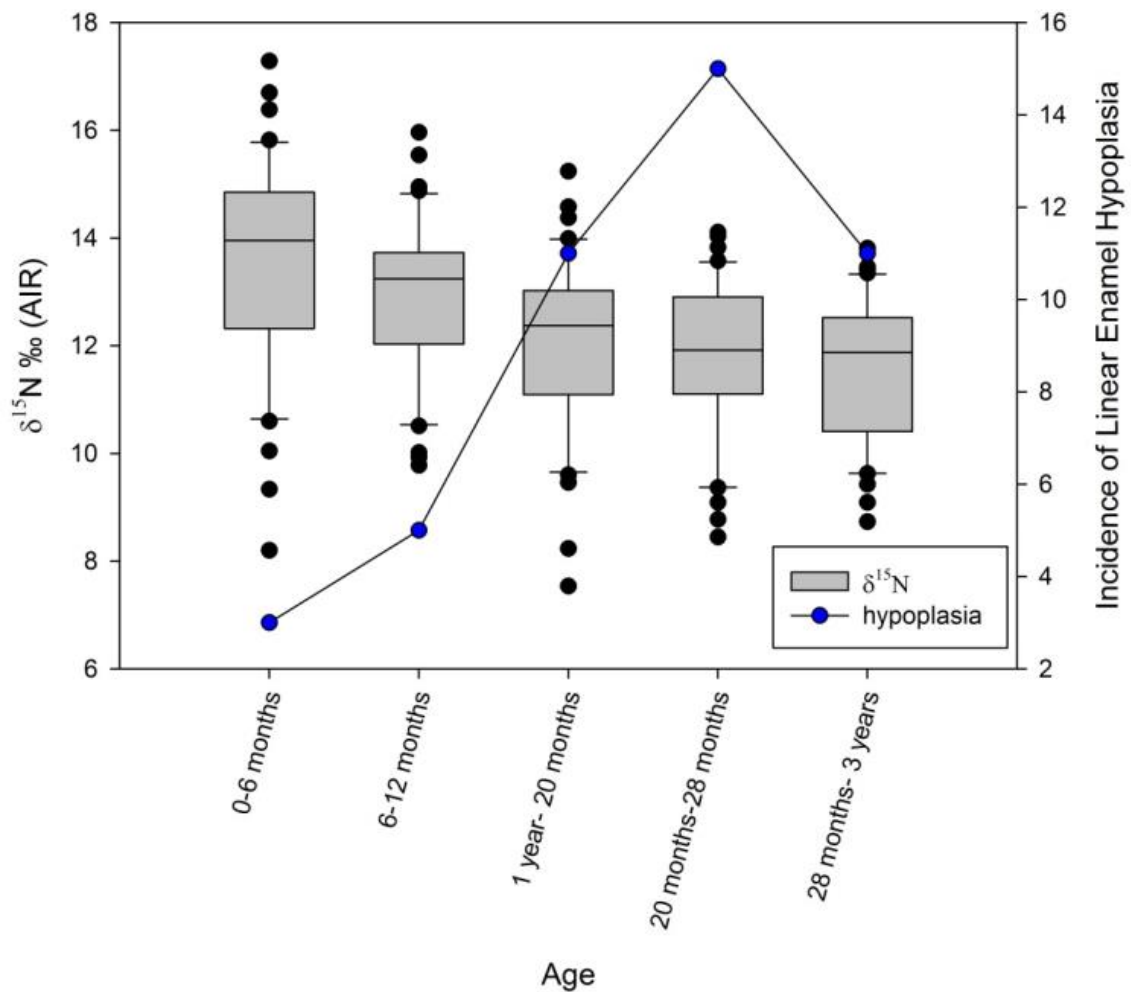


Figure 25. The number of incidences of enamel hypoplasia in each age bracket is shown as a line graph, which is plotted in relation to the diet, shown as box and whisker plots.

6.5 Interpretation and Discussion

The 0-6 month age bracket has the lowest number of defects, which is expected due to the mechanism of formation of the cuspal area. There is an underrepresentation of hypoplasia in the cusps due to the formation of the enamel in this region, resulting in the developmental features being hidden. This means hypoplasia is not visible on the outer crown surface in the cuspal area (Rose 1977). In contrast to the cusps, the central part of the enamel is more likely to show hypoplasia than any other part of the crown, a phenomenon which is probably to do with the thickness of the enamel in this region (Goodman and Armelagos 1985b). The peak in hypoplasia

at 20-28 months occurs in this part of the enamel. This difference in hypoplasia presentation has to be taken into account in the interpretation. Although stress may not be observable during the breastfeeding period, this does not mean it did not occur. No attempt is made to interpret the health of infants during this time. As weaning occurred after the development of the cusps, it is this time in life which is the focus of the interpretation.

The results suggest there is no direct correlation between the beginning of the weaning process and the peak in the age of linear enamel hypoplasia. The incidence of hypoplasia peaks after other foods have become the main form of subsistence. If a peak in hypoplasia occurred in the early segments, it could be concluded that the initial decrease in breast milk was causing the hypoplasia. Alternatively, if the peak in hypoplasia occurred around 1 year- 20 months, it could be concluded that a diet with limited breast milk caused the hypoplasia peak. Even though there is a small delay in the development of the enamel in relation to the dentine (Raj Bhussry 1976), this is minimal compared to error caused by the time it takes for the stable isotopes to be incorporated into the tissues (around 5 weeks in bone) (Nitsch *et al.* 2010, Hillson 1996). While the lag for dentine in humans has received little attention, it has been estimated there is a 7-11 week lag in bovine dentine due to the mixing of the dentine layers (Zazzo *et al.* 2005). If this latter error is taken into account, it increases the difference between the time when weaning finishes and when the peak incidence of stress occurs. It is more difficult to assess the lag between an episode of stress and the time for hypoplasia to form because the formation of enamel is a complex two-step process. As hypoplasia is thought to occur in the maturation stage, this would suggest a lag could be present. The lag in hypoplasia showing and the lag in isotopes being incorporated into the dentine possibly cancel each other out.

It is possible the late occurrence of hypoplasia at 20-28 months is caused by delayed stress due to weaning. It is known breast milk has long and short-term immunological effects. If it takes several months for the immunological protection of breast milk to wear off after a child is weaned, it is

conceivable that a delayed stress reaction could occur (Michie *et al.* 1998, Fewtrell 2004). Unless this delay could be predicted, it would make it unviable to use peaks in hypoplasia to predict weaning age in other populations. It is clear from the variable timing of the peaks in hypoplasia discussed in the literature review that this is a possibility. Alternatively, it is possible that the final removal of a small quantity of breast milk from the diet at this point, which can be difficult to identify using stable isotopes, had a major detrimental impact on the children's health. In the St Saviour's population the end point of weaning is hard to interpret because the childhood dip in $\delta^{15}\text{N}$ may represent physiology rather than the diet. Other potential reasons for a hypoplasia peak to occur in the 20-28 month period fall into a number of categories. Physiological factors to do with enamel development, the introduction of external factor(s) which become influential at this age and the behavioural development of the child are all possible influences.

Regarding the environment in which a child is raised, there may be periods when infants are socialised more with other children, increasing the chances of disease transmission between children at particular ages. In the UK today, children often become ill when they start school as they are exposed to other children and consequently diseases their immune systems have never before had to cope with. This can cause epidemics throughout the population (Johnston *et al.* 2006). Although it is unlikely the children from St Saviour's parish were schooled at this early age, there may have been similar social reasons why a peak would occur, for example children could have been collectively nursed at the age of 2 years. Such a scenario is not mentioned in the literature, in contrast to the free care provided at home by older siblings amongst poor families. Amongst richer families a governess or nurse would have been in charge of children (Hughes 1993, Gathorne-Hardy 1973).

The industrial environment in London during this era would, however, have influenced the foods available to a child and diet is known to influence patterns of hypoplasia. This is particularly notable for dietary deficiencies, such as Vitamin D and C or in cases where famine occurs (Schour

and Massler 1945, Harris and Sullivan 1960, Zhou and Corruccini 1998). At St Saviour's this would seem a rational explanation for some of the incidences of hypoplasia, although it seems unlikely that this pattern in hypoplasia would be seen across many different populations and diets, if it was the sole explanation.

The presence of a neo-natal line in first molars is common across all populations, regardless of cultural influences. This suggests there are common physiological causes for at least some of the incremental features which develop in teeth (Whittaker and Richards 1978). There are also developmental markers in childhood which are believed to relate to disease incidence. Children around the age of 2 all have intrinsic developmental similarities (Plooij 1987). Children start to move around more as they learn to crawl and walk, they explore their environment, including putting objects, which are potentially contaminated, in their mouths. Foreign objects in the mouth can result in blunt force trauma to the teeth during their development which can cause hypoplasia, although fenestrations on the enamel are a more common occurrence (Suckling 1980, Skinner and Hung 1989). Although children across populations will differ slightly in their development due to nutrition, disease, and race amongst other factors, there are developmental markers which are common to all of them.

There is an interaction of the central nervous system with the immune system throughout life. At various intervals in a child's development, reorganization of the central nervous system occurs, which is also thought to have an impact on the function of the immune system. This has been shown to be the case with chimpanzees, which have abrupt reorganizations at the specific ages of 2, 5, 7, 11 and 18 months, leaving the animal more vulnerable to disease. Periods of stress are more likely to occur during these intervals (Plooij 1987). Evidence suggests that for human children, periods of reorganisation may occur at the ages of 2, 5, 7.5-9, 12 and 18 months. During these intervals developmental changes occur, including physical and vocal advancement and cognitive development, the timing of which coincides with peaks in illness (Plooij and van de

Rijt-Plooij 1989). A physiological transition, common to children across populations, is supported by the data. Small variations in the timing of the peaks may be caused by small differences in the timing of the children's development.

One of the problems with relating the reorganisation argument to peaks in hypoplasia is that while a major peak occurs around the age of 2, there is little evidence for subsequent peaks which should occur during later periods of reorganisation. There are too few second and third molars from St Saviour's Burial Ground to make a viable study of later hypoplasia development in this population, but there is no mention in the literature of trends in hypoplasia occurring across populations during all these periods. This may in part be due to the greater interest in the weaning period, however it remains clear that there are no obvious cross-cultural later peak trends. It is possible that some periods of reorganisation are more stressful than others. A vast number of changes take place around 2 years of age, which could perhaps suggest this period would be particularly difficult for a child compared to other reorganisation periods (Plooij 1987). The immune system may also be weaker in toddlers than in later childhood. Our understanding of these vulnerable periods needs greater attention if we are to understand how they might influence hypoplasia patterns.

Non-breastfed infants have a low level of hypoplasia at St Saviour's, which is unexpected given their lack of access to the immunological protection that breast milk can provide. Although surprising, in an early medieval Great Moravian study, stress was not associated with infant feedings patterns, despite large differences in infant feeding practices within the sample (Kaupová *et al.* 2014). Similarly, a high rate of hypoplasia is known to occur in populations which breastfeed, sometimes for extended periods of time, demonstrating that environmental factors may be more influential in stress incidence (Tsutaya *et al.* 2014). Nevertheless, it is known from historical records, such as bills of mortality and contemporary sources, that infants without breast milk were less likely to survive in such populations and the immunological benefits of breast milk

are today unchallenged (Fildes 1995, Fildes 1986). The results of non-breastfed children at St Saviour's Almshouse are therefore probably not reflecting the fact that these infants were healthier, but they were immunologically challenged from a young age. Most of these infants would have died, but those who survived infancy were advantaged because their immune systems were able to cope with pathogens more effectively during their childhood.

6.5.1.1 Implications for Other Studies

In the St Saviour's Almshouse population, the position of the linear hypoplasia cannot be used as a reliable indicator of the period when weaning took place, as even if it reflects the final cessation of breast milk consumption, it does not reflect the main events in the process, particularly the initial drop in breast milk consumption around 6 months. The results thus support the conclusion drawn by Blakey *et al.* (1994), that weaning is not directly related to the peak in hypoplasia. While this study shows no direct temporal correlation, the results cannot be used to produce a universal rule stating that weaning never causes hypoplasia.

Other populations would benefit from stable isotope analysis to help establish when dietary transitions occurred. If these trends are genuine, and a correlation does occur in some populations, it is likely to be due to population specific factors. This may include the type of weaning foods to which a child is introduced and whether the foods contain all the nutritional requirements. As stated previously, different populations are susceptible to different pressures and different weaning foods will have different effects on the child. In the examples provided, two are black African slave populations in the USA (Blakey *et al.* 1994, Rathbun 1987), groups which are known to have suffered high rates of stress which did not have suitable weaning foods available for their children. Similarly, the transition in America to maize production, as reported by Rose (1977), is thought to have been a difficult era for children, who could not get the nutrients they required during weaning.

A less stressful weaning period may be experienced by populations with better weaning foods, which are introduced at an appropriate time. It could be hypothesised that weaning suddenly would be more detrimental to a child because its body would have less time to adapt to the nutritional changes and the immunological protection provided by breast milk would be removed before a child had time to develop its immune system sufficiently. The alternative, that weaning is extended, could also be problematic if a child is not receiving enough non-breast milk nutrition early enough in its life. Contaminated foods would have a similar effect (Iversen and Forsythe 2003). The length of time the transition occurred over and the abruptness of the transition could be factors which are integral to understanding whether a population may or may not have a correlation in hypoplasia and weaning (See Chapter 1).

6.6 Post-Medieval London Hypoplasia and its Variability Regarding

Class and Sex

6.6.1 Enamel Hypoplasia and Sex

There are a limited number of published large scale post-medieval weaning studies. This prevents a more detailed comparison of weaning age and childhood diet in relation to the effects of socio-economic circumstances on feeding practices. In contrast, enamel hypoplasia studies are often routinely carried out for osteoarchaeological reports in the commercial sector, providing data comparable to St Saviour's Almshouse Burial Ground. A table comparing the incidence of enamel hypoplasia across different post-medieval London cemeteries has been compiled to show the variation (Table 14). The table shows the prevalence of enamel hypoplasia differs between assemblages and the proportion of males or females affected shows similar variation between populations. It is noted whether a cemetery was conformist or otherwise as non-conformist cemeteries often included immigrants such as Irish Catholics, whose early lives differed from the local population. Some sites suggest males were the healthier sex, others indicate females were healthier. Figure 26 shows the geographical relationship of the sites to each other.

The assemblages in Table 14 are all London based and several are located near each other due to the redevelopment of some regions around London and the commercial archaeological units involved. The New Bunhill Fields assemblage from Southwark has a similar percentage of hypoplasia in relation to sex compared to the St Saviour's Almshouse assemblage (Miles and Connell 2013), perhaps suggesting there may have been a common cause of hypoplasia in this area or at least a similar level of health. To add to the confusing complexity in the incidence of hypoplasia, the Cross Bones site, also situated in Southwark and representing a similar socio-economic group, has different levels of hypoplasia (Brickley *et al.* 1999). This assemblage not only has a higher incidence of enamel hypoplasia than either New Bunhill Fields or St Saviour's Almshouse Burial Ground, but also a higher incidence of stress amongst females compared to males. It is not clear what could have caused this difference between populations buried within a local area. It is unlikely affluence could have caused these variations, given all three sites are representative of the working class. Small differences in the local environment or cultural preferences in burial location are more likely explanations.

The frequency of enamel hypoplasia within the St Saviour's Almshouse Burial Ground is not high in relation to other sites, despite its association with an almshouse, its poor catchment area in Southwark and its industrial urban setting. It would be justifiable to expect less urban populations on the outskirts of the city would have fewer incidences of enamel hypoplasia than those in the centre of London, given the negative effects of industrialisation are well established (Lewis 2002b). It is therefore surprising that the enamel hypoplasia results from the more rural site of All Saints, Chelsea, actually reflect a much higher incidence of hypoplasia than many of the more urban sites (Cowie *et al.* 2008). Although differences in data collection must be taken into account, if a high incidence of enamel hypoplasia also occurred across other more rural sites, it would suggest either life on the outskirts of London was biologically stressful, perhaps for different reasons than those in the centre of the city, or these people were working or migrating from other areas.

On the assumption that the lower classes were living and working in less healthy environments than those higher up the social scale, it might be expected that individuals from lower status backgrounds would show higher incidences of enamel hypoplasia, but this does not appear to be the case. Based on the results presented here, socio-economic background is not a predictor of enamel hypoplasia incidence. This could be because socio-economic status and health were not correlated, with people from all classes suffering similar incidences of ill health, although not necessarily from the same cause.

All arguments are based on a number of assumptions and there remains a possibility that methodological problems may bias the interpretation. These issues are discussed in detail in Chapter 2. Most data presented here have been collected by archaeological commercial units and although the publications do not always specify the methods used to collect the data, it is likely to be based on visual examination rather than expensive, labour intensive, high resolution methods.

Table 14. Incidence of enamel hypoplasia across London post-medieval cemeteries.

Site	Period of analysis	Class/status	Conformist (Church of England)	Incidence of hypoplasia	Reference
Almshouse Burial Ground, Park Street	1730-1860	Working	Yes	Males 7.65% Females 3.89%	Teague <i>et al.</i> (2013)
Cross Bones, Southwark	Later period of its use (1800s)	Working	Yes	Males 29% Females 38%	Brickley <i>et al.</i> (1999)
New Bunhill Fields, Southwark	1821-1853	-	No	Males 7.2% Females 4%	Miles and Connell (2013)
Spitalfields	18 th -19 th centuries	Middle	Yes	Higher in females	King <i>et al.</i> (2005)
City Bunhill burial ground, Golden Lane	1833-1853	Mixed, mainly representing the cheaper part of the cemetery	No	Males 6.7% Females 10.3%	Connell and Adrian (2010)
St Marylebone Church and burial ground, Westminster	18-19 th centuries	Upper	Yes	Males 21%, Females 19.4%	Miles <i>et al.</i> (2008a)
St Benet Sherehog Churchyard	16 th -19 th centuries (mostly representing the latter)	Mixed, but the area was amongst the more affluent	Yes	Males and Females 12.3%	Miles <i>et al.</i> (2008b)
All Saints, Chelsea Old Church	17 th -19 th century	Upper, less urban	Yes	Males 19.3%, Females 15.2%	Cowie <i>et al.</i> (2008)

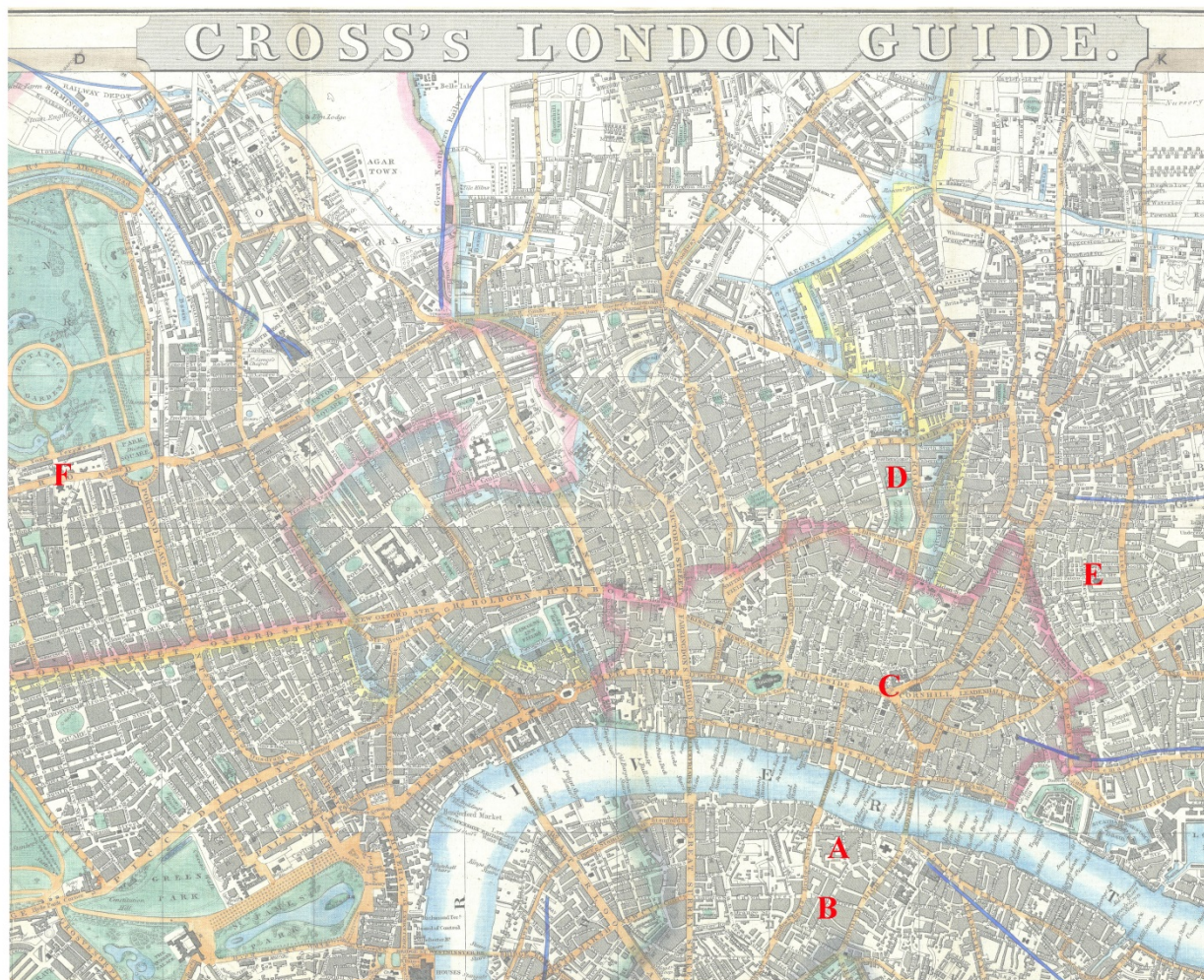


Figure 26. Map of London (Cross 1850), manipulated to show the approximate location of the sites discussed. A= St Saviour's Almshouse Burial Ground, B= Cross Bones, C= St Benet Sherehog Churchyard, D= Bunhill Fields Burial Ground, E= Spitalfields, F= St Marylebone Church and Burial Ground. All Saints Church, Chelsea, is off the map.

6.7 Summary

In this study breastfeeding and weaning age at St Saviour's, which has been identified using stable isotopes, is compared with the peak incidence of hypoplasia in the same individuals. This avoids assessing the relationship using a methodology where information about infant feeding patterns is based solely on historical records or where assumptions about the timing of dietary change is made.

The conclusions support the idea that peak incidences of hypoplasia identified within a population cannot be used to identify when solid foods were introduced to infants in all populations. Whilst a relationship between health and infant feeding is not contested (breastfeeding patterns may have had more long term effects on hypoplasia) hypoplasia timing is not an accurate predictor of when weaning took place. In the St Saviour's population, the peak in hypoplasia occurs significantly after breast milk is reduced and other foods are introduced. Although this may not be a feature of all populations, it means it is not possible to generalize across populations.

Too many studies identify a peak incidence in hypoplasia and conclude, without evidence, that weaning and hypoplasia are correlated. A different scenario is proposed here, suggesting that while infant feeding patterns can potentially cause health problems, the peak in hypoplasia which occurs around 20-28 months in the St Saviour's population is more likely to be caused by a combination of two factors. These are the different susceptibility of the enamel to hypoplasia in different parts of the tooth and the physiology/behaviour of a child around the age of 2 years.

Future research should consider the long term effects of breastfeeding/weaning and whether hypoplasia peaks occurring after weaning have any relation to infant feeding patterns. Comparing the incidence of hypoplasia throughout tooth development between individuals who were and were not breastfed and between those who weaned early and late would make this achievable.

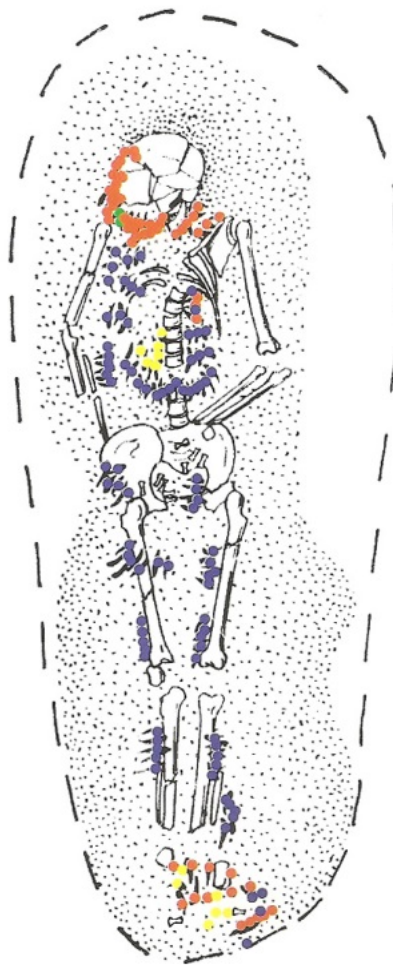
Most archaeological populations would be unsuitable because breastfeeding would have been the only option available.

The application of the techniques used in this study to other archaeological populations is required. Given the multitude of variables in infant feeding practices, looking at a variety of populations would increase the chance of identifying the factors involved in peak occurrence of hypoplasia. An enhanced understanding of enamel hypoplasia, including specific details about why it forms, may provide the key to understanding the patterns. The debate over the role of cultural versus biological factors in the development of hypoplasia appears to be a dormant area of research. While hypoplasia incidence continues to be reported, our understanding of the causal factors is not increasing. Once this is addressed in greater detail, the research area will be able to develop.

Looking at patterns of hypoplasia across different post-medieval London populations, it is clear there is great variability in both the incidence of hypoplasia and in the prevalence of the defects between men and women. This does not appear to be influenced by either class or status. This can be interpreted in several ways, either hypoplasia is not a reliable tool to consider the impacts of class or gender, or hypoplasia incidence is unrelated to either of these variables.

Part Two

A Hunting, Gathering and Fishing Population from Northern Latvia (c. 8150-4190 BP)



Grave 170 at Zvejnieki, the coloured points show where the pendants were found. From Larsson (2006, p.258 Fig 3).

Chapter 7 Zvejnieki Cemetery

7.1 Introduction

The transition from the Mesolithic to the Neolithic in Europe was a time of major change and social upheaval during a period of economic transition. While the Mesolithic is traditionally associated with small mobile egalitarian bands of people hunting and gathering across the landscape, the Neolithic is associated with settled farming communities, subsisting more on domesticated animals and crops, in a growing population which became more hierarchically organised (Mithen 1994). These simplified ideas mask the complexity in both the Mesolithic and Neolithic, as well as differences across Europe. The problem is particularly evident in parts of eastern Europe, where the Mesolithic and Neolithic periods do not conform to these generalizations (Zvelebil and Lillie 2000). In Latvia, like many other regions in eastern and northern Europe, the term Neolithic does not necessarily imply agricultural practice, as many people continued hunting and foraging. They were however less mobile and the population may have increased. Zvejnieki is a good example of this.

The area of Zvejnieki in Latvia has both occupation and cemetery sites dating to the Neolithic and Mesolithic (Zagorskis 2004), making it an important site with the potential to explore some aspects of the way people lived in this society and the degree of change and continuity there was over the Mesolithic and Neolithic periods. Here the focus is on the exploration of the human remains recovered from the cemetery to explore the lives of children across these eras. The contextual background to the site and the Mesolithic and Neolithic periods is given in this chapter, including details about the site of Zvejnieki, and a summary of information relating to Zvejnieki and the people who lived there. The site was excavated to a high standard and has produced a large body of published research, which considering its early discovery is particularly impressive. Details about the selected samples and individuals are presented. This gives the

supporting background information for the following chapter, which discusses the aims and results of the research undertaken.

7.2 Zvejnieki

The site of Zvejnieki is positioned in northern Latvia, on the bank of Lake Burtnieks (Zagorskis 1987) (Figure 27). Its existence has been known at least since the 1870s when flint artefacts were collected from the local vicinity and burials were detected. Despite its early discovery it was not until the 1970s that detailed exploration of Zvejnieki began. This was prompted by gravel extraction which led to the disturbance of some graves, fuelling a renewed interest by scholars (Zagorska 2006a). Excavation has carried on intermittently up to the present. The continued interest in the cemetery demonstrates the importance and magnitude of the site (Nilsson Stutz *et al.* 2013).

Zvejnieki remains today one of the most important Stone Age finds in northern Europe and one of the largest Stone Age cemeteries, with over 300 inhumations. A more precise figure is unavailable, given the destruction caused by modern gravel extraction and the continued reuse of the cemetery in antiquity, causing disruption to the older graves (Zagorska 2006a). The site's importance is based not only on the magnitude of the cemetery and the number of human remains recovered, but by its extended use throughout the Mesolithic and Neolithic, into even later periods. A substantial number of radiocarbon dates have confirmed the age of a number of burials, demonstrating this continual use and providing a framework on which other analysis is based (Liiva and Loze 1993, Zagorska 2006b).

The earliest radiocarbon dates have shown the cemetery was established in the Middle Mesolithic, although this period is represented by a sparse number of human remains, indicating limited use of the area. There is a greater number of dated Late Mesolithic and Neolithic burials, indicating more extensive use of the land in this period (Zagorska 2006b). The low number of Middle Mesolithic human remains is exaggerated by taphonomic problems which have limited

the survival of the earliest burials. Large scale Mesolithic cemeteries are rare across Europe, meaning the site is key to our understanding of the lives of these people and the changes which occurred as the Neolithic period began.

Although considerable attention has been paid to the cemetery because of the wealth of information it has provided, the area was also used as a settlement. The settlement and cemetery appear to have been used at the same time, but it is not yet known if the settlement was continually occupied throughout the cemetery's use as it has not been fully excavated. It is possible the earliest settlers during the Pre-Boreal period did not bury their dead on the site (Larsson 2009).



Figure 27. Location of Lake Burtnieks within Latvia. Author's own image, 2015.

7.3 Continuity or Change at Zvejnieki?

The archaeological evidence points to a large degree of continuity between the Mesolithic and Neolithic periods, reflected in similar burial practices, the continued use of symbolism such as red ochre and pendants, a sustained reliance on hunting, gathering and fishing (Eriksson 2006, Zagorskis 2004) and a continued desire to utilize and reuse a cemetery which was known to be there. Much of the evidence relating to paleopathology also illustrates there was no dramatic change between the eras (Jankauskas and Palubeckaitė 2006). In many ways this is unsurprising, as Zvejnieki is more similar to cultures such as Ertebølle in Scandinavia than it is to cultures in other parts of Europe. The Ertebølle people continued to hunt, gather and fish and as a consequence scholars continue to define the Ertebølle people as Mesolithic (Gron 2013, Enghoff 1994, Kubiak-Martens 1999). Although Zvejnieki has been classified as Mesolithic and Neolithic in the literature because of archaeological theory and classification in Eastern Europe, it is seen in North-Western Europe as a Mesolithic culture. The distinctions between the Mesolithic and Neolithic periods as discussed in this thesis should therefore be considered lightly, representing periods of time rather than two cultures.

While traditions remained similar at Zvejnieki, some subtle changes took place throughout the site's use. This is reflected by the published stable isotope data (Eriksson 2006), zooarchaeological remains (Lõugas 2006) and various small changes in burial customs (Zagorskis 2004, Loze 2006). Although fishing, hunting and gathering continued throughout the Mesolithic and Neolithic, the resources exploited were changing as the climate fluctuated and the environment evolved. Osteological evidence hints at some shifts, including a slight increase in caries incidence into the Neolithic period along with an increase in the incidence of calculus. This is unlikely to represent a large change in diet, but does suggest a small dietary shift (Palubeckaitė and Jankauskas 2006). A further change is observable in human stature throughout the Mesolithic and Neolithic, a physical attribute which is known to be influenced by a variety of factors including genetics, environment and health. A reduction in size occurred at the start of the Neolithic, with stature later increasing

again in the Late Neolithic. The changes are not attributed to farming in this area, but rather a product of changing environmental conditions (Gerhards 2006).

Early Neolithic burials continue to show many features which are characteristic of the Mesolithic era, but subtle changes are discernible in burial practices. A greater range of animal pendants is associated with the Early Neolithic and there is an indication red ochre was used less frequently in graves (Zagorskis 2004). There is some clustering of burials by period, suggesting burial location changed to a small degree within the parameters of the cemetery. Many of the Late Mesolithic burials are positioned on the north western slope and are characterised by an assortment of features. Skeletons are generally laid out in extended supine positions, placed in individual graves and sometimes show evidence of having been wrapped or tied up prior to burial (Nilsson Stutz 2006). Red ochre and grave goods are common inclusions, with animal tooth pendants a regular feature. Early Neolithic individuals are predominantly grouped around the northern slope of the ridge and dispersed across other areas (Zagorskis 2004), while Late Neolithic burials are scattered across the cemetery and as a generalization are recognisable by a decrease in grave goods and the crouched position of the skeleton (Loze 2006).

In the Early Neolithic, there is evidence for a greater number of settlements and greater archaeological visibility, perhaps indicative of an increasing population (Zagorskis 2004) or of the better survival of archaeological deposits from this period. An earlier peak in female mortality during this period has been used to conclude that women began to reproduce earlier in life. Evidence for violence occurs in the Neolithic for the first time, a marker which could further indicate an increase in population numbers and pressure on resources. In general however, evidence for conflict is notably low for men and women at Zvejnieki, perhaps suggesting the environmental resources were able to sustain this population increase (Jankauskas and Palubeckaité 2006). It was not until the Bronze Age that evidence for violence becomes more

significant in this region of Eastern Europe, coinciding with the final transition to agriculture in the eastern Baltic (Iankauskas 2012).

A further possible cause of increased population numbers is immigration to the area. It is suggested that Latvia as a whole drew in immigrants from the South East (the Dneiper- Donets culture) and the South West (Ertebølle culture) during the Mesolithic and Neolithic. The combined influence of these groups created the material culture seen at Zvejnieki, sometimes known by archaeologists as the Narva culture. Analysis of the teeth show two groups, a north European group, with mixed Europoid and eastern features, and a Central European group who originally inhabited the area. It was these people that made up the Narva culture, which was later to be replaced by the Comb Ware Culture in the Late Neolithic. It is argued this was the result of a new wave of migration from South East of the East Baltic (Zagorskis 2004). While cultures can be formed by the movement of people, the level and effects of migration have sometimes been over estimated. With limited evidence and the possibility of interpreting the archaeological record in different ways, these so-called 'cultures' may also be the natural evolution of a group which remained in the region for thousands for years.

7.4 Environment and Climate

Shifts in climate and environment occurred throughout the sites extended use. During the Mesolithic and Neolithic these periods are known as the Preboreal, Boreal and Atlantic (Zvelebil 2008). The changes in environment influenced the site's use, impacted the subsistence strategies of those inhabiting the area and perhaps influenced factors such as immigration and innovation.

The Early Mesolithic period roughly correlates with the Preboreal (10,300-9,300 BP), a period when the local environment around Zvejnieki was sparsely populated by birch and pine forests, dispersed with meadows and pastures (Zvelebil 2008). This pattern continued into the Boreal phase (9,300-8,000BP), when the climate became dryer and milder. A drop in the water level of Lake Burtnieks created more areas of land where pine forest could thrive, allowing the forest to

spread. Pine took over from the birch/pine mixed forest and extended into ever greater areas. The impact of human populations on the landscape is notable for the first time during this period. Pollen from *Plantago major/media*, *Rumex acetosa/acetosella* and *Urtica* are present in these sediment layers, which are associated with human occupation. The impact of humans is also notable in the creation of some open areas, illustrating that the local environment was being artificially manipulated (Kalnina 2006).

The Late Mesolithic to Neolithic shift occurred during the Atlantic period (8,000-5,000BP), when the climate became warmer and more humid. Lake levels rose again and broadleaved forests returned (Eberhards 2006). Human presence in the environment is visible as large pastures and meadows opened up (Kalnina 2006). This new environment supported a different range of species, invariably affecting hunting practices as a greater range of resources, including elk, wild boar, aurochs, red deer and roe deer became more readily available in the local vicinity (Zagorska and Larsson 1994). The changes culminated in the introduction of farming around 5000 BP (Zvelebil 2008).

7.5 Subsistence: Evidence from Stable Isotopes and Faunal Remains

Faunal remains have been recovered from the settlement site and the cemetery which help to clarify the subsistence strategies. Remains from the settlement site are believed to represent animals which formed a major part of the diet, while faunal remains from the cemetery are believed to have had a more symbolic meaning (Lõugas 2006). Seemingly, animals which were consumed in the settlement area were not considered suitable for grave goods. The earliest graves contain only ruminant animals and wild boar, but the assemblage was extended in the Middle Neolithic, with a greater range of animals including dogs and an array of carnivores (Lõugas 2006). In the settlement, the presence of fish remains shows the importance of the lake resources in the diet. Terrestrial species consumed include elk, red deer, aurochs, brown bear and wild horse. A shift in the Middle Neolithic, probably due to climate change, is observable, as

reliance on elk, red deer and aurochs decreased and wild boar and beaver became more prevalent (Löugas 2006).

A large isotopic study has already been done by Eriksson (2006), with data available for fauna and humans. The stable isotope results suggests a variable diet during the Late Mesolithic and Early Neolithic, with $\delta^{15}\text{N}$ ranging from 6.2‰ to 17.7‰ and $\delta^{13}\text{C}$ ranging from -25.0‰ to -18.8‰ (Eriksson 2006). This broad range indicates substantial dietary differences between individuals, those with lower $\delta^{15}\text{N}$ values suggest dietary protein was predominantly from plants, while those with higher $\delta^{15}\text{N}$ values suggest a significant input from freshwater resources. Although the lowest $\delta^{15}\text{N}$ value of 6.2‰ is subsequently discussed as a potentially inaccurate human sample, even with its removal there are a wide range of values, suggesting that resources were wide-ranging. Comparing stable isotope values across the periods, there is no evidence for a dramatic shift from foraging to farming, rather a greater diversity in diet from the Late Mesolithic to Neolithic. Freshwater fish continued to play an important dietary role in the Neolithic, but stable isotope results paired with faunal evidence suggest birds and mammals also became important sources of protein (Eriksson 2003). The Late Mesolithic and Early Neolithic appear to have had a higher intake of freshwater products than the Later Neolithic and Bronze Age, when stable isotopes indicate more terrestrial products were consumed. The average adult $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ during the Late Mesolithic/Early Neolithic is -23 ± 1.1 ‰ and 11.9 ± 1.1 ‰ and the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ during the Late Neolithic/Bronze Age is -21.5 ± 0.3 ‰ and 10.5 ± 0.7 ‰. The Student's unpaired t-test shows the change in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in the Late Mesolithic/Early Neolithic and the Late Neolithic/Bronze Age to be statistically significant ($p=0.04$, $df=20$) (Eriksson 2006).

Based on the relatively low $\delta^{13}\text{C}$ and moderately high $\delta^{15}\text{N}$ values, the majority of adult individuals during the Mesolithic and Neolithic were reliant on freshwater resources for their protein intake (Eriksson 2006), which seems a sensible conclusion given the proximity of the settlement area to the freshwater resources which were available from Lake Burtneiks. There is evidence at least

one person had contact with the coast. This individual, 165, had a $\delta^{13}\text{C}$ value of -18.8‰ and a $\delta^{15}\text{N}$ value of 12‰. This likely indicates a marine dietary input, unlike any other individual currently analysed from this cemetery (Eriksson 2006). The unusual results obtained from this person led to an early life history study, the only one known to have thus far been attempted on an individual from this population. Tooth dentine was extracted and subject to $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope analysis. The M1, M2 and M3 were analysed, providing samples representing the age brackets of 2-4, 5-10 and 10-16 years, taken from the area around the cervix of the tooth. Stable isotope values relating to adult diet were obtained from skull bone, representing the diet between 20-35 years. The results demonstrated the highest $\delta^{15}\text{N}$ value from the age categories sampled was the youngest age, at 2-4 years. This is interpreted as a breastfeeding signal. The subsequent differences in stable isotopes throughout the later years led to the author suggesting the individual grew up at Zvejnieki, moved to the coast for a few years and then returned during adulthood. Frequent travel to and from the coast could also not be ruled out (Eriksson 2007).

A number of features point towards movement throughout the landscape and coastal contact being commonplace among these people, including the short distance between the coast and Zvejnieki. The pathological evidence suggests long distance walking was practiced (Jankauskas and Palubeckaitė 2006). Although stable isotope results from only one individual so far analysed is consistent with direct coastal contact, stable isotope analysis on dog teeth found in the graves of the Zvejnieki people provide a further tantalizing piece of evidence. The results indicate a number of the dogs were consuming food from marine resources. This could indicate coastal people were trading pendants with inland people (the presence of seal pendants supports this), trading dogs with them, or that the people from Zvejnieki were travelling to the coast (Eriksson and Zagorska 2003). All of these hypotheses suggest these people were not isolated and they may have interacted with people close to the sea or travelled there themselves, despite most of them not relying on coastal foods.

7.6 Childhood Experiences at Zvejnieki

The general incidence of linear enamel hypoplasia at Zvejnieki is low, with small fluctuations over time. The Mesolithic had the lowest incidence of hypoplasia, which were mostly mild, suggesting illness of a short duration or low severity. A peak in hypoplasia timing occurred at 3 years of age during this period, which is suggested to be a combination of weaning stress, the vulnerability of children at this age and the physiological formation of the teeth (Palubeckaitė and Jankauskas 2006). The incidence of hypoplasia increased during the Neolithic, which could be an indication there were less suitable foods, nutritional problems, or increased disease incidence compared to the Mesolithic. It is however difficult to conceive of a scenario where there this could occur, as the available foods changed little over the Mesolithic and Neolithic. Alternatively, children may have had a better chance of survival in this period compared to the Mesolithic (Palubeckaitė and Jankauskas 2006). During the Neolithic the peak incidence of hypoplasia occurred at the age of 4 years, a later age compared to the Mesolithic. No significant differences between males and females were found in any era, although there is an indication Neolithic males suffered slightly greater incidences of stress, of a more severe nature, compared to females. This was the opposite during the Mesolithic, when females had a slightly higher incidence (Palubeckaitė and Jankauskas 2006). There has been no research published specifically on other childhood pathology at Zvejnieki, although there is evidence for healed fractures which occurred during childhood (Jankauskas and Palubeckaitė 2006).

Paleodemographic research suggests there was no dramatic change in demography between the Neolithic and the Mesolithic, although there may have been a small shift towards an increased population in the Neolithic. The number of children buried at Zvejnieki however, did change over time and in the Middle Neolithic/Late Neolithic, the proportion of child and juvenile burials fell by half compared to the Late Mesolithic (Zarina 2006). Whether this is a reflection of a change in mortality rates or a change in ideas about who should be buried in the cemetery is not known.

7.7 Selected Samples for Early Life History Studies

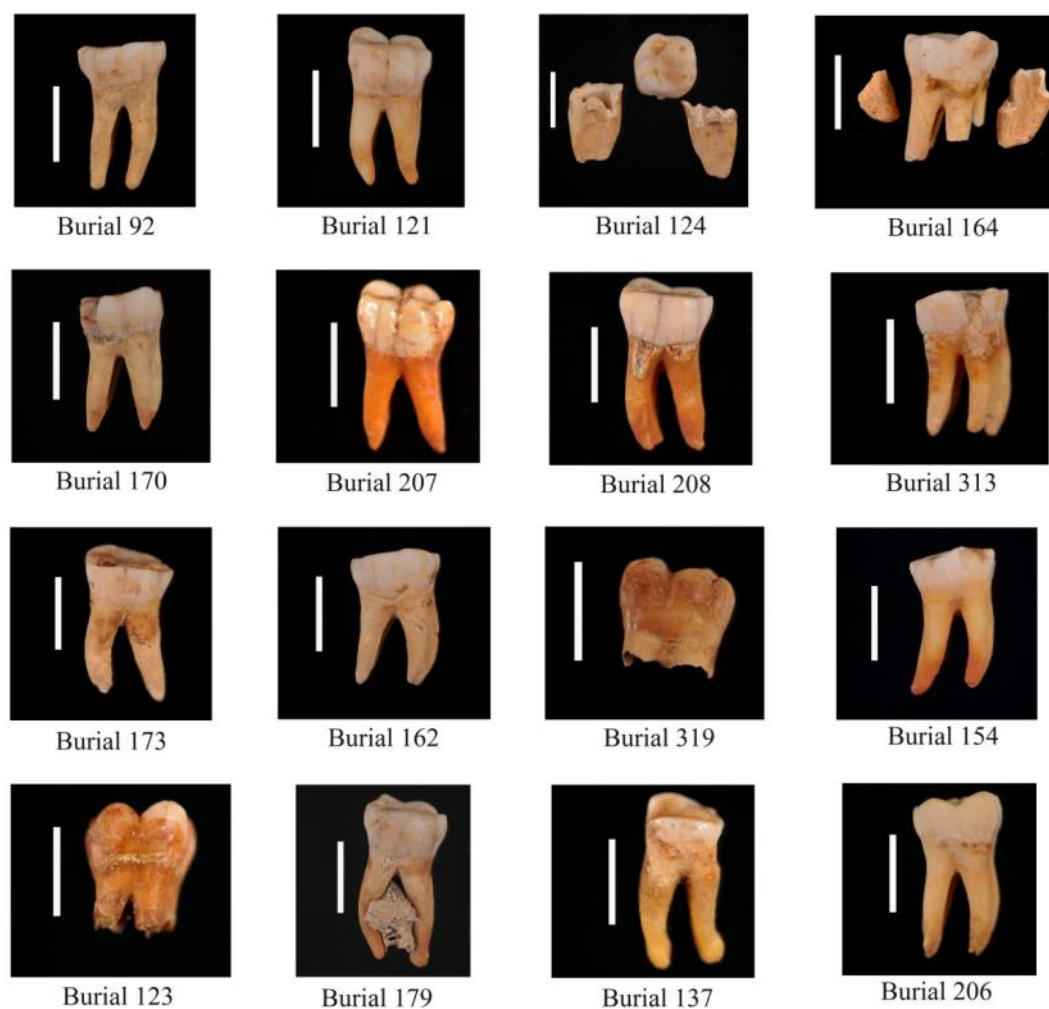
In order to explore the early life histories of the people who lived and died at Zvejnieki, sixteen teeth were selected to represent the major periods over which the cemetery formed. They were analysed according to Method 1 outlined in Chapter 3, and selected according to the following criteria. Samples which had been radiocarbon dated were preferentially chosen, providing an absolute date for each individual. This allowed a comparison of change or continuity in early life history experiences to be made throughout the Mesolithic and Neolithic eras. Many of the individuals from which the sixteen selected teeth originate have also been included in a wide variety of other studies. This body of information includes not only radiocarbon dates, but also the age, sex, burial position, burial location, inventory of grave goods and other scientific analysis, in particular the results of isotope analysis undertaken by Eriksson (2006). In some cases this meant adult $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope values were also available, which allowed a fuller life history to be created.

All first molars were taken from the left side of the mandible. Some of the selected samples did exhibit attrition, which is often a feature of hunters and gatherers who consume coarser, grittier foods compared to the processed foods often eaten today. The full life histories spanning 0-8 years old were not available in these cases. Where loss of the crown had occurred, the number of segments lost was predicted. Given that extended breastfeeding is often practiced by hunter-fisher-gatherers and a breastfeeding signal was picked up in one individual at the age of 2-4 years (Eriksson 2006), it was considered likely that this period of infancy would still be identifiable in later segments.

A cautionary note should be added about all radiocarbon dates given here. In the case of most existing radiocarbon dates on humans, the reservoir effects of aquatic foodstuffs have not been taken into account. Radiocarbon dating produces dates which are 'too old' when a person consumes a diet high in marine or freshwater products. The amplitude of the freshwater reservoir

effect is still being considered. Meadows *et al.* (2014) compared the available radiocarbon dates of some human burials at Zvejnieki to radiocarbon dates obtained from faunal bone in the graves and between individuals who were archaeologically contemporary to each other. The results for individual 208 show a reservoir effect of almost 600 years. Similarly, burial 206 cannot be older than burial 208 based on the stratigraphy, but it has an older radiocarbon date (5285 ± 50 BP compared to 5345 ± 60 BP). This is a strong indicator that a freshwater reservoir effect is causing some dating inaccuracies, with an error of up to 500 years. The evidence suggests humans consuming fewer freshwater products are likely to have more accurate radiocarbon dates. The individual in burial 137 who, based on the adult $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values, consumed less fish, had a similar radiocarbon date to a herbivore found in the grave. This indicates it is the high consumption of freshwater products which is producing discrepancies in the dating. Even with this potential inaccuracy however, the radiocarbon dates obtained from Zvejnieki still give a range of samples covering the Mesolithic and Neolithic periods.

All sixteen teeth analysed are pictured in Figure 28 and descriptions of each individual and their context is presented below in chronological order. Accumulated information on the individuals from which the samples come from is given in Table 15. Adult isotopic results from the bone of individuals analysed in this study, obtained from Eriksson (2006), are presented in Table 16. Further details about all the individuals, including more information on grave goods, can be found in Zagorskis (2004), where an inventory is given.



Scale represents 1cm

Figure 28. Images of the teeth analysed and their burial numbers. Author's own photomontage, 2014. Due to the high incidence of attrition on the teeth at Zvejnieki, it was not possible to select unworn teeth. This is particularly notable for individuals 92, 313, 137, 154 and 137.

Table 15. List of samples included in the current analysis, including radiocarbon dates, period, age and sex of each individual where known (Zagorska 2006b, Jankauskas and Palubeckaitė 2006). Information on age and sex was provided by Gunita Zarina (personal communication 2014).

Burial	Sex	Age (years)	Radiocarbon date (years BP)	Archaeological Period
92	Male	Adult	6510±50	Late Mesolithic/Early Neolithic
121	Female	Adult	6145±80	Late Mesolithic/Early Neolithic
123	Male	Child	6395±60	Late Mesolithic/Early Neolithic
124	Male	Adult	5280±55	Middle Neolithic
137	Female	Adult	4280±60	Late Neolithic
154	Male	Adult (40-45)	7730±70	Middle Mesolithic
162	Male	Adult (30-35)	5635±65	Early Neolithic
164	Male	Adult (25-30)	5230±95	Middle Neolithic
170	Female	Adult	8150±80	Middle Mesolithic
173	Male	Adult	5895±65	Early Neolithic
179	Male	Adult	5895±70	Early Neolithic
206		Child (7-14)	5285±50	Middle Neolithic
207	Unknown	Adult (12-16)	4850±60	Late Neolithic
208	Male	Adult	5345±60	Middle Neolithic
313	Female	Adult	7525±60	Middle Mesolithic
319	Unknown	Child (6±2)	7635±60	Middle Mesolithic

Table 16. Stable isotope values for seven individuals obtained from previous analysis (Eriksson 2006).

Burial	Age represented by sample	Element Analysed	percentage collagen	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C/N
121	Child	canine tooth	5.8	-21.2	10.9	3.3
	Adult	skull bone	6.9	-23.1	10.9	3.3
137	Adult	Skull	2	-21.6	9.7	3.3
162	Adult	Fibula	1.2	-22.3	10.1	3.2
164	Adult	Scapula	3.4	-22.1	11.7	3.1
173	Adult	Femur	1.8	-23.7	12.7	3.1
179	Adult	Pelvis	1.7	-22.6	10.5	3.1
	Adult	skull bone	1.5	-23.8	12	3.3
208	Adult	skull bone	5.1	-22.2	13.6	3.2

7.7.1 The Middle Mesolithic

The earliest burials are represented by the samples 154 (Figure 30), 170 (Figure 29), 319 and 313.

The oldest burial so far recovered on the site is burial 305 which was dated to 8270 ± 70 BP (not included in this analysis). Burial 170 is dated to 8150 ± 80 BP, burial 154 to 7730 ± 70 BP, burial 319 to 7635 ± 60 BP and burial 313 to 7525 ± 60 BP (Zagorska 2006b). While this group forms the oldest known burials, there is the possibility there were once older burials at the site. The deliberate reuse of the cemetery over an extended period of time is known to have resulted in the destruction or disturbance of older graves, as discussed above (Nilsson Stutz *et al.* 2013).

Burials 170 and 154 were situated on the highest part of the gravel ridge. Both were supine burials, 170 with the head in the north and 154 to the west. These individuals had grave infill containing dark and light soil and red ochre had been placed in both graves, a common feature across the cemetery throughout both the Mesolithic and Neolithic (Zagorska 2006b). Burial 154 had a stone setting and a notable pathological feature, a healed fracture on the nasal bones which could have been caused by violence or accident. The same individual had auditory exostoses on the skull (Jankauskas and Palubeckaitė 2006), bony lumps which form on the auditory meatus due to repeated ear infections caused by exposure to cold water (Kennedy 1986).

170 had an impressive array of grave goods, evidence which suggests this person was likely to have been an important member of the community with high status or success. Animal teeth from elk, wild boar and aurochs are a particularly prominent feature. These were formed into pendants (of which there were a total of 167), ornaments and a headdress (Zagorskis 2004). In both the Mesolithic and Neolithic, elaborate headdresses such as the one which was worn by this individual, were associated with young males. Perhaps because of their economic importance for hunting and fishing, they achieved a higher status in the community and their early deaths were particularly well celebrated (Zagorska 2006b).

The individual in burial 319, unlike 170 and 154, died at around the age of 6 ± 2 years. This child was recovered in the most recent stage of excavation in 2009, from the area around the farmstead. 319 was part of a double burial with 320 (Nilsson Stutz *et al.* 2013).

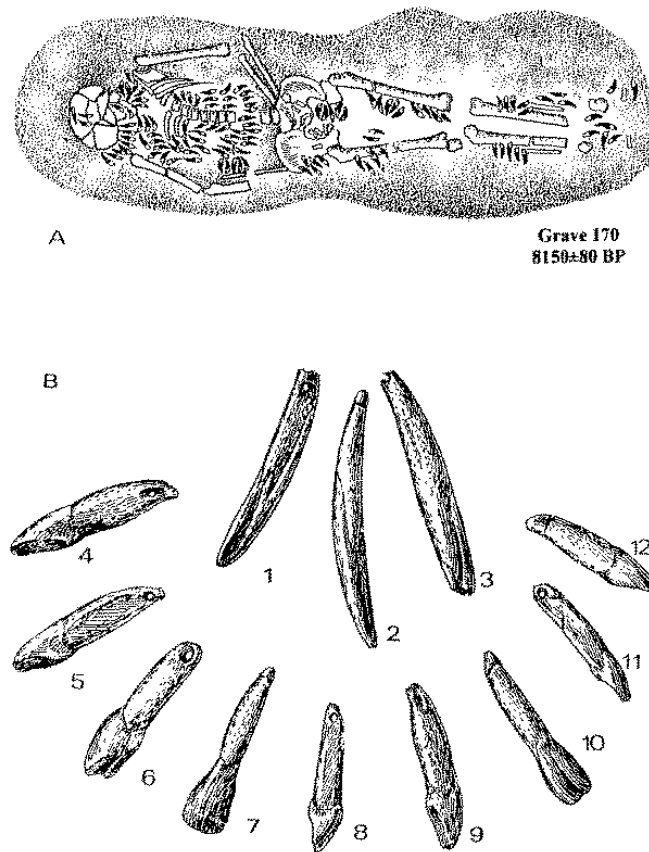


Figure 29. Burial 170, including detail of grave goods. 1-3 represent tooth pendants from wild boar, 4-12 represent tooth pendants from elk (Zagorska 2006b p.95 Fig 2).

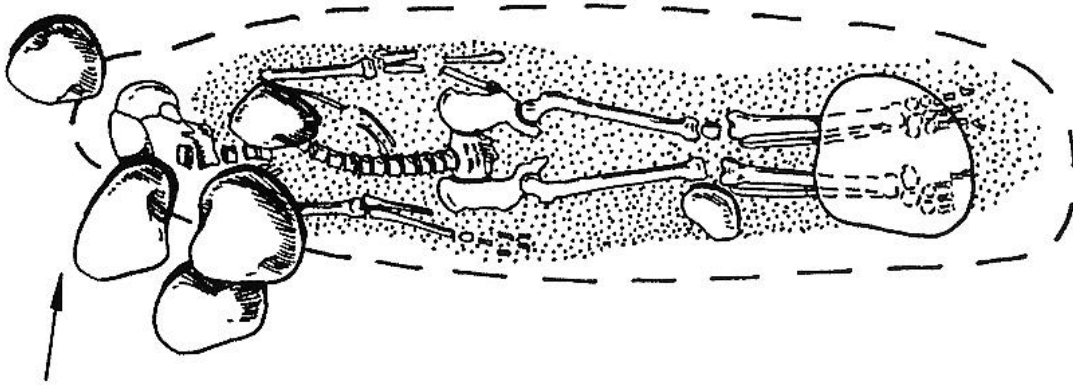


Figure 30. Burial 154 (Zagorskis 2004 p.31 Fig 15).

7.7.2 Late Mesolithic/Early Neolithic Transition

Individuals 121 (Figure 31), 92 (Figure 32) and 123 (Figure 33) represent people transcending the period between the Mesolithic and Neolithic. They date to 6145 ± 80 BP, 6395 ± 60 BP and 6510 ± 50 BP. There is no true break in tradition between the Mesolithic and Neolithic, although some small shifts have been discussed (Zagorska 2006b). Burial 121 is part of a 'compact group of burials', which are situated on the northern slope of the gravel ridge. The grave is positioned S-N. The skeleton shows evidence that there was bi-lateral pressure of the thoracic cage and the upper limbs were rotated inwards and extended by the side of the body. This has been taken as evidence that this individual was wrapped, although no fabrics have survived (Nilsson Stutz 2006). A small trapezoidal stone object in the shape of a reptile or frog was associated with this grave (Zagorskis 2004).

Burial 123 was interred in a supine position, with the head to the south. This child was buried above a male skeleton, burial 122, with extensive red ochre and tooth pendants (Zagorskis 2004). Burial 92 is a partly destroyed collective burial with individuals 90 and 91. It appears burial 92 and 91 were in the extended position, with their heads in opposite directions. 92 was buried with the head in the north. This skeleton is destroyed from the waist down (Zagorskis 2004).



Figure 31. Burial 121. From Zagorskis (2004, p.26 Fig 13).

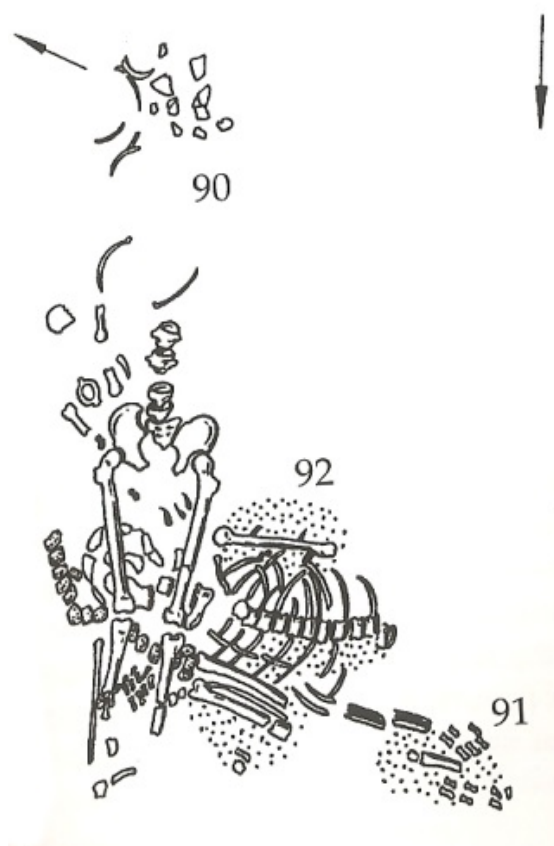


Figure 32. Burial 92 and associated burials. From Zagorskis (2004, p.23 Fig 11).

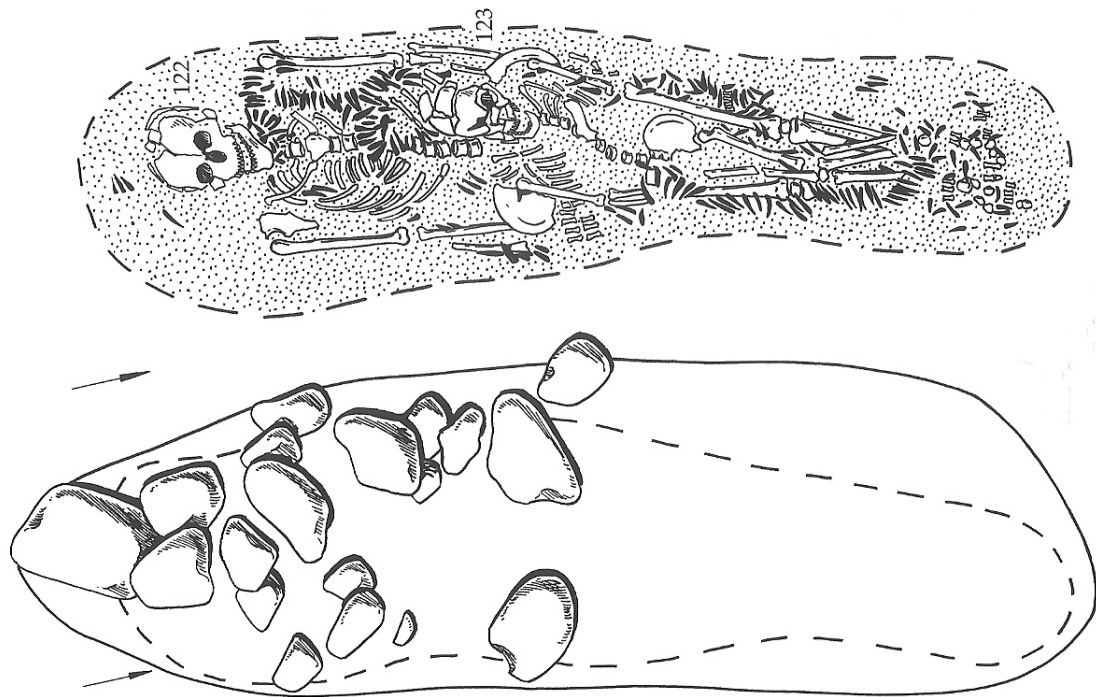


Figure 33. Burial 123, positioned on top of burial 122 (Zagorskis 2004, p.27 Fig 14).

7.7.3 Early Neolithic

Burials 162 (Figure 34), 173 and 179 (Figure 35) have been dated to the early Neolithic period, with the respective radiocarbon dates of 5635 ± 65 BP, 5895 ± 65 BP and 5895 ± 70 BP. These burials are situated along the southern slope of the ridge, most of which are orientated W-E. As with the Mesolithic graves, common features include a grave fill of lighter or darker earth, the addition of stones in some graves, red ochre and tooth pendants. Burial 179 is distinguished in that several individuals were buried together (178-182). These five individuals, all adults, were not arranged in a uniform way and several show signs of conflict which could have led to their deaths (Zagorska 2006b). 179 is positioned in an extended prone position with the head to the left. The pelvis has four round holes from wounds to the front and a flint flake was lodged in the third thoracic vertebra.

Burial 162 was in an extended supine position, with the head in the east. The burial was partly destroyed in the mid region of the skeleton. Individual 162 had degenerative joint disease (DJD)

of the left elbow, a problem which is often connected to physical stress. In general, pathological features suggest males, like 162, led more physically demanding lives than females, including lifting heavy objects, fishing on ice, swimming and long-distance walking. Some males clearly suffered the consequences of these activities (Jankauskas and Palubeckaitė 2006). A bird's head was represented on a bone plaquette in this grave (Zagorskis 2004).

Burial 173 was also partially destroyed. The head was in the west and the body slightly to the right. No grave goods are associated with this individual. The body of a child, 174, was positioned to the left of this person (Zagorskis 2004).



Figure 34. Burial 162. From Zagorskis (2004, p.33 Fig 16).

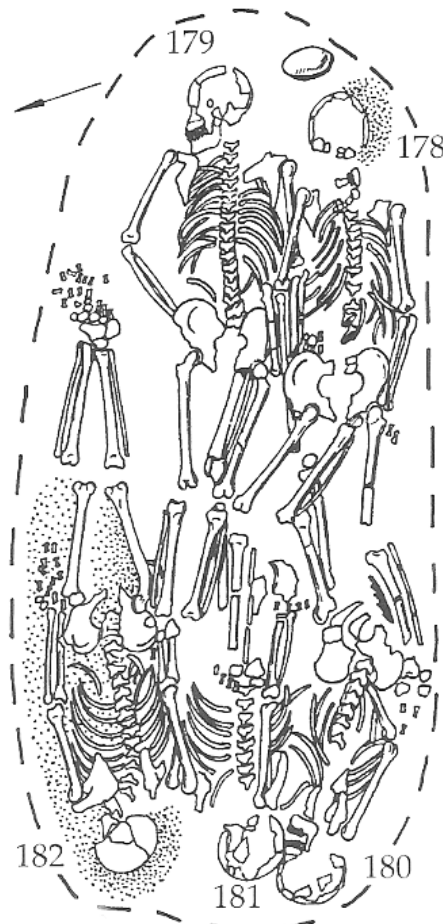


Figure 35. Burial 179 and associated burials. From Zagorskis (2004, p.35 Fig 17).

7.7.4 Middle Neolithic

Burials 124 (5280 ± 55 BP), 164 (5230 ± 95 BP) (Figure 36), 206 (5285 ± 50 BP) and 208 (5345 ± 60 BP) (Figure 37) represent the Middle Neolithic. Most Middle Neolithic burials are situated on the south-eastern end of the gravel ridge around the farmstead, which has recently been the subject of renewed investigation. Some of the burials continue to the highest part of the gravel ridge. The key features during this period are the inclusion of amber jewellery, arrowheads, flint spearheads, tools for hunting and fishing, slate rings, clay figurines, pottery, votive deposits and the continued use of red ochre. Burials 124 and 164 both had tooth pendants from dog, badger and seal. There are some differences in the Middle Neolithic compared to earlier eras which begin to manifest themselves in this period (Zagorska 2006b).

The individual in burial 124, which is partially destroyed, was buried in a supine position with the head in the south west (Zagorskis 2004). 164 was buried in a supine position with the head in the east (Zagorskis 2004). Most burials are in a supine position during this period and some burials have multiple occupants ranging between 2-6 individuals. One of these multiple burials contained individuals 206 and 208. The group, consisting of burials 206-209, included the bodies of a child and three adolescents. Burial 208 was situated at the bottom of the grave with individual 209. A child, 207, was laid to the side of these and burial 206 was laid above burial 209. In burial 206, a blue-grey clay mask, which would have covered the face, was included in the grave. Amber discs had been placed in the eye sockets. Several other individuals were subject to a similar symbolic treatment. The features of this burial have led to a suggestion these individuals were newcomers to the region (Zagorska and Larsson 1994). Burial 208 was buried with a bone harpoon under the knee, one under the lower leg, a bone point, bone dagger and flint chips (Zagorskis 2004).

Burial 164 is also particularly notable for the number of bird bones included in the burial. 38 unmodified carpometacarpi and 2 wing phalanges from jay birds (*Garrulus glandarius*), along with seven tooth pendants which would have formed a headdress and 17 bone spearheads. The bird bones may have had feathers attached to them, which on the jay would have been blue. It is estimated at least 17 jay birds would have been used to provide the decoration and that these might have been sewn onto a costume (Mannermaa and Storå 2006, Mannermaa 2008).

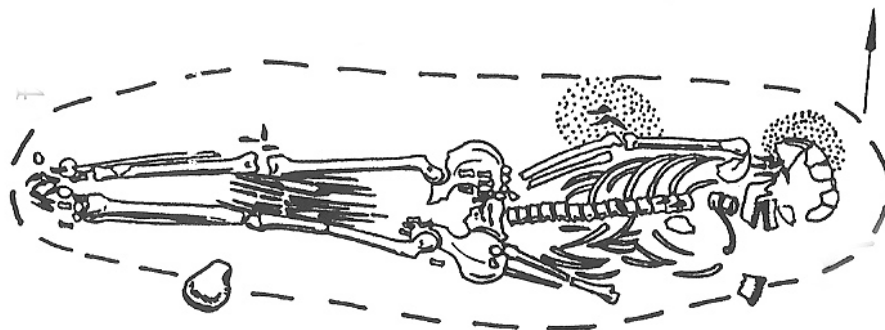
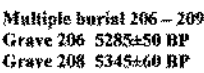


Figure 36. Burial 164 (Zagorskis 2004, p.33 Fig 16).



reservoir effect. This would mean that although this individual is categorised here as Late Neolithic, there is a possibility this individual is actually younger.

The Late Neolithic burials are mostly scattered across the cemetery. Distinct from previous periods, they contain no ochre and have few grave goods. Burials are often in a crouched position. The damaged burial 137 is distinct because it contained a flat bottomed amphora, bone awl, a chisel made from a domesticated goat and two animal pendants (Zagorska 2006b). This individual is the earliest Corded Ware individual in the Eastern Baltic (Loze 2006).

Burial within the cemetery does not end with Late Neolithic settlers and younger burials, dated to the Bronze Age and Medieval period, have been recovered. No samples were selected from these later periods. The location of the burials is given in Figure 38, Figure 39 and Figure 40.

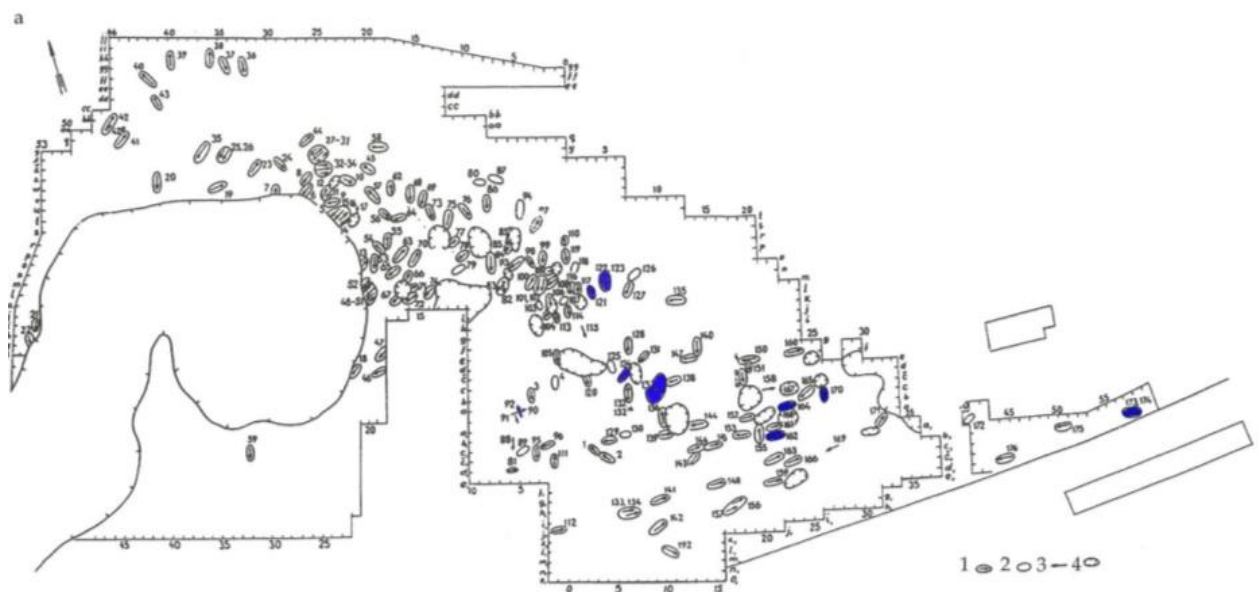


Figure 38. Plan of Burials in the North West part of the cemetery. Blue burials represent those selected for early life history analysis. Adapted from Zagorskis (2004, p.6 Fig 3).

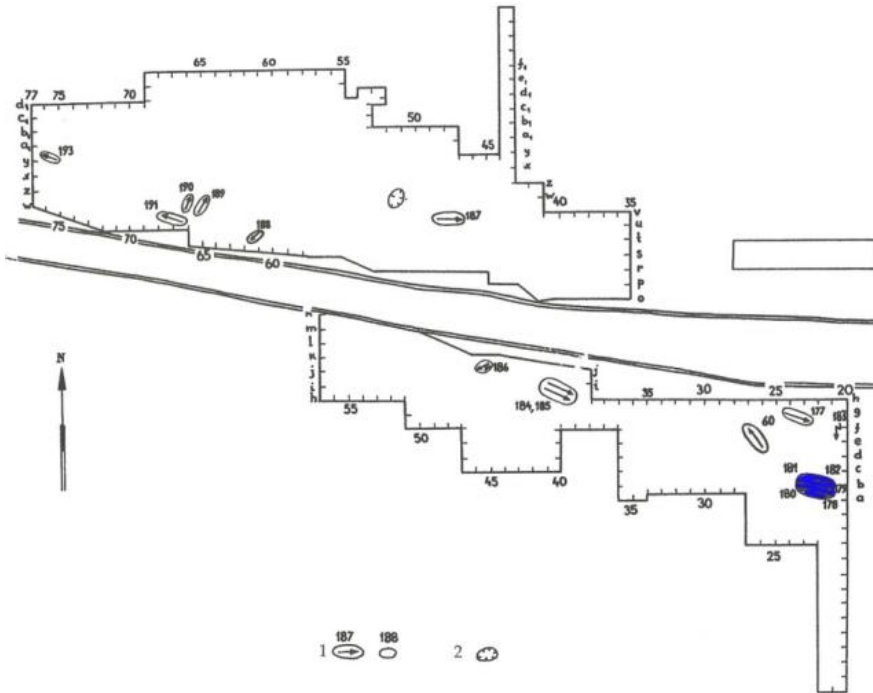


Figure 39. Plan of burials in the middle zone of the cemetery. Blue burials represent those selected for early life history analysis. Adapted from Zagorskis (2004, p.8 Fig 4).

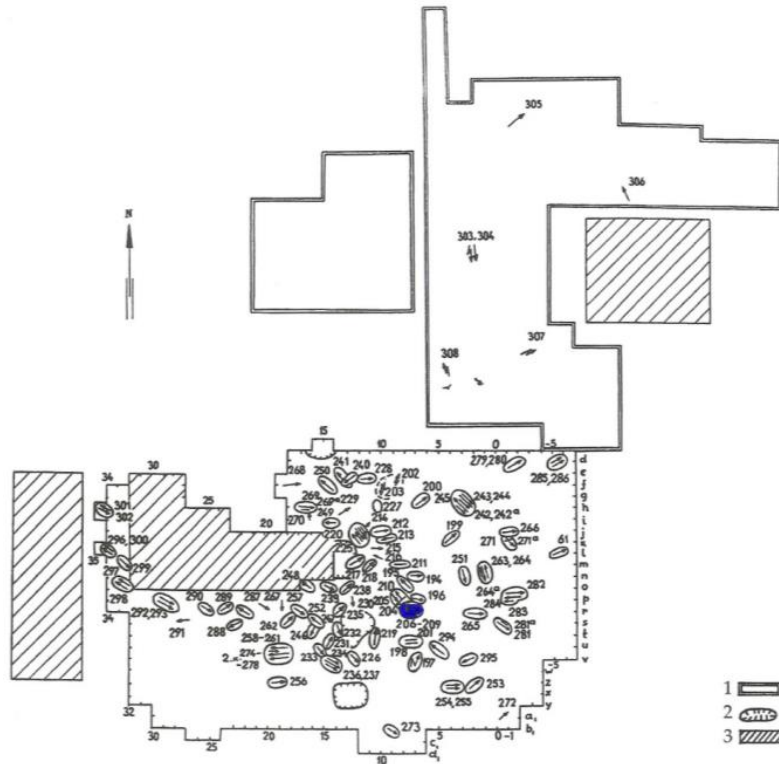


Figure 40. Plan of burials in the south eastern part of the cemetery. Blue burials represent those selected for early life history analysis. Adapted from Zagorskis (2004, p.10 Fig 5).

7.8 Summary

Since its excavation starting in the 1970s, the Zvejnieki site has proved to be an archaeologically rich resource, providing a vast amount of information about the way some Stone Age people lived and died. The cemetery contained over 300 individuals, forming a rare collection of skeletal remains transposing a vast period of time. The longevity of the cemetery's use means continuity and change between the Mesolithic and the Neolithic can be studied. This is a shift which is hard to interpret in Eastern Europe, as unlike other parts of Europe the Neolithic is not defined by the introduction of farming. The degree of continuity and change between the two eras is therefore debateable. Although the use of pottery, rather than agriculture, is a marker of the Neolithic period in Latvia, there is an indication that a variety of small changes were occurring. These are picked up by a change in stature, caries incidence, dietary stable isotopes, species of fauna recovered in the settlement area and burial rites. These are likely to be a consequence of changing environmental and climatic conditions, as well as immigration.

Sixteen samples have been selected from the Mesolithic and Neolithic periods to investigate the early life histories of those living at Zvejnieki. All of these individuals have been radiocarbon dated and many have been analysed in other ways, giving them a full context.

Chapter 8 Early Life Histories at Zvejnieki

This chapter considers the early life experiences of those from the Mesolithic and Neolithic era at Zvejnieki. The study traces their dietary intake throughout the first 8 years of life and where possible compares this to previous isotope results obtained from bone, representing the adult diet. Several key themes are addressed, including whether any difference in childhood diet occurs between the Mesolithic and the Neolithic, with the aim of providing an insight into the broader topic of change or continuity between the two eras. The data are also viewed collectively, to address topics such as the timing of dietary change in infancy and childhood, variability in childhood feeding patterns and how early life histories may have been influenced by factors such as status and wealth. These topics provide an insight into the lives of those at Zvejnieki and hunter-gatherer childhoods in general, which in the past are poorly understood. This study is one of the few to consider hunter-gatherer childhoods using stable isotopes.

8.1 Building on Previous Isotope Analysis

This study builds on the work of Eriksson (2006), (2003) and (Eriksson *et al.* 2003), who have published all other available isotope data connected to Zvejnieki. These results are described in Chapter 7. Many of the individuals analysed in Eriksson's study were not ideal choices for sampling. Seven of the human samples were obtained from grave goods i.e. human teeth or bone made into pendants and placed in the graves of other individuals. Analysing human artefacts means little is known about the person. Important information such as the time period they were from, sex, age, whether they were given grave goods or how they were buried (or even if they were once buried) is lost. Although the samples are in context as grave goods, as human remains they are without context. The criterion for selecting teeth to be made into pendants is also unclear. The teeth may have belonged to their ancestors, their enemies or they may have been randomly taken from exposed graves in the Zvejnieki cemetery.

To make the interpretation more complex, the seven human teeth were taken from four graves. Eriksson (2006) estimated they belonged to between 4 and 7 individuals, making it unclear how many people make up the sample. One artefact-derived value, obtained from a worn human incisor in grave 190, gave a $\delta^{15}\text{N}$ isotope value of 6.2‰, which in comparison with other humans and the faunal remains is suspiciously low. Either this individual must have consumed mainly plants in their childhood, or the sample has been misidentified. The additional problem of using human artefacts as samples is that they lack radiocarbon dates. It would be interesting to see how old these samples are in relation to the people who were buried with them, as this would establish whether they might have been derived from known ancestors, contemporary people, or whether they were recycled from much older, unknown, people. Either way, without being radiocarbon dated it is not possible to use isotopes from these people to explore factors such as dietary change through time.

The use of tooth artefacts to obtain isotopic values did mean the diet of children could be considered in Eriksson's (2006) study. It is not stated how the samples were taken, it is assumed they were derived from bulk dentine values, thus reflecting an averaged childhood diet over a number of years. While a nursing signal was identified by Eriksson (2006), no conclusion is made beyond the fact this signal is present in the population, presumably because of the difficulty in aging the samples and the use of bulk dentine. The results from three children's bones were also available.

The present study aims to focus on the childhood period to form a more detailed understanding of children's early life experiences, which can be compared to the adult values obtained previously. All samples selected have been radiocarbon dated and were taken from skeletons rather than a grave good context, meaning a greater body of information is available.

8.2 Aims and Questions Concerning Childhood Experiences at Zvejnieki

8.2.1 Change or Continuity in Infant Feeding?

There are a number of stereotypes associated with hunter-gatherer groups, often based on ethnographic parallels. They are in general associated with child rearing strategies involving prolonged breastfeeding, a product of multiple factors including mobility patterns, energy expenditure, work requirements and subsistence (Fouts 2004). As there was no distinct transition to farming at the onset of the Neolithic in this region, it could be postulated that childhood feeding strategies remained the same throughout the Mesolithic and Neolithic. It might also be expected that these feeding strategies were typical of hunter-gatherer child rearing patterns, which include an extended breastfeeding period. There is a large body of evidence which suggests hunting and gathering continued at Zvejnieki throughout the Mesolithic and Neolithic. This includes the continued reliance on freshwater fish and terrestrial mammals (Lõugas 2006, Eriksson 2006), the continual habitation of the Zvejnieki settlement and the continual practice of what appears to be a uniform definable culture which transcended the Mesolithic and Neolithic (Zagorskis 2004) (see Chapter 7).

The opposing concept is that while hunting and gathering appears to have remained the major subsistence strategy, there are hints that there were changes between the Mesolithic and Neolithic. Chapter 7 details a number of features differentiating the Mesolithic from the Neolithic, which could have impacted childhood experiences or are indicators that childhood experiences may have changed over the period of the cemetery's use. In particular, there are a number of key points in the argument for change which should be reiterated. Firstly, a small increase in population numbers during the Neolithic suggests either immigration into the area, a change in infant survival or a change in birth rate occurred (Zarina 2006). Palaeopathological results suggest there may have been a slight increase in the exposure to pathogens in the later periods or a better rate of infant survival (Jankauskas and Palubeckaitė 2006). This could be the product of a shorter breastfeeding duration, which would increase the number of offspring a

woman had. Alternatively, if the pattern was caused by an increased survival rate, elongated breastfeeding could have been a factor. Likewise, small changes in the incidence and peak timing of linear hypoplasia combined with changes in stature could suggest children were either flourishing or experiencing greater health problems over time, perhaps influenced by a change in diet (Gerhards 2006, Palubeckaitė and Jankauskas 2006). Potentially, small changes in the weaning diet of infants as the Neolithic period progressed could have caused some of these changes. This could have been brought about by the advent of pottery, which could have facilitated the preparation of different infant and childhood foods.

This study aims to provide a further line of evidence to either support or contradict the role of infant feeding in these changes. The questions explored can be summarized as follows:

- There is a statistical difference in the incidence of hypoplasia between the Mesolithic and Neolithic, with 15% of Mesolithic individuals showing hypoplasia and 48% of Neolithic individuals showing hypoplasia (Palubeckaitė and Jankauskas 2006). Are changes over the Mesolithic and Neolithic, such as differences in the incidence of hypoplasia, likely to be a consequence of a change in feeding practices, given that some infant feeding patterns are more stressful than others?
- There is a statistical difference in the stature of individuals between the Neolithic and Mesolithic. Individuals assigned to the Mesolithic/Neolithic transitional period were statistically shorter than those from the Late Mesolithic ($p < 0.01$), while the Neolithic saw individuals increase in size again. The tallest were the Late Neolithic people (Gerhards 2006). As stature can indicate the health of a person, could any of these changes be a cause or consequence of a change in diet during infancy or childhood?
- Can we predict whether they were likely to be healthier or not based on the feeding patterns and the known immunological impact of breastfeeding?

- A peak in hypoplasia is seen at the age of 3 years in the Mesolithic and 4 years in the Neolithic (Palubeckaitė and Jankauskas 2006). If we are to believe that weaning causes this peak in infancy, this would suggest that weaning occurred later in the Neolithic. Is this the case?
- Is there a difference in infant feeding strategies between the Mesolithic and Neolithic people? Eriksson (2006) found a statistical difference in adult diet between the Mesolithic/Early Neolithic and the Late Neolithic/Bronze age. Is this also reflected in children's diets? Could this have caused a slight increase in population numbers which brought about other changes?

8.2.2 Is There Variability in the Population?

Children's life experiences can be varied, particularly in groups where there are a large number of social factors, such as religion, status and wealth to name a few (see Chapter 1). It could be argued that variability might reflect how socially cohesive a population was. Hunter-gatherer groups are often depicted as egalitarian, although a number of factors suggest that this is not the case at Zvejnieki. There are differences in the provision of grave goods and the demography suggests some individuals, particularly females, are underrepresented (Zagorskis 2004, Zarina 2006). This could reflect differences in wealth and status within the Zvejnieki community. Seemingly, children were not immune to these social differences, as some children were also buried with abundant grave goods, suggesting status was ascribed from birth (Zagorskis 2004). By looking at grave goods and comparing this to diet, it might be possible to pick out those who had a higher status.

Eriksson (2006) identified a large degree of variability in diets at Zvejnieki, which it has been suggested were caused by seasonality. Two individuals, 179 and 189, had two different elements analysed, which produced results with a greater variability than expected. This variability was the basis for the suggestion that seasonality might have played a role in the range of values obtained from different individuals. Using incremental analysis of dentine, it is possible to identify more

discrete periods, over a series of years. This should allow an insight into the possible role of seasonality in the diet.

The questions can be summarized as follows:

- How varied are children's life experiences in this era? Can they be related to status?
- It has been suggested that variability seen between some individuals analysed previously is caused by seasonality (Eriksson 2006). Using incremental analysis, is this shown to be reasonable theory?

8.3 Dentine Results

8.3.1 Age Related Patterns in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$

Collagen preservation was generally good and all samples had C:N ratios within the acceptable range of 2.9-3.6‰, but not all segments yielded enough collagen to provide a sample. Individuals 319 and 313 were particularly affected, each of which only yielded enough collagen for one sample each, meaning the full childhood trajectory could not be obtained. Both of these individuals were amongst the oldest samples, dating to the Middle Mesolithic. They were also both obtained in recent excavations, from the area around the farmstead, perhaps suggesting collagen preservation in this area is not as good. This is something which should be considered when conducting future analysis.

Due to heavy attrition of the occlusal surface and the smaller sample obtainable from the cusps, the 0-6 month age span is represented by 10 individuals. The mean $\delta^{15}\text{N}$ value is $14.5 \pm 2.1\text{‰}$, with a range of 18.4-11.9‰. The following segment representing 6-12 months averaged $14.4 \pm 1.9\text{‰}$, with a maximum of 17.4‰ and a minimum of 11.1‰. Subsequent segments, starting from 1 year-20 months have reasonably uniform $\delta^{15}\text{N}$, with the final available segment, representing the 7-8 year age category, producing a $\delta^{15}\text{N}$ value of $12.9 \pm 1.9\text{‰}$. There is little notable change in $\delta^{13}\text{C}$ throughout the infant and childhood trajectory, the average value for the 0-6 month category is -

22.6±0.9‰ and for the 6-12 month category -22.8±1.2‰. The average of -22.9±1.1 in the 7-8 year category shows little change from the early segments (Table 17). Although there is some variation between individuals, the boxplots produced for the statistical analysis illustrate this lack of change in the mean isotope values over the 3-8 year period of both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (Figure 47 and Figure 48). Figure 41 and Figure 42 represent the individual projections throughout the first 8 years of life and the data collectively. Several individuals, 124, 154 and 179 show opposing covariance, possibly indicating nutritional stress.

Although no third molars reflecting adult diet were analysed in this study, stable isotope values from bone analysed previously are available for some of the individuals included in this study (Eriksson 2006). Stable isotope values from the bone represent an averaged diet from the last few years of each individual's life, meaning it is a reflection of the adult diet. The average $\delta^{15}\text{N}$ value for individuals 137, 164, 162, 173, 208, 121 and 179 (all individuals included in the early life history study) is 11.4±1.3‰. This suggests the $\delta^{15}\text{N}$ declines in adulthood, at an unspecified time. There is little difference in the adult $\delta^{13}\text{C}$ value from the bone of -22.7±0.8 compared to the earlier values.

Figure 43 presents the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ of the different age brackets in relation to results obtained from local fauna. Human results, regardless of age, are correlated most strongly with the otter, a high trophic level animal, relying on freshwater fish for its main subsistence. Although it has been shown there is variability in $\delta^{15}\text{N}$ depending on age, compared to the variety of values obtained from other fauna, the human values cluster quite tightly. This puts the variability of infant, child and adult diet into context.

Not all individuals were sexed, leaving only a small sample of 4 females and 9 males. This was not considered a large enough sample, particularly for females, for a difference in diet between the sexes to be considered.

The full $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ results are reported in Appendix F.

Table 17. The average $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for each age bracket, all individuals included.

Age	0-6 months	6-12 months	1 year-20 months	20-28 months	28 months-3 years	3-4 years	4-5 Years	5-6 years	6-7 years	7-8 years	Adult (Bone)
$\delta^{15}\text{N}$	14.5±2	14.4±1.9	13.9±1.9	13.7±1.9	13±1.6	12.5±1.6	12.3±1.6	12.2±1.6	12.3±1.9	12.9±1.9	11.4±1.3
$\delta^{13}\text{C}$	-22.6±0.9	-22.8±1.2	-23.3±1.3	-23.3±1	-23.1±1	-22.9±0.9	-22.9±1	-22.8±1	-22.8±1.2	-22.9±1.1	-22.7±0.8

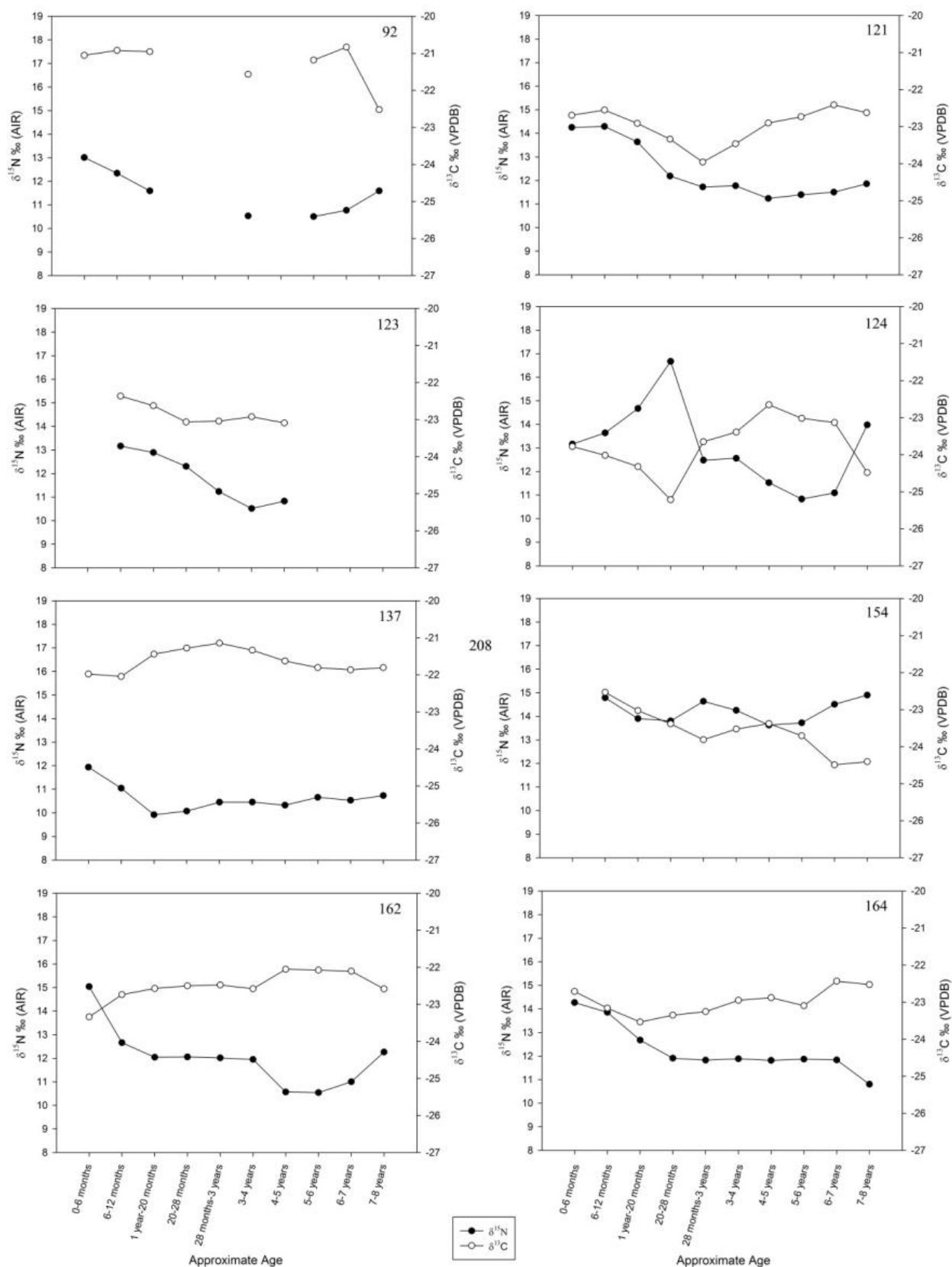


Figure 40. Graphs showing $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ trends over the first 8 years of life in each individual.

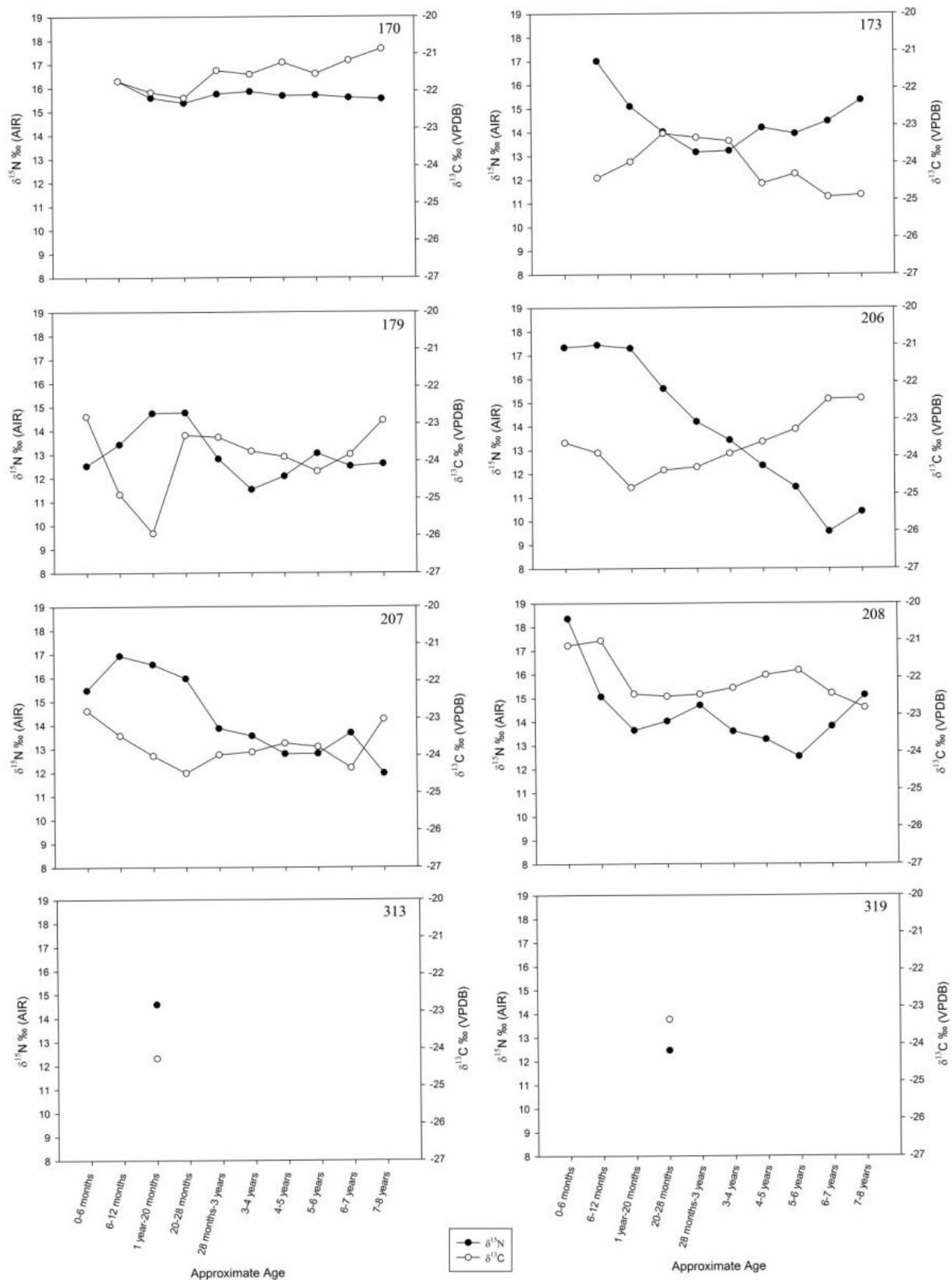


Figure 41 continued. Graphs showing $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ trends over the first 8 years of life in each individual.

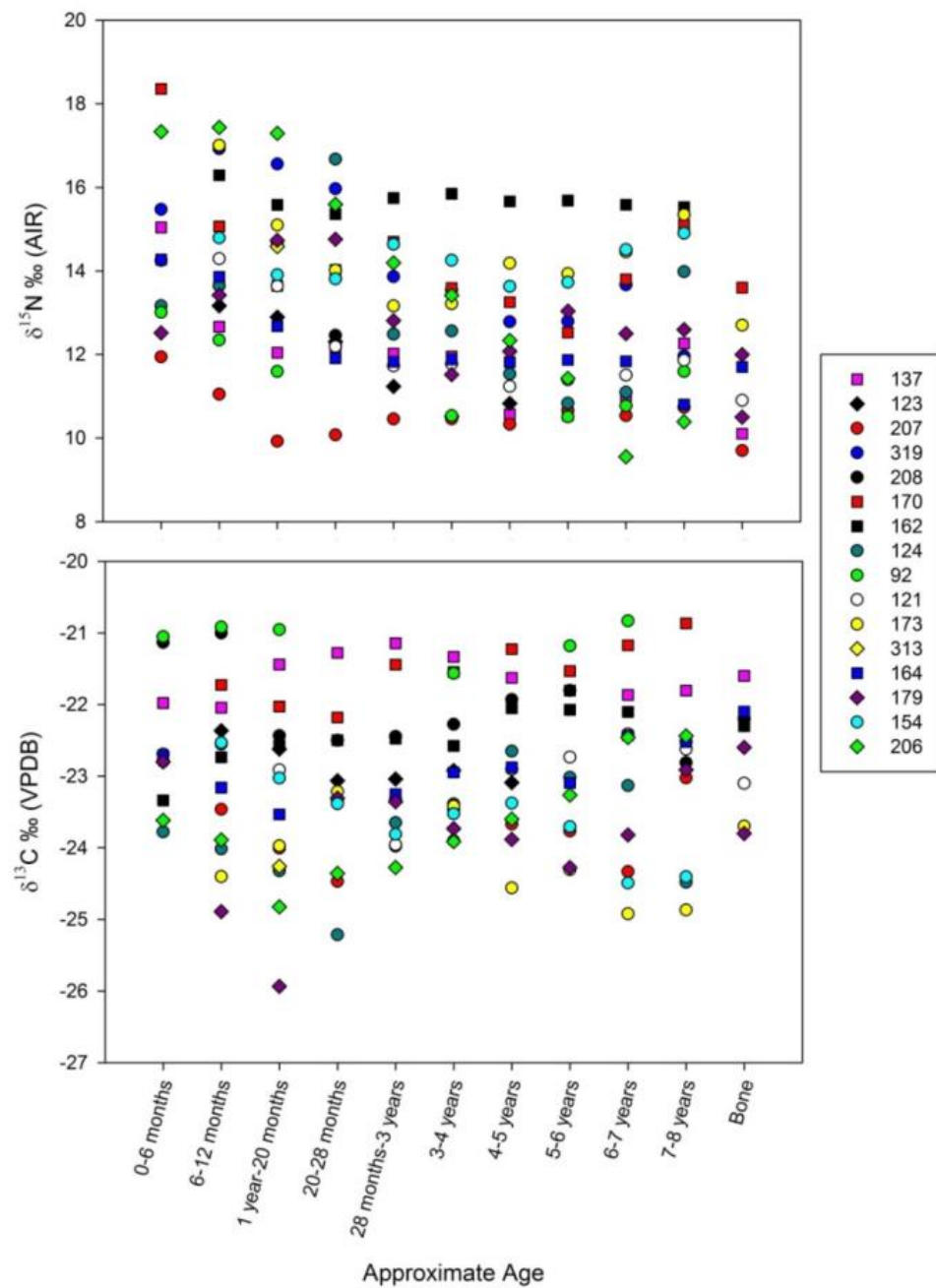


Figure 42. Graphs showing the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ results for each individual by age category. Results from the bone have been included from Eriksson's (2006) study. These mostly represent an averaged adult value, with the exception of those who died in late childhood. Two different results were available for individual 179, one from the pelvis the other from the skull bone, both have been included.

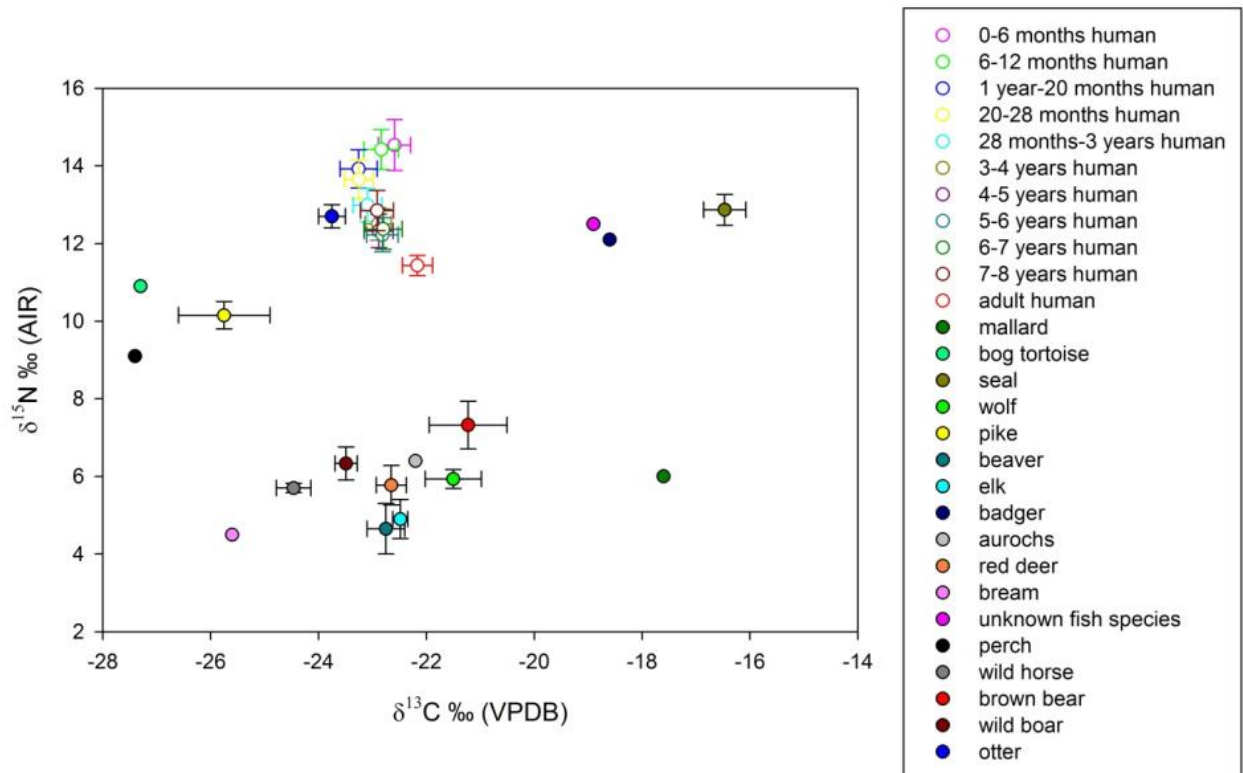


Figure 43. A comparison of the average $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in humans of different ages, compared to faunal remains from the site. Note that seals recovered from Zvejnieki are included, but are not part of the local ecology. Data from adults and fauna from Eriksson (2006).

8.3.2 $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in Relation to the Radiocarbon Age of the Sample

Figure 44 illustrates the changes in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ over life, compared to the radiocarbon age of each individual. In the earliest age brackets, up to 28 months-3 years, the $\delta^{15}\text{N}$ from all the time periods is similar to each other. Following this infancy period, at around the 3 year mark, there are hints that small changes in the $\delta^{15}\text{N}$ occurred over the Mesolithic and Neolithic periods. The oldest samples from the Middle Mesolithic, represented by individuals 170 and 154, consistently have two of the highest $\delta^{15}\text{N}$ values in each age bracket. The youngest sample from the Late Neolithic, represented by individual 137, has one of the lowest $\delta^{15}\text{N}$ and least negative $\delta^{13}\text{C}$ values in childhood. All other samples, representing the Late Mesolithic, Early Neolithic and Middle Neolithic periods cluster with each other throughout childhood. Generally speaking, there is less variability in $\delta^{13}\text{C}$ between samples compared to $\delta^{15}\text{N}$.

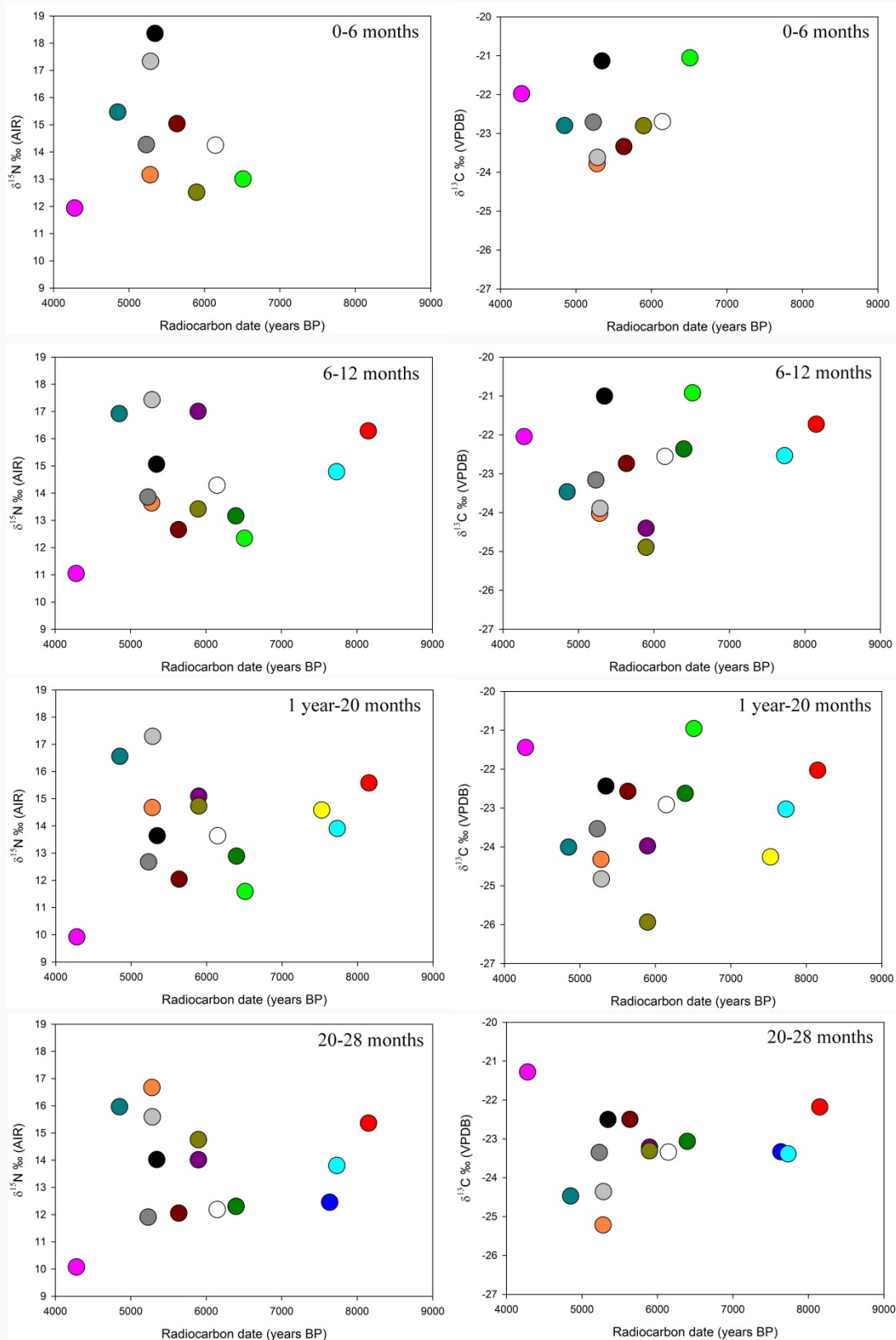


Figure 44. Scatterplots showing the relationship between the radiocarbon date of the samples and the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ for each individual over the first 8 years of life.

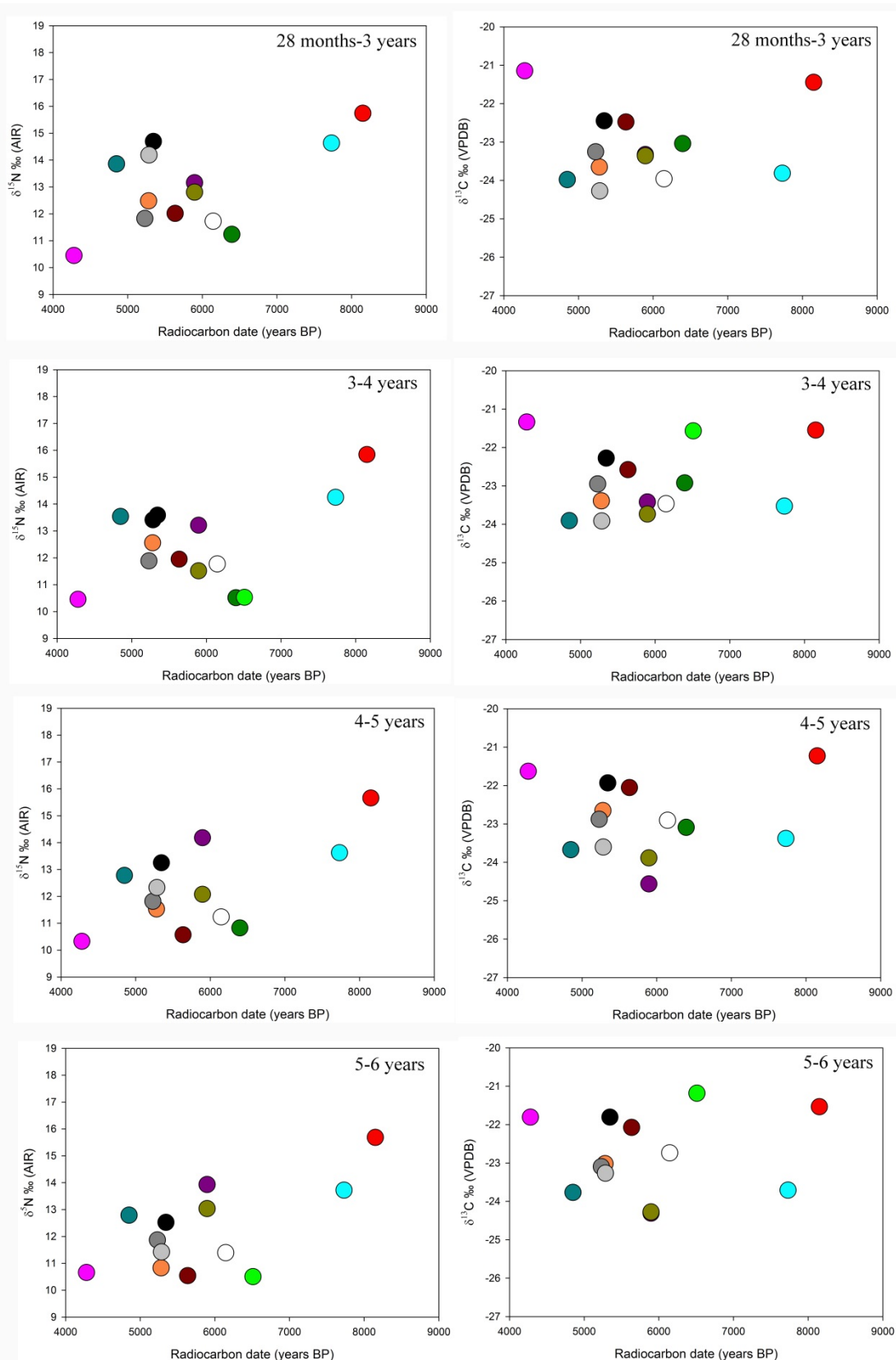


Figure 44 (continued). Scatterplots showing the relationship between the radiocarbon date of the samples and the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ for each individual over the first 8 years of life.

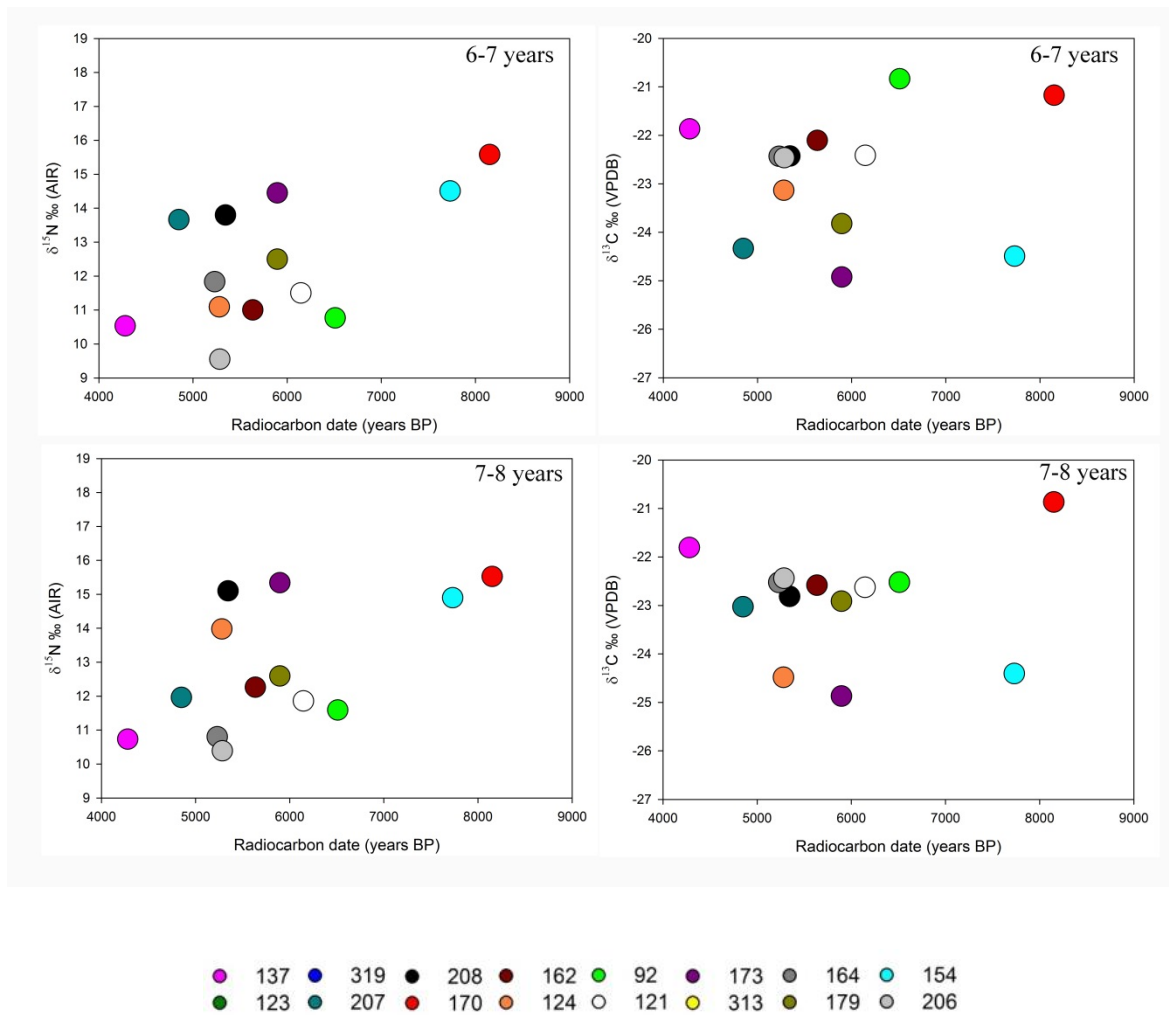


Figure 44 (continued). Scatterplots showing the relationship between the radiocarbon date of the samples and the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ for each individual over the first 8 years of life.

8.3.3 $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in Relation to Grave Goods

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from all 16 individuals was examined in relation to grave goods. The predominant grave goods which were ubiquitous throughout all time periods are pendants made from teeth and bone. Table 18 lists whether pendants were included in each grave or not. Other grave goods, such as amber and figurines, were too small in number to carry out any meaningful analysis.

The results from the last 5 time slices only, representing the years 3-8, were compared to grave good incidence. The first 5 time slices were excluded to avoid the more variable breastfeeding

and weaning period, meaning that only the childhood diet is focused on. A preliminary look at the data in Figure 45 suggests there may be a relationship between the stable isotopes and whether a person was buried with pendants. The data appear to show those without pendants had lower $\delta^{13}\text{C}$ and elevated $\delta^{15}\text{N}$. To establish whether this relationship was correct, statistical analysis was carried out. The relationship between adult diet and whether pendants were included as grave goods or not was also investigated (Figure 46). Not all of these adults were the same individuals which were used for incremental dentine sampling. Table 19 lists the adults included in this analysis and their radiocarbon dates.

Table 18. Table showing which individuals were buried with pendants and the number of these artefacts. Included are individuals isotopically analysed by Eriksson (2006).

Individual	Presence of pendants in grave	Number of pendants
137	Yes	2
123	Yes	339
207	No	0
208	No	0
170	Yes	167
162	Yes	6
124	Yes	7
92	Yes	2
121	Yes	87
173	No	0
164	Yes	13
179	No	0
154	No	0
206	No	0
5	Yes	32
62	Yes	49
219	Yes	5
83	Yes	14
201	No	0
153	Yes	22
186	No	0
189	Yes	51
190	Yes	224
226	Yes	80
261	No	0

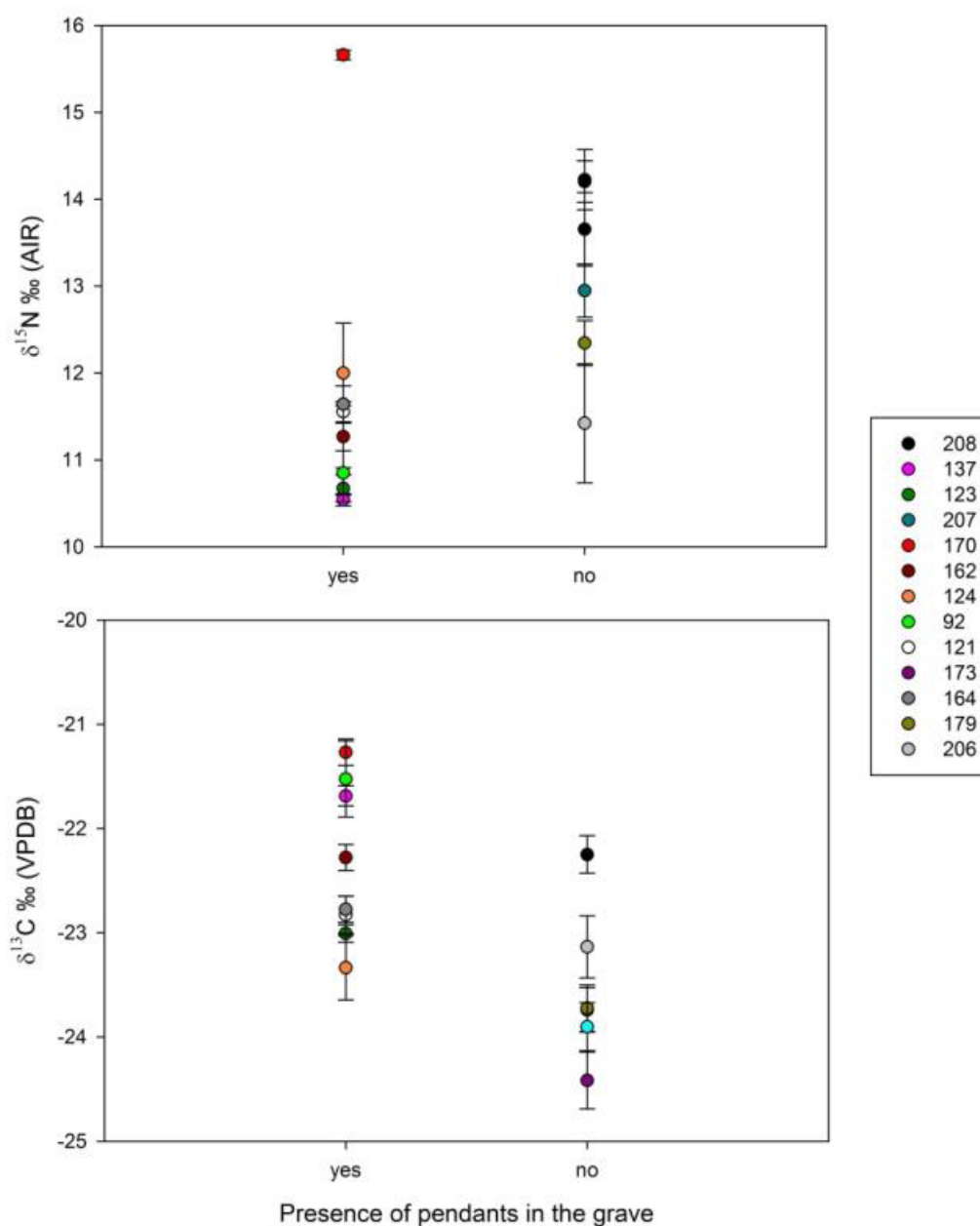


Figure 45. Scatterplots comparing the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in childhood of those buried with and without pendants. The average was calculated from the last 5 segments, representing the age range of 3 to 8 years. This means the infant breastfeeding and weaning period is excluded. Individuals 313 and 319 have been excluded as a grave good inventory was not available. The presence of grave goods was based on the report by Zagorskis (2004) and included all pendants made of both tooth and bone, from all species.

Table 19. Individuals included in the adult analysis. Most samples are from the Mesolithic and Neolithic, with the exception of individual 141.

Adult Sample	Radiocarbon date	Period
76	6900±75	Late Mesolithic
137	4280±60	Late Neolithic
141	2770±65	Bronze Age/Iron Age
158	-	Early Neolithic?
162	5635±65	Early Neolithic
164	5230±95	Middle Neolithic
165	5480±100	Middle Neolithic
178	6185±80	Early Neolithic
179	5895±70	Early Neolithic
197	6400±95	Early Neolithic
199	4825±85	Middle Neolithic
221	5180±65	Middle Neolithic
228	5090±55	Middle Neolithic
269	-	Neolithic?
277	5545±65	Middle Neolithic

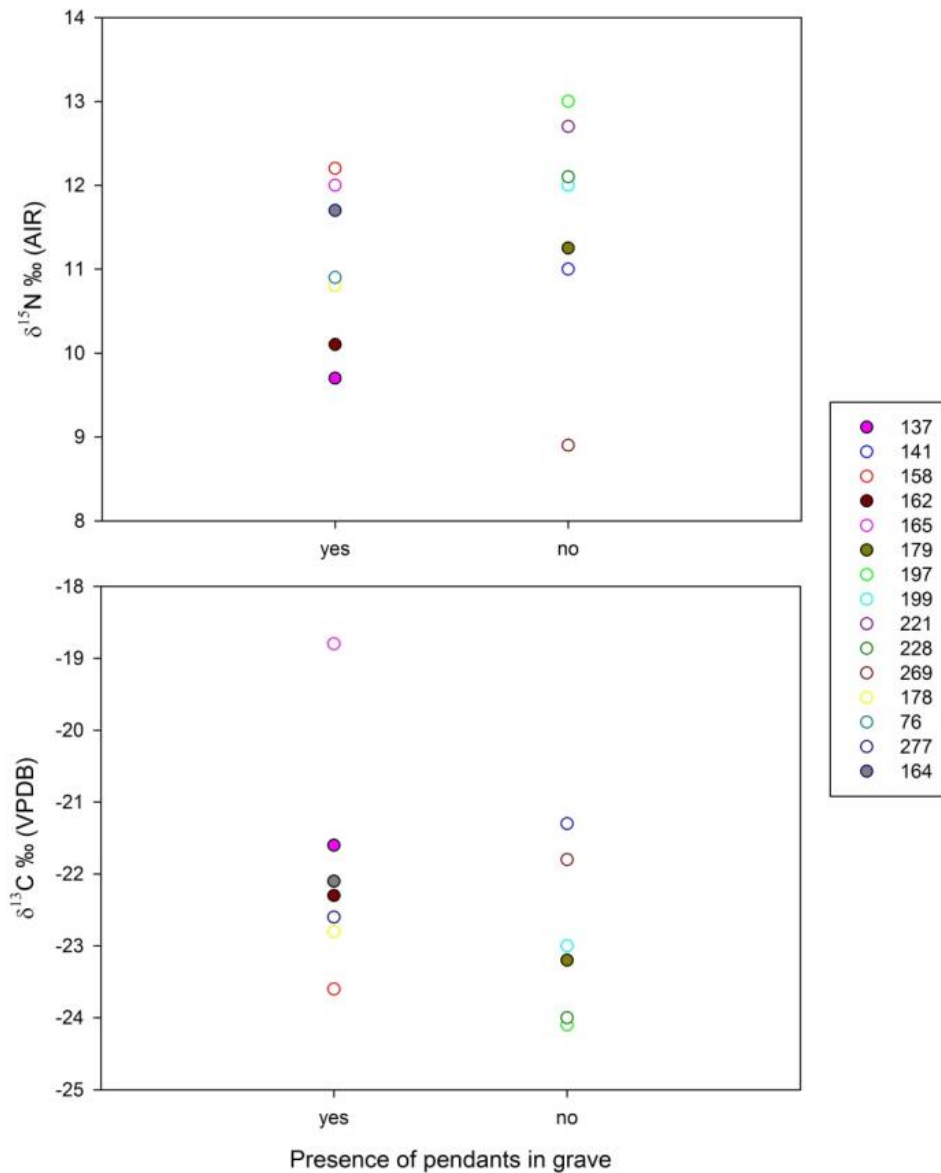


Figure 46. Scatterplots comparing the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in adulthood of those buried with and without pendants.

Results were obtained from Eriksson (2006). The presence of grave goods was based on the report by Zagorskis (2004) and included all pendants made of both tooth and bone, from all species.

8.3.3.1 Statistical Analysis of Pendants in the Graves

The differences in mean isotope levels for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ were analysed with Analysis of Variance using the `aov` and `lm` functions in R. Preliminary investigations revealed that there was no difference in the mean isotope values taken from different sections of the teeth over the age range 3-8 years so age effects could be eliminated. This lack of significant isotopic change with

age at the time of tooth formation is shown clearly in the box plots below (Figure 47 and Figure 48).

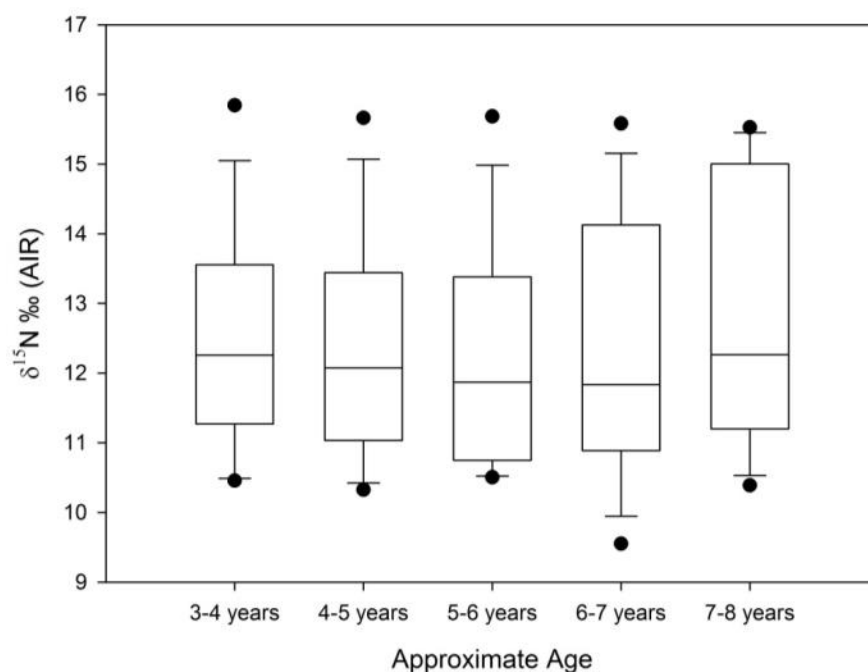


Figure 47. $\delta^{15}\text{N}$ boxplot of the last 5 time slices, representing the years 3-8, for all individuals analysed.

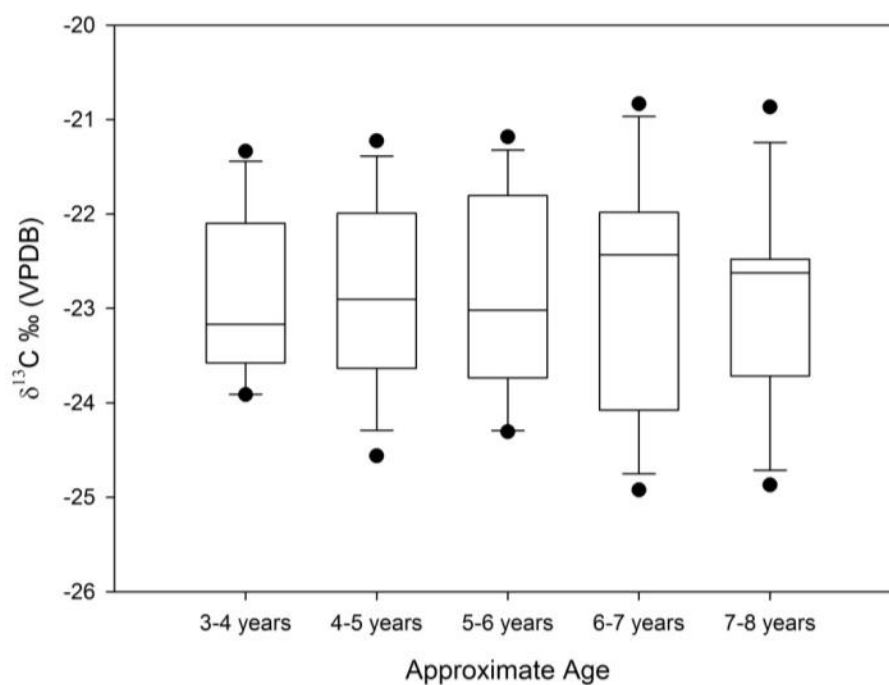


Figure 48. $\delta^{13}\text{C}$ boxplot of the last 5 time slices, representing the years 3-8, for all individuals analysed.

The two box plots showing the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in relation to pendant presence clearly indicate that pendants are a predictor of both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (Figure 49 and Figure 50). It is notable that for $\delta^{15}\text{N}$ there are a series of outliers in the 'yes' group, these are from individual 170. This individual has $\delta^{13}\text{C}$ within the range of the other individuals with pendants, but $\delta^{15}\text{N}$ which is more elevated within the group. This individual is the oldest sample obtained, dating to the Middle Mesolithic.

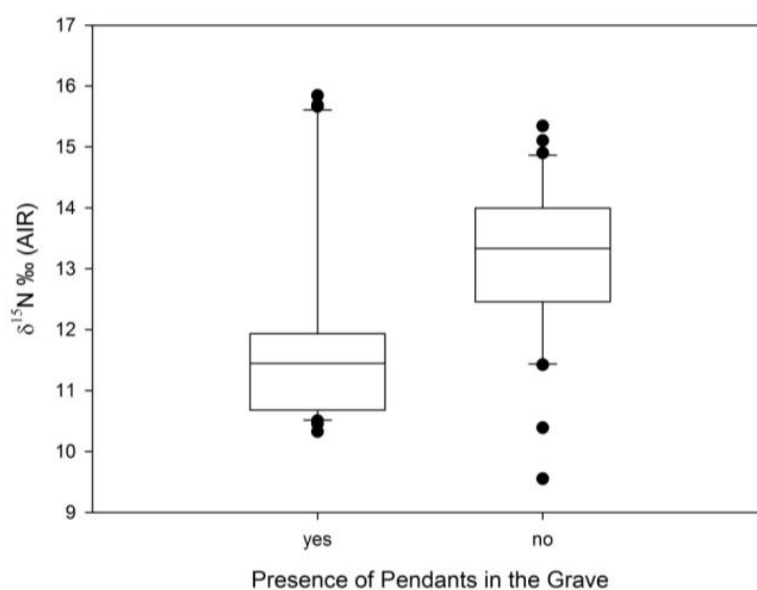


Figure 49. Boxplot comparing the $\delta^{15}\text{N}$ of those with and without pendants in the grave.

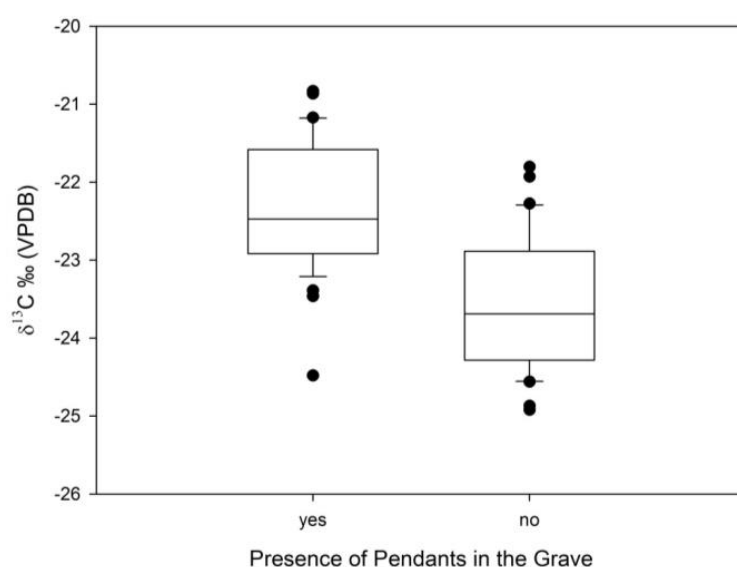


Figure 50. Boxplot comparing the $\delta^{13}\text{C}$ of those with and without pendants in the grave.

Following an investigation of a range of possible models using general linear models it was concluded that the following models presented as word equations were the best predictors of isotope levels.

$$\delta^{15}\text{N} = \text{Pendant} + \text{Individual and}$$

$$\delta^{13}\text{C} = \text{Pendant} + \text{Individual}.$$

These models assumed that the variation in isotope ratios relate to both the individual and also presence of pendants.

$\delta^{15}\text{N}$

The results of the two-way ANOVA showed highly significant differences in mean $\delta^{15}\text{N}$ isotope values with respect to both individual and pendant presence (Table 20). It can be concluded that the presence of pendants was related to the observed $\delta^{15}\text{N}$ and that some individuals were also significantly different from each other.

Table 20. Analysis of variance table for $\delta^{15}\text{N}$. Only children were included.

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Pendant	1	25.244	25.2436	42.32	3.040e-08 ***
Individual	12	121.284	10.1070	16.944	6.139e-14 ***
Residuals	52	31.018	0.5965		

$\delta^{13}\text{C}$

The results of the two-way ANOVA showed highly significant differences in mean $\delta^{13}\text{C}$ isotope values with respect to both individual and pendant presence (Table 21). It can be concluded that the presence of pendants was related to the observed $\delta^{13}\text{C}$ and that some individuals were also significantly different from each other.

Table 21. Analysis of variance table for $\delta^{13}\text{C}$. Only children were included.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Pendant	1	24.473	24.4727	104.603	4.752e-14 ***
Individual	12	32.458	2.7049	11.561	7.844e-11
Residuals	52	12.166	0.2340		

A statistical analysis was undertaken to test for a relationship between the number of pendants present and the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ isotope values. The significance of a linear model and an analysis of variance were undertaken using the lm function in R.

The basic model was of the form:

$$\text{Number of pendants} = \delta^{13}\text{C} + \delta^{15}\text{N}$$

Models were investigated that used the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ isotope values of each tooth segment separately and also the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ over all the 5 segments. In all models investigated no significant relationship was detected. Table 22 shows the results for the model using average values which clearly shows no significant relationship.

Table 22. Table showing there is no significant relationship between the number of pendants and the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using the model: Pendant number = average $\delta^{13}\text{C}$ + average $\delta^{15}\text{N}$.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
AveC	1	4037	4037.3	0.3738	0.5534
AVeN	1	79	79	0.0073	0.9334
Residuals	11	118801	10800		

The difference in mean isotope levels in adults for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ were analysed by Analysis of Variance using the aov function in R. The null hypothesis was that there was no difference in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ between those with and without pendants. The results showed that this null hypothesis was correct (Table 23 and Table 24).

Table 23. Analysis of variance table for $\delta^{15}\text{N}$. Only adults were included.

	Df	Sum sq	Mean sq	F value	Pr(>F)
Pendants	1	0.68	0.68	0.515	0.486
Residuals	13	17.16	1.32		

Table 24. Analysis of variance table for $\delta^{13}\text{C}$. Only adults were included.

	Df	Sum sq	Mean sq	F value	Pr(>F)
Pendants	1	2.08	2.080	1.181	0.297
Residuals	13	22.89	1.761		

8.4 Discussion

8.4.1 General Patterns in Infant and Childhood Feeding

8.4.1.1 Infancy

The $\delta^{15}\text{N}$ shows there is a clear breastfeeding signal in infancy, with elevated $\delta^{15}\text{N}$ in the 0-6 month age bracket. Although there is a drop in $\delta^{15}\text{N}$ between the 0-6 month and 6-12 month age brackets, this is minimal (the difference between the averages is 0.1‰). This suggests small amounts of other foods began to be introduced to some individuals, but in general there was a reasonably constant diet of breast milk between these two age brackets. The greater decline in $\delta^{15}\text{N}$ occurs between the 6-12 month and 1 year-20 month age brackets (an average decline of 0.5‰). This greater change indicates this was the period when breast milk began to be withdrawn to a larger degree. Breast milk continued to be withdrawn during the weaning period until around 20-28 months, although it played a more minimal part in the child's nutrition by this point.

The provision of breast milk over the first year of life either suggests mothers or carers at Zvejnieki were aware of the importance of breast milk, that there was little other available choice in foods or that culturally dictated norms influenced feeding strategies. Of course it is not possible to rule out other reasons for this infant feeding pattern, such as sedentism, gender roles, beliefs

and customs etc. Although extended breastfeeding was practiced, the Zvejnieki women understood that other foods were needed in the diet before the child reached the age of 1 year.

There is a large degree of variability between individuals in both the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ during infancy. This is either a reflection of different infant rearing strategies, or a reflection of the mother/carer's trophic level. Given that there is a large degree of variability in the adults, this lends support to the idea that the variability in infants is probably a reflection of the different diets consumed by the women feeding the children. Alternatively it could represent the introduction of small amounts of solid foods into some infants' diets early on. It is also possible that some infants were more stressed than others, meaning their $\delta^{15}\text{N}$ could be reflecting physiology rather than dietary variability. The individuals with elevated $\delta^{15}\text{N}$ into childhood, after it is likely weaning had taken place, such as 124, 157 and 179, may illustrate that these individuals were stressed.

8.4.1.2 The Transition to Childhood

After the 20-28 month time period, the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ remain fairly constant throughout the rest of the childhood trajectory. The $\delta^{13}\text{C}$ indicates that aquatic animal foods were widely consumed during childhood, as it is more negative than may be expected for diets based solely on terrestrial food sources, particularly when compared to the Zvejnieki fauna. The $\delta^{15}\text{N}$ gives a similar indication that high trophic level foods were being consumed, as they remain elevated compared to other terrestrial animals. Freshwater fish are likely to have formed part of the diet of these children, although there is a large degree of variation between individuals. This suggests that there were various dietary options available and flexibility in childhood feeding was not discouraged.

The childhood period is the most appropriate time to consider the effects of seasonality on diet in this study. Infancy is unsuitable because of the variability caused by breastfeeding and weaning practices and without M2s or M3s, later trajectories are not available. The consistency of $\delta^{15}\text{N}$

and $\delta^{13}\text{C}$ values throughout childhood does not support the theory that seasonality played a large role in the variability of the stable isotopes. Although the time slices during this period represent more than one season, there is a lack of variation over each individual's early life, despite the fact the children were probably born at different times of the year and in different years. Looking at the species of animals to which the Zvejnieki people had access, the faunal remains give a clear indication of the freshwater species which are likely to have formed a major part of the diet. Pike and perch were two of the major fish species recovered archaeologically (Löugas 2006). Neither of these are seasonal species, meaning they should have been readily available all year round. This suggests that if seasonal food changes were occurring, plants or terrestrial species are more likely to have caused a variation in diet. As all plants consumed by humans and other animals in this area were C3, using stable isotopes to detect plant or terrestrial animal change is difficult.

8.4.1.3 From Childhood to Adulthood

If one considers all data together, a difference in the childhood and adult stable isotope composition indicates that a change in diet occurred between these age groups. The lower $\delta^{15}\text{N}$ seen in the adult bone, compared to the childhood dentine, may suggest that lower trophic level foods were being consumed in adulthood compared to childhood. A possible scenario is that children past the weaning age were consuming larger amounts of freshwater fish or meat compared to adults. Without analysis of teeth which develop after 8 years old, the timing of this transition is unclear. Although the trophic level of adults is slightly lower than that of children, compared to other species the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of all age groups in humans remain clustered. This indicates there was not a dramatic dietary shift, but rather a small change. Adult diets were still based predominantly on freshwater products, indicated by the similarity of the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values to the otter. It is conceivable that adults were exchanging some fish in their diet for a slightly greater quantity of high trophic level terrestrial products, causing a small drop in $\delta^{15}\text{N}$ during adulthood.

Whatever the proportion of animal food, it is clear that fish were of integral importance in the diet for both children and adults. This lends support to the idea that the faunal remains recovered from the settlement area better represents the diet of these people, as opposed to the faunal remains recovered from the burial site. The burial site contained very few fish or other freshwater animal species- fifteen graves contained waterfowl and six had bones of fish, a limited number compared to the vast number of other terrestrial animals in the graves (Lõugas 2006). The fish remains recovered from the settlement site were for some reason not considered desirable grave goods. The likelihood is they were so ubiquitous that they had little symbolic meaning.

As discussed previously, there is a large degree of variation between adult individuals, as reflected also in the array of infant values from children still breastfeeding. While freshwater resources are dominant factors in the diet for many, some individual's diets point more towards a reliance on terrestrial resources. This variability could be caused by a difference in diet, or because some individuals were not local to the area. There is some evidence showing that these people had contact with the coast, such as the presence of seal remains and the marine isotope values from the dogs (Eriksson 2007, Lõugas 2006), but there is no evidence that the majority of individuals were relying on this contact for their dietary needs (Eriksson 2006). Individual 165 remains the only individual thus far with a clear marine isotopic signature in their childhood, seemingly an anomaly, unless future analysis proves otherwise (Eriksson 2007). While it is not suggested that other members of the population did not travel to the coast, they did not stay long enough for this to be reflected isotopically.

The alternative possibility is that different members of the community may have selected (by choice or otherwise) different diets. The impact of wealth and status, as defined by grave goods, is something which is discussed in detail below. The influence of variation due to sex has not been possible in this study, as the sample was composed of too few females. This is a reflection of the composition of the cemetery, which is biased towards males. In the late Mesolithic, male burial

exceeded those of females by a factor of 1.8, while in the Middle and Late Neolithic, this rose to 2.2. This appears to have been a common feature across Latvia up until the 14th-15th centuries AD (Zarina 2006). This underrepresentation of women could suggest a society in which higher status was more achievable for males, or the difference may reflect different burial practices. Future analysis should attempt to rebalance the number of females sampled.

8.4.1.4 Childhood Diet and Changes through Time

Although the results from Zvejnieki have been discussed collectively, not all individuals are contemporary, allowing us to consider how diet altered by period. In general, there is a lack of change in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ between the Mesolithic and Neolithic, with individuals between the Late Mesolithic and Middle Neolithic clustering together and reflecting similar trends. This points towards a reasonably uniform diet during these periods.

There is however a hint at dietary differences occurring at either end of the spectrum. After 3 years of age the older two samples consistently have some of the highest $\delta^{15}\text{N}$ values, which could indicate a larger portion of aquatic fauna was consumed in the Middle Mesolithic childhood compared to late periods. While the Middle Mesolithic samples do have less elevated $\delta^{15}\text{N}$ after 3 years, they remain some of the higher values throughout the rest of the childhood trajectory. Although this could be explained by the sustained provision of breast milk into childhood, the continued elevation of $\delta^{15}\text{N}$ in the subsequent years makes this scenario less likely. Breast milk as a major dietary component cannot continue indefinitely. For a child to survive, almost the whole diet would have to come from other sources and there is no indication life expectancy was dramatically shorter in the Middle Mesolithic. The consumption of high trophic foods throughout these years is a more plausible explanation, indicating that different weaning and childhood foods might have been consumed in the Middle Mesolithic. Alternatively, these individuals may have suffered more childhood stress, elevating the $\delta^{15}\text{N}$.

At the other end of the spectrum, the youngest burial analysed was individual 137, from the Late Neolithic period. The low $\delta^{15}\text{N}$ during infancy, in comparison with all other individuals, is likely to be a reflection of the mother's low $\delta^{15}\text{N}$. After the infancy and weaning period, this individual has some of the lowest $\delta^{15}\text{N}$ and most elevated $\delta^{13}\text{C}$ out of all the samples. It is commonly thought that domesticated crops and animals began to have a greater impact in the area during this period, although it was not until the Bronze Age that farming had taken over as the main economy (Vasks *et al.* 1999). If this individual (and its mother or carer) are reflections of the population as a whole, it is consistent with the idea that the consumption of freshwater products had declined and there was a greater dependence on crops and terrestrial species during the Late Neolithic.

Before attempting to draw conclusions, it should be noted that there are only a few samples from each designated period, making all current interpretations preliminary pending further sample analysis. However, an apparent shift in diet is reflected in the adult isotope analysis. Eriksson (2006) found there was a statistical difference between the isotopic composition of the Late Mesolithic/Early Neolithic and Late Neolithic/Bronze Age, with the latter selecting terrestrial animals and plants rather than fish. This evidence was used to suggest the shift took place somewhere in the Middle Neolithic. The result from individual 137 supports a change in the Late Neolithic, a period which is archaeologically distinct enough that it has been defined as a 'culture', the Comb Ware Culture. This culture was thought to be created by immigration into the area from South East of the East Baltic (Loze 2006). Individual 137 could have been an immigrant or alternatively a local who had adapted or been influenced by the movement of these people.

Aside from small dietary shifts during childhood, there is no obvious difference in breast milk provision between the Mesolithic and Neolithic. This is consistent with the linear hypoplasia results, which indicate little change in overall health over time (Palubeckaitė and Jankauskas 2006). Should the infant feeding strategy have changed during one or other period, it might be

expected that the frequency would change as children either became more or less biologically stressed. The change in the peak age when hypoplasia occurred did however change. The peak in the Mesolithic occurred at 2 years, while in the Neolithic it occurred at 3 years (Palubeckaitė and Jankauskas 2006). The causes of peaks in hypoplasia have been discussed in Chapter 6 and a discussion on whether hypoplasia peaks are caused by weaning is made therein. If this change in peak incidence in the Zvejnieki population was related to weaning, it should be possible to discern a 1 year difference in weaning initiation between the two periods, something which the data do not support. The cause of the childhood hypoplasia peak remains uncertain.

Many studies deal with the effects of breastfeeding duration and the weaning period, rather than the consequences of changes in children's diets (excluding modern studies of social and health issues such as obesity). Any changes which did occur over the Mesolithic and Neolithic period do not seem to be related to breastfeeding practices. Breastfeeding duration did not suddenly alter, or become minimal at the start of the Neolithic, adding to the pool of evidence suggesting cultural continuity rather than change throughout these periods.

In theory however, the small difference in childhood dietary experiences shown by the Middle Mesolithic and Late Neolithic samples compared to the cluster of other samples, could have contributed to, or been the product of, a small social shift. Assuming that small changes occurred in children's diet at some point between the Mesolithic and Neolithic, what could the effects have been? Childhood diet may have influenced the timing in the onset of puberty, resulting in earlier or later reproduction. The age when puberty occurs is reliant on a number of factors, including nutrition, weight and height (Frisch and Revelle 1970). Malnutrition can delay puberty, but this is unlikely to have been the case at Zvejnieki as the linear hypoplasia did not suddenly increase in the Neolithic. Changes in height, weight and body fat percentage however are more feasible suggestions, which can be related to diet. In general, women who achieve a greater height,

weight and body fat percentage, along with having a good supply of nutrition, hit puberty at a younger age than those without. A review of this is given in Kirkwood *et al.* (1987).

Zarina (2006) found there was a shift in demography in the Neolithic, suggesting women began reproducing at a younger age. This could be a consequence of a change in height, weight, or body fat percentage, as a consequence of diet. Height is known to have changed over the Mesolithic and Neolithic, with a reduction in size occurring at the start of the Neolithic, increasing again in the Late Neolithic (Gerhards 2006). Many factors affect stature, making it impossible to relate change solely to diet, but it is possible that diet could have been a factor in this change, which in turn could have altered reproductive age. Energy expenditure is another likely reason for a change in reproduction, as women with higher outputs generally hit puberty at a later age (Cumming and Rebar 1983).

8.4.2 Status, Identity, Freshwater Products and Pendants

8.4.2.1 The Pendants

The presence of grave goods, specifically pendants, at Zvejnieki allows us to consider the relationship between the inclusion of these artefacts and the diet of those they were buried with. A cautionary note should be made however, which is that an assumption is made about the symbolism of the pendants. The phrase '*The dead don't bury themselves*' has to be brought into consideration (Parker Pearson 1993). This means that the grave goods people are buried with are a reflection of the artefacts living people wished a dead person to be buried with, rather than a choice made by the deceased. Whether they belonged to a person in life or not is often unclear. Wear on some pendants at Zvejnieki suggests some were reused, while others had been newly created, possibility specifically for burial purposes (Larsson 2006).

Even if the pendants did not belong to a person in life, it is arguable that those given pendants in death were either well liked, well connected, powerful, or they identified with a particular social group. The pendants may also have had a religious purpose. Whatever their meaning, the

pendants appear to have had some symbolic significance, being a continual feature of the Mesolithic and Neolithic. The persistence of this tradition and the abundance of these items testify to their social importance. While the continued use of pendants occurred, small changes are notable, such as the way they were drilled and the species of animal from which they were obtained. Pendants were made from a larger number of species in the Late Mesolithic and Early Neolithic compared to the Middle Neolithic (Larsson 2006). Wild boar was the most prevalent species in the Middle Mesolithic, elk, red deer and wild boar in the Late Mesolithic/Early Neolithic and dog in the Middle to Late Neolithic (Lõugas 2006). Despite these changes, the pendants are a key clue to the continuation of a culture or religion which lasted thousands of years.

Using the incremental tooth method made it possible to consider the relationship between the inclusion of pendants in the graves and the childhood diet in the same individuals. If one considers the presence of pendants as evidence of wealth, status or a symbol of identity, then the inclusion of these artefacts in the burials allows us to consider the position the buried person had within society. Status and/or identity is predicted using the grave good inventories published by Zagorskis (2004). Although there are a variety of grave goods, the predominant grave goods were the pendants which were included in both male and female graves. If the pendants are representative of status or wealth ascribed from birth, or the identity a child was given at birth, it is likely a genetic relationship or affiliation with a particular group had something to do with the provision of these grave goods. Alternatively, this perceived status, wealth or identity might have been gained during a person's life and had no bearing on their upbringing. By considering the early life experiences of these people, it is possible to shed light on whether there is a difference between the early life histories of those who were buried with or without pendants.

8.4.2.2 The Relationship between Diet and the Pendants

At Zvejnieki, there is a link between higher $\delta^{15}\text{N}$ and more negative $\delta^{13}\text{C}$ in individuals who were buried without pendants. This evidence can be used to suggest individuals without tooth

pendants were consuming a diet with a greater contribution of freshwater foods during their childhoods than those who were buried with pendants as grave goods. The predominance of freshwater animals in the faunal assemblage indicates these products were easy to catch and were abundant. Because these foods were readily available, freshwater resources might have been lower status foods. This suggests that children were born into a group, perhaps a stratum of society, which dictated what they were given to eat or what foods were available to them. Whatever factor caused this dietary difference stayed with this individual throughout his or her life, influencing the artefacts which they were given as grave goods by those who buried them.

It would also be a reasonable hypothesis that children were fed different diets depending on the role their parents had in the group. For example, children whose parents were skilled fishermen might be more likely to feed their children freshwater fish, while children with hunting parents would be more likely to feed their children larger quantities of meat. Different roles within the community would have affected childhood experiences, even if these were the roles of adults with which they were associated. The lack of relationship between $\delta^{15}\text{N}$, $\delta^{13}\text{C}$ and the presence of pendants seen in adults suggests that if different roles existed, this was not reflected in the adult diet. It is possible that there was a greater degree of food exchange amongst adults, which was not transmitted to their children.

The idea that people had different roles within the population may be represented by the pendants themselves, as hunters not only had more meat but also the animal teeth to represent this. The animal teeth and bone derived pendants may have been symbols of hunting prowess. In this scenario, individuals from hunting families were buried with tooth and bone pendants, while families or individuals whose main skill or role was in fishing were buried without pendants. Freshwater fish have not been recovered often in the cemetery, but have been recovered in vast numbers in the settlement area. The faunal remains recovered from the settlement are thought to represent species consumed, while those from the cemetery had a symbolic meaning (Lövgas

2006). This suggests fish remains were not valued symbolically in the same way as other fauna and perhaps fishermen and women also had a different value within the community. It cannot be argued they had no status, as other grave goods have been found in some of their graves aside from pendants, including flint spearheads, arrowheads, tools, amber, pottery and flakes. There must surely also have been other, now invisible grave goods, which have perished. All graves, regardless of childhood diet, were also decorated with red ochre.

The concept of a familial role which was passed on to the children assumes the children were not influencing their own diet or role. This is not inevitably the case, as children are not always passive members of a group, dependent on their parents for all their dietary requirements. Children in hunter-gatherer groups often collect food, help parents prepare foods, or take a limited part in hunting (Bird and Bliege Bird 2000). Children at Zvejnieki might have been born into a family which taught them the familial hunting and gathering traditions they needed to procure food, which remained throughout their lives. Which hunting and gathering skills were transmitted might have differed between children but is not possible to establish why. It is clear from the burials that children did have status or that they were valued by the people who buried them, suggesting their membership of the group was important. They were buried alongside adults in the cemetery, with their own grave goods. They were given their own outfits and appendages, which were either specifically made for them or they inherited them (Larsson 2006). They were valued members of the group, perhaps economically important, who were mourned by those who buried them.

An assumption is made that these children were all local and that the difference in pendants was not due to some individuals being immigrants, from a different culture, with a different diet. The stable isotopes do not support the notion that two groups are represented in the cemetery and there is no evidence to suggest these people had separate, distinct, childhoods in different locales or that they came from different cultural backgrounds which might have dictated their burial. It

also seems unlikely that those without pendants were immigrants, given that this variation in grave goods continued over thousands of years. Were there two groups using the same burial ground, the immigrants would have amalgamated with the local tradition within a generation. The movement of groups of children between populations also seems unlikely.

How the sex of an individual may have been affected their childhood or adult diet and social position cannot be determined at this stage. If a scenario is proposed in which people had social roles ascribed from birth, or at least related to their chosen activities, rites of passage such as marriage may have provided an individual with a change in circumstances. For example, women may have had more moveable roles in the community when they reached marriageable age. At this point they could potentially cross social strata or social roles. This could mean that children were born into a role or family with a particular diet, their position may have changed at some point in the late teenage years or adulthood, but their childhood background may have been honoured or remembered in death by the presence of particular grave goods.

Whatever the reason for the patterns which have been observed, it is clear this was a population with complex traditions. Differences in the use of pendants and dietary isotopes have made this apparent, but have only given us a small insight into what might lie behind the data. This in itself tells us something. These people who were still hunting, gathering and fishing, living thousands of years ago, were part of an intricate social system.

8.5 Summary

Evidence from 16 Zvejnieki first molars selected for analysis have been used to assess the general patterns of diet in children between the ages of 0-8 years old. As a whole, there is evidence that individuals were breastfed from birth and that the contribution of breast milk declined after the 6-12 month age segment, being completely withdrawn by the age of 3 years. After this period there is little change in diet, as shown by the consistency of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. The large range of

stable isotope values between individuals is probably a reflection of the wide ranging adult diets, as in infancy the mother's baseline value would affect the infants' $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$.

Following infancy, the childhood diet was derived from high trophic level food sources, which had a freshwater and terrestrial meat component. Comparing the results to the adult values obtained by Eriksson (2006), it appears that as adults, these individuals were eating a slightly lower trophic level diet. It is suggested that this might be caused by a slight shift towards consuming larger amounts of terrestrial meat as opposed to freshwater products. Fish were still clearly a major part of the adult diet, as indicated by the position of all humans compared to the local fauna.

There is no dramatic shift in infant feeding patterns throughout the time periods, but there are some hints at possible small changes. The samples from the Middle Mesolithic have some of the highest $\delta^{15}\text{N}$ values during childhood, which could indicate a higher trophic level childhood diet for these children compared to those of the Neolithic. In contrast, the Late Neolithic sample has the lowest $\delta^{15}\text{N}$ and least negative $\delta^{13}\text{C}$, indicating that this could have been a period when adults and children alike were shifting away from freshwater resources, focusing instead on domesticated crops.

Statistical analysis has shown that there is a difference in the childhood diet of those who were buried, as adults, with and without bone and tooth pendants. Those without pendants had higher $\delta^{15}\text{N}$ and more negative $\delta^{13}\text{C}$, which it is suggested is caused by a greater quantity of freshwater fish being consumed by this group of people. Assuming large quantities of grave goods are symbolic of higher status individuals, it is likely that freshwater fish were not considered such high status foods. This lack of status is reflected in the lack of fish bones recovered in the cemetery as opposed to the settlement site. The status of people at Zvejnieki was ascribed from birth and particular roles within society, such as fishing, might have been filled by people born into the trade. Conversely, there is no relationship between the adult diet and the presence of pendants in their graves, suggesting that either foods were shared more equally during adulthood

or that there was some movement between groups or social strata, for example due to marriage.

A person's upbringing was not forgotten in death.

Chapter 9 Conclusion

Two case studies have been explored which represent populations from distinct socio-economic circumstances. The Zvejnieki samples represent hunter-gatherers from a Mesolithic and Neolithic population in Latvia while the St Saviour's samples represent an urban population from post-medieval London. No attempt has been made to directly compare the early life histories of the individuals from these two groups, but there are a number of comparable features, including trends in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, which require discussion. These trends occur during childhood and infancy and are reported across a variety of populations. Aside from the elevation in $\delta^{15}\text{N}$ due to breastfeeding, these patterns are the ^{15}N depletion in childhood shown by the St Saviour's population, detailed in Chapter 5, and the $\delta^{13}\text{C}$ 'trophic level' breastfeeding elevation. Neither the St Saviour's population nor the Zvejnieki population show an elevation in $\delta^{13}\text{C}$ during the breastfeeding period, while the decline in $\delta^{15}\text{N}$ is shown by the St Saviour's population but not the Zvejnieki population. The reasons for this variation between populations are examined. The breastfeeding and weaning patterns of both groups are then discussed in relation to other populations from different socio-economic backgrounds. This aims to consider whether there are stereotypes associated with particular socio-economic groups. Finally, a discussion is made concerning the use of the incremental dentine technique and where the future of the research may lie.

9.1 Why You Are Not What You Eat During Childhood

The children in the St Saviour's population have low $\delta^{15}\text{N}$ during the period after weaning, prior to adolescence. Two possible causes of this have been proposed. It could be a reflection of the diet, but while this is a viable hypothesis the observation of this pattern across different populations makes this less plausible. The favoured interpretation is a physiological causation. It is proposed in Chapter 5 that during distinct periods of development, when the rate of tissue synthesis is high, the body is unable to differentiate between the ^{14}N and ^{15}N isotopes effectively. In such

circumstances, the ^{15}N would be depleted in the body's tissues. This physiological phenomenon could be amplified in individuals with a low protein intake, which would cause the body to use all available nitrogen for protein synthesis. This was first proposed by Schurr (1997).

In the case of St Saviour's Almshouse, fish and meat, which are both good sources of protein, are likely to have contributed to the post-medieval London diet. This is described by historical sources and perhaps also observed in the elevated $\delta^{15}\text{N}$ values of the adults sampled and possibly the $\delta^{13}\text{C}$ decline in infancy, discussed above (see Chapter 5). Despite the potential for some high protein sources to have entered the diet, fish and meat were apparently not consumed in large enough quantities to prevent the depletion of ^{15}N during childhood.

While the intake of fish and meat could be debated in the St Saviour's population, it is difficult to avoid the conclusion that aquatic foods represented an important component of the diet in most individuals at Zvejnieki. The adult $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values cluster most tightly with high trophic level riverine feeders, such as otters, and the presence of fish remains in the settlement area support this interpretation (see Chapter 8). Although elevated $\delta^{15}\text{N}$ could reflect a lack of protein availability and the recycling of body tissues during growth, the zooarchaeological evidence would suggest protein was not limited, although stress cannot be ruled out in some cases. However, the undisputed prominence of fish in the diet makes this an important case study when considering the reasons for the decline in $\delta^{15}\text{N}$ during childhood seen across other populations. If the characteristic ^{15}N depletion in childhood is related to problems in acquiring enough protein, it would be expected that if any population could avoid the $\delta^{15}\text{N}$ 'dip', it would be those from Zvejnieki. This does appear to be the case, at Zvejnieki there were no low $\delta^{15}\text{N}$ values during childhood. It is possible however that the $\delta^{15}\text{N}$ values would be elevated further if it were not for childhood physiology, a question which is currently beyond the scope of this analysis.

Table 25 compares the trends in children's diet across different populations discussed throughout the thesis. It is first notable that many studies have not considered the childhood diet, focusing

solely on the diet during infancy in an attempt to gain information about breastfeeding and weaning. Some of these studies also include adults, but this has left a gap in the intermediate period between these stages of life. The studies which do report childhood diet show a variety of isotopic patterns, some populations with declining $\delta^{15}\text{N}$ values and some without. Looking at the subsistence strategies of these groups, there are two populations which are comparable to Zvejnieki. These are Matjes River Rock Shelter, South Africa and Cis-Baikal, Siberia, both of which were hunting and gathering groups which had subsistence strategies that included the consumption of large amounts of fish. Neither of these groups had declining $\delta^{15}\text{N}$ values during childhood, further supporting the hypothesis that a depletion in ^{15}N occurs in populations which do not have high levels of protein in the diet.

In a similar pattern to St Saviour's, the Spitalfields population and some individuals from the Lukin street population have low $\delta^{15}\text{N}$ in childhood (Nitsch *et al.* 2011, Beaumont *et al.* 2012a, Beaumont *et al.* 2012b). This suggests that the childhood trends in $\delta^{15}\text{N}$ might be similar for industrial post-medieval groups, regardless of class or wealth. Assuming that the middle class Spitalfields individuals were well nourished, the similarity of the trend would imply the decline in childhood $\delta^{15}\text{N}$ at St Saviour's is not caused by extreme protein deficiency. Those at Spitalfields did have meat and fish in their diets, indicating that protein has to be consumed in notably large quantities for dietary tissues to not be depleted in ^{15}N . The amount of protein in the diet required to prevent the ^{15}N depletion is unknown.

Overall, there is some indication that trends in childhood $\delta^{15}\text{N}$ may be predictable by the economy of a group, or more specifically the likelihood that they can obtain sufficient quantities of protein. Variability in the pattern of $\delta^{15}\text{N}$ between populations with different economies is thus to be expected. Comparing the $\delta^{15}\text{N}$ dip between populations with different subsistence strategies has shown that childhood $\delta^{15}\text{N}$ values in some groups will not be representative of the diet. This raises an interpretive problem, particularly when it is not clear how much protein was

available to the group. The problem is exacerbated in studies where some age ranges are unavailable, as there would be no basis for comparing how children's $\delta^{15}\text{N}$ differs from the values of adults. The potential problems with childhood $\delta^{15}\text{N}$ do not seem to be routinely taken into account in dietary stable isotope interpretations. Infants are sometimes excluded from isotope studies to avoid the bias of $\delta^{15}\text{N}$ elevation due to a breastfeeding signal, or included in studies where it is hoped a breastfeeding signal can be identified. In contrast, trends in $\delta^{15}\text{N}$ associated with children after the infancy period are not being considered in the selection or interpretation of samples. Children's $\delta^{15}\text{N}$ values should be compared to those of adults to establish if the $\delta^{15}\text{N}$ is reflecting the diet or not, while the subsistence strategy of the group should also be taken into account. Until more research reveals why this ^{15}N depletion occurs, $\delta^{15}\text{N}$ values from children must be treated cautiously.

The uncertainty in the interpretation of childhood $\delta^{15}\text{N}$ may represent a problem in early life history studies, but there is the possibility the observations can be used beneficially. If the protein requirement/growth hypothesis is correct, the identification of populations without declining $\delta^{15}\text{N}$ values during childhood may be used to identify populations with abundant high protein resources, such as fish. This would particularly be applicable to hunter-gatherer populations, in situations where a reliance on marine and freshwater products is questioned or where debate exists concerning dietary transitions, such as fishing and hunting to farming.

9.2 The Effect of Breastfeeding on $\delta^{13}\text{C}$

Neither the St Saviour's nor the Zvejnieki populations show an elevation in $\delta^{13}\text{C}$ during infancy. This could be because there are two isotope effects that influence the $\delta^{13}\text{C}$ during breastfeeding. One is the 'trophic level effect', which predicts ^{13}C enrichment during breastfeeding, in concert with ^{15}N enrichment. This is reviewed in greater detail below. The other effect is caused by the high concentration of lipids in milk, which is depleted in ^{13}C (Wright and Schwarcz 1998). The net

effect on humans, who produce milk that is not as rich in lipids as some other animals, could be that there is no change in isotopic composition. The two effects could cancel each other out.

This pattern is not seen in all populations, as elsewhere the trophic level effect on $\delta^{13}\text{C}$ has been well documented, although it is both variable and small (around 1‰). This trophic level or 'carnivore' effect is documented in connection to breastfeeding in a large number of studies (Richards *et al.* 2002, Fuller *et al.* 2006a). A more limited number of studies have shown no significant elevation in $\delta^{13}\text{C}$ (Fogel *et al.* 1989, Waters-Rist *et al.* 2011). In the first modern isotopic study of the nails of mothers and infants, Fogel *et al.* (1989) found that $\delta^{13}\text{C}$ did not reflect a breastfeeding signal, thus the conclusion was initially drawn that $\delta^{13}\text{C}$ could not be used to track infant feeding patterns. In an archaeological context, Waters-Rist *et al.* (2011) also did not observe an elevation in $\delta^{13}\text{C}$ relating to breastfeeding in a Neolithic population from Lake Baikal, Siberia. A summary of studies which either do or do not exhibit $\delta^{13}\text{C}$ elevation during infancy is given in Table 25, indicating that the 'carnivore' effect in $\delta^{13}\text{C}$ is variable across populations.

Waters-Rist *et al.* (2011) made the suggestion that the lack of trophic level effect shown in $\delta^{13}\text{C}$ during infancy at Lake Baikal could be due to the early introduction of weaning foods, before breast milk was withdrawn. They suggest that these foods would have had a high fat content, resulting in depleted ^{13}C . This could negate the $\delta^{13}\text{C}$ elevation caused by breastfeeding. It is suggested that at Lake Baikal these fatty foods could have been salmonids and graylings. Fogel *et al.* (1989) made no comment on the lack of $\delta^{13}\text{C}$ elevation in the modern population, as their study was the first of its kind to attempt a breastfeeding isotopic study. Unlike the results from Fogel *et al.* (1989), another study on modern infants and mothers by Fuller *et al.* (2006a), found that $\delta^{13}\text{C}$ was elevated in this group during infancy. Fuller *et al.* (2006a) suggest that a lack of $\delta^{13}\text{C}$ elevation during infancy in some archaeological populations was due to the analysis of the bones of infants who did not survive to adulthood. These individuals may have been given non-breast milk foods early in life, which would have contributed to their early deaths.

The incremental dentine technique shows that those studied from the St Saviour's and Zvejnieki population exhibited no $\delta^{13}\text{C}$ elevation but did survive until adulthood or late adolescence. A lack of $\delta^{13}\text{C}$ elevation is therefore not a predictor of early death, despite the fact it might indicate the early introduction of solid foods. Based on the $\delta^{15}\text{N}$ elevation, breast milk was still being provided to most individuals during this period, which suggests that as long as breast milk was consumed, the introduction of other foods before weaning occurred was not affecting the survival of children at Zvejnieki or St Saviour's. This is not an expected conclusion, given that solid foods were often contaminated, particularly in the post-medieval era. It is assumed therefore that the immunological effects of breast milk provided effective buffering against pathogens found in these early foods.

Looking at sites which are comparable, infant $\delta^{13}\text{C}$ results from Zvejnieki can be likened to the Lake Baikal and Marsh Creek Native American populations. Neither the Zvejnieki nor Lake Baikal data show an elevation in $\delta^{13}\text{C}$ during infancy, which could be due to similar practices. In their early life history projections, Eerkens *et al.* (2011) conclude that $\delta^{13}\text{C}$ does not show a strong weaning pattern in the 6 individuals selected from the Marsh Creek site, but 4 of them have a small drop in $\delta^{13}\text{C}$ as breast milk decreases. The change in $\delta^{13}\text{C}$ averages 0.7‰ in these individuals. Waters-Rist *et al.* (2011) discuss the behaviour of ethnographic hunter-gatherer groups, stating that while hunters-gatherers are stereotypically associated with elongated breastfeeding, this does not take account of the early introduction of other foods which often occurs. This is also suggested by the findings of Sellen and Smay (2001), who compared infant feeding strategies between pre-industrial societies. While breastfeeding certainly took place amongst the Zvejnieki population, other foods may have been introduced to infants from a young age. This is also a reasonable explanation for variability in $\delta^{13}\text{C}$ at Marsh Creek.

The lack of $\delta^{13}\text{C}$ elevation at St Saviour's can be compared to the working class Lukin Street cemetery, which has a mixture of individuals with and without an elevation in $\delta^{13}\text{C}$. In contrast,

the Spitalfields population shows a clear elevation in $\delta^{13}\text{C}$ of 1-2‰ during infancy, which they attribute to breastfeeding (Nitsch *et al.* 2011). At St Saviour's it is also possible that non-breast milk foods were being consumed alongside breast milk from an early age, although it is unlikely that children were suckling on fish, as was suggested for those in the Lake Baikal population (Waters-Rist *et al.* 2011). Fish would have been harder to access in comparison to populations such as Zvejnieki, and an argument has been made that the childhood $\delta^{15}\text{N}$ dip is caused by protein deficiency. It is however possible that some fish and animal fats could have contributed to the pre-weaning and weaning diet, which were not provided in such great quantities during childhood.

A further possibility is proposed in Chapter 5 that breastfeeding practices, including the frequency and duration of suckling episodes could influence the elevation of $\delta^{13}\text{C}$ in the earliest stages of life. The composition of breast milk changes according to the needs of the infant and the breastfeeding practices of the mother or carer. It has been shown the proportion of fatty acids in the milk changes according to the frequency, duration and intensity of suckling (Quandt 1995). This could have an isotopic effect, as infants consuming milk with a higher lipid content would have more depleted ^{13}C . Given the large number of factors which could influence infant feeding regimes, it is unsurprising there is variation across populations. The combined influence of these variables makes $\delta^{13}\text{C}$ an unreliable indicator of infant feeding patterns.

9.3 Using Economy to Predict Childhood Experiences

We have many preconceived ideas about the circumstances in which children flourish and how groups from different socio-economic backgrounds might raise their children. On the one hand, infants and children have specific nutritional requirements at different stages in their lives. For a child to survive, these developmental markers have to be observed. On the other hand, children can survive in many highly variable circumstances, created by all manner of social and biological factors.

9.3.1 Stress and Economy

The children at St Saviour's were suffering major deprivation, as shown by the high incidence and width of enamel hypoplasia. In addition, the $\delta^{15}\text{N}$ patterns for some individuals suggest they were not breastfed at all, which for the reasons given in Chapter 1, is likely to have affected their health. The frequency of enamel hypoplasia would suggest that commonly held views about the negative impact of industrialisation on children do have foundations. Although enamel hypoplasia frequency is subject to interpretation problems, evidence from other sources favours the hardship hypothesis (Lewis 2002b).

A full study of enamel hypoplasia was not attempted with the Zvejnieki samples, as the sample size was small, but the enamel hypoplasia was less frequent and as a general observation, the periods of illness were less intense than those observed on the St Saviour's individuals. Slightly longer breastfeeding in the Zvejnieki population may have helped to buffer children for longer, while their environmental conditions were also likely more favourable for their health. These observations fit with the common concepts associated with economy and health. This suggests major health problems arose due to increased settlement and reliance on agriculture (Armelagos *et al.* 1991). The health of hunter-gatherers in general is hard to judge because of the few skeletal remains available for osteological analysis and the difficulties in comparing ethnographic groups to archaeological populations. Modern hunters and gatherers are often not fully dependent on hunting and gathering, and are in almost all cases marginalized in some way or experiencing modern health problems, such as those caused by the effects of smoking (Cohen 1989). While it is not suggested that all archaeological hunter-gatherer groups are like Zvejnieki, childhood health at Zvejnieki is probably a better reflection of health in many past foraging groups. Other archaeological hunter-gatherer populations, such as the Late Stone Age foragers of South Africa also show good health (Pfeiffer 2007).

Numerous factors determine the frequency and intensity of hypoplasia which a population experiences and childhood mortality plays a prominent role in whether hypoplasia is seen in the

adult population. Despite this difficulty, looking at the variability in hypoplasia between these two examples, industrialization was a more difficult period for children at St Saviour's than it was for the hunter-gatherer children at Zvejnieki. This difference is likely to be linked to dirty conditions, pollution, cramped living conditions and the prevalence of infectious diseases in post-medieval London. Children at Zvejnieki in contrast were probably better equipped nutritionally, had access to clean water and lived in a less densely populated settlement, with a lower incidence of disease.

9.3.2 Infant Feeding and Economy

There is a concept that infant feeding patterns can be predicted based on the economy of the population, particularly between populations with agricultural or hunter-gatherer economies. The timing of dietary change and the introduction of foods are factors which could potentially be used to differentiate populations with different economies. The longevity of breastfeeding is particularly associated with economic stereotypes. Traditionally, it has been viewed as more likely that hunter-gatherers elongate breastfeeding, while agriculturalists wean earlier. The later weaning age amongst hunters and gatherers is often attributed to factors such as the availability of weaning foods and preparation equipment (Buikstra *et al.* 1986, Molleson 1995). While the relationship between elongated breastfeeding and hunting and gathering communities is frequently stated, hard evidence is rarely provided to support this view.

One major study often quoted in favour of the economy-weaning relationship is the case of the Bofi foragers and farmers who have different infant feeding patterns from each other (Fouts 2004), but the reason this example is frequently quoted is because other examples are difficult to find in the literature. This could be partly a consequence of there being few hunting and gathering groups left to study in the world. In the ethnographic literature there are examples of some hunting and gathering groups continuing to practice extended breastfeeding, but comparisons between the same people occupying different niches is rare. Aboriginal Australians traditionally breastfed their children exclusively for 6 months, but continued to breastfeed during the weaning process for up to 4 years. This breastfeeding period dropped dramatically as Aboriginal mothers

became urbanised (Gracey 2000, Holmes *et al.* 1997). The effects of other factors are important in an example such as this, where the influence of colonialism, disease and marginalization are likely to be greater than merely the urban and or rural setting in which they raised their children.

Another ethnographic group which is frequently quoted as an example of hunting and gathering communities practicing extended breastfeeding are the !Kung, whose infants are reportedly breastfed until their 4th year of life, although other foods are introduced at around 6 months old (Konner 1976). Aka children in the Congo are typically weaned at 3-4 years, but prior to this they also consumed a broad ranging adult diet from their 2nd year (Fouts and Brookshire 2009). This raises an important point, just because breastfeeding is extended in these groups, does not mean the contribution of breast milk is large.

In a study comparing patterns of weaning strategies in relation to subsistence, Sellen and Smay (2001), in contrast to the perceived stereotypes, found there was little variation in feeding patterns in relation to subsistence. The provision of weaning foods was actually delayed in agricultural populations compared to less agricultural ones, although hunting and gathering populations did breastfeed slightly longer. This was not attributed to a lack of weaning foods. There is therefore some doubt over the predictability of infant feeding practices in relation to their economy. To some degree this is because all humans will adapt to their conditions, which are variable even in a group with a unified economy. Within a hunting and gathering economy, the foods which are consumed differ and the strategies used to procure them will vary, as will the culture.

Analysis of the Zvejnieki hunting, gathering and fishing group has shown this population breastfed their children until about 12 months old, although other foods were being introduced from an earlier age and breastfeeding did not suddenly stop after 1 year (Chapter 8). In the UK today, it is suggested weaning should occur at 6 months, when other nutrients are required by the growing infant (WHO and UNICEF 2003). The continued breastfeeding of infants by mothers or carers at

Zvejnieki until 6-12 months suggests more extended breastfeeding was occurring than might be expected amongst modern western societies. It could be argued the hunter-gatherer stereotype, which predicts these people are likely to continue to breastfeed after the 6 month period, is true at Zvejnieki. However, the small decline after the 0-6 month age bracket shows some individuals were clearly being provided with other foods at a similar time to modern UK populations.

Whether breastfeeding up to 1 year of age can truly be considered to reflect extended breastfeeding is a matter of debate. When considered alongside the practices of some ethnographic groups, 12 months is not an extended period of time. The examples reported above suggest some hunting and gathering groups were breastfeeding into the 3rd and 4th year of a child's life (Fouts and Brookshire 2009, Gracey 2000, Holmes *et al.* 1997, Konner 1976). This could have occurred at Zvejnieki, but if breast milk was consumed in minimal quantities compared to other foods, it may not be recognised isotopically. In cases where extended breastfeeding occurs in hunting and gathering groups, breast milk must be minimal after the age of 1 year, if not before, for a child to thrive. The contribution of milk in the diet beyond this age is therefore overestimated in societies which practice extended breastfeeding.

At St Saviour's the breastfeeding patterns are similar to modern UK patterns, with breast milk declining after the age of 6 months in those individuals who were breastfed (Chapter 5). Breastfeeding was not prolonged to buffer children from their harsh environmental conditions. The fact this industrial population was breastfeeding at all given their circumstances is interesting, as it might be expected that mothers would not be on hand to breastfeed their infants. Whether the patterns are surprising or not, this group conforms to the industrial stereotype, where children are weaned before their first year.

9.3.3 Economy and Intra-Population Variation in Infant Feeding

In theory, intra-population variability in infant feeding practices could reveal information about the cohesion of a group, including variations in religious practices and beliefs, immigration, ethnic

identity and class. For example, Kaupová *et al.* (2014) found that Medieval infant feeding practices differed between rural and urban environments, with urban infant feeding patterns showing greater variability. It was concluded that this could have been caused by the greater influence of Christian beliefs in the urban population, immigration or the influence of wealth and status in the urban environment. Similarly, Pearson *et al.* (2010) found there were variable breastfeeding patterns between two contemporary populations which occupied slightly different environments and consumed different diets in Early Neolithic Turkey. At Aşıklı Höyük, where there was a less diverse range of cereals to consume alongside bovids, weaning occurred substantially earlier than the site of Çayönü Tepesi. This suggests the economy of the population, or more specifically the foods which they were able to grow, was affecting early life histories.

These examples show variation can be expected between groups, but they also suggest that variation within a group is to be expected if those within the community are from different backgrounds. Many groups are made up of individuals with different religious beliefs, people who are local and non-local and those with different access to certain types of food, which could be caused by factors such as wealth (see Chapter 1). A large degree of variation in the timing of breastfeeding, weaning and the composition of the adult diet within the St Saviour's population is not unexpected given these factors. A high rate of immigration, variability in work practices and variation in social factors such as religion would all have contributed to differences in infant feeding practices. A similar amount of variability also occurs in the Spitalfields and Lukin Street populations (Beaumont *et al.* 2012a, Nitsch *et al.* 2011), suggesting this may be a feature of post-medieval London populations. Variation at St Saviour's therefore conforms to the expected trends in an urban industrial setting.

Urban groups with large populations are likely to have sub-cultures, and therefore a high degree of variability in their diets. Conversely, it could be argued that rural populations, including hunting and gathering groups, with more limited population numbers might be more cohesive and unified

in their diets and early life histories. They are however, opportunistic in their feeding practices and influenced more heavily by seasonality, which could easily cause them to adapt their child rearing strategies when needed. The data from Zvejnieki show there is evidence for variability in infant feeding practices, illustrating the latter hypothesis is more likely to be correct. The $\delta^{15}\text{N}$ in the 0-6 month age band in individuals 124, 207 and 179 is not as elevated as may be expected, given that the $\delta^{15}\text{N}$ is more greatly elevated in a proceeding age category. This might indicate larger amounts of other non-breast milk foods were provided from birth to these children compared to other individuals at Zvejnieki. Similarly the $\delta^{15}\text{N}$ lowers earlier in some individuals than others during the weaning period, suggesting that breast milk was withdrawn faster. These points indicate that childhood experiences were not uniform at Zvejnieki.

Variable feeding practices are a feature of many societies, including rural and hunting and gathering groups. Eerkens *et al.* (2011) noted that feeding practices were highly variable amongst a Native American hunting and gathering group from California. From the six individuals analysed in their study, some were weaned abruptly at around 1 year, while others were weaned around 3 years. At the Matjes River Rock Shelter, there is also some variability in infant feeding practices, with wide ranging $\delta^{15}\text{N}$ values. Some non-surviving infants may have died before breast milk could be reflected in the isotopic signature, but after this period there is still variability (Clayton *et al.* 2006). Some amount of personal choice may be partly responsible for this variability. For example, amongst the Bekaa Bedouin in Lebanon, older mothers are more likely to breastfeed for longer, as they believe this benefits their health (Joseph 2004). In a different context, Hawkes *et al.* (1997) discussed the use of grandmothers amongst the Hadza women, suggesting that women with help were more likely to wean their children earlier.

Without greater knowledge of the background of the population at Zvejnieki, it is not possible to predict the factors which could have caused variable infant feeding patterns, but it is clear there are many possible reasons for a lack of homogeneity. There is no reason why immigration would

not occur between hunting and gathering groups, facilitated by trade and social exchange, including marriage. At Zvejnieki, individual 165 is known not to be from the local area, but his burial in the cemetery at Zvejnieki suggests he was incorporated into the group (Eriksson 2007). It has also been shown that there were differences in the childhood diet between those buried with and without pendants. It is not clear why this is, but it has been suggested a social system existed, where people were born into different roles within the community. They are therefore not simply a cohesive group, but a complex group with at least a two-tiered social system operating within it. There is every reason to expect a variety of infant feeding practices within groups such as these.

There are also some variables which are likely to affect hunters and gatherers more than modern industrial populations. Without permanent houses, heating systems and the mass transportation of food, seasonality may have a greater effect on hunting and gathering groups. This would have affected when they weaned their children. Referring back to the example of the Gogo people, Tanzania, children were weaned when particular foods were available to them in March and April (Mabilia 2005). Assuming children are born at different times of the year, this means they would also be weaned at different ages within the same cultural group.

The main exception to the idea of variable infant feeding practices in hunting and gathering groups is a Middle Neolithic group from Ajvide, Gotland, where there were small differences in the timing of supplementation, but the longevity of breastfeeding remained very similar over time (Howcroft *et al.* 2014). It is suggested there was a strongly-held belief about breastfeeding duration, which was passed down the generations. Leaving aside the small number of examples which show a uniform infant feeding practice, Table 25 indicates that a greater number have highly variable infant feeding strategies. These represent those from hunting and gathering backgrounds, to settled rural people, to those living in urban industrial conditions. They also represent people from different parts of the world.

Table 25. A list of some of the major infant and child dietary case studies discussed in this thesis, summarizing the patterns in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for different populations.

Author	Population	Date	Is there evidence for a $\delta^{13}\text{C}$ elevation during the breastfeeding period?	Does the $\delta^{15}\text{N}$ decline during childhood?	Additional details
Fogel <i>et al.</i> (1989)	Modern		No	Unknown, study goes up to 14 months old.	
	Tennessee Valley, Benton County, USA	Middle and Late Archaic Period (5500-2000 BC)	Not considered, as the modern test study showed no $\delta^{13}\text{C}$ pattern.	No individuals over 5 included, aside from adults, but there is some evidence.	Hunting and gathering subsistence with no maize. $\delta^{15}\text{N}$ declines around 18-20 months in children.
	Scully site, South Dakota, USA	1650-1700 AD	Not considered, as the modern test study showed no $\delta^{13}\text{C}$ pattern.	Yes	Horticultural subsistence with maize, squash, beans and sunflowers. Decline in $\delta^{15}\text{N}$ at 18-20 months.
Schurr (1997)	Angel Site, Indiana, USA	1300-1450 AD	Not reported.	Yes, $\delta^{15}\text{N}$ rises after late adolescence.	Subsistence of maize, but no domesticated livestock. Breastfed until 2 years.
Katzenberg <i>et al.</i> (1993)	MacPherson, Ontario, Canada	1530-1580 AD	Yes. Thought to be related to the introduction of maize in the weaning diet.	Too few children beyond the infancy period.	Maize subsistence strategy.
Prowse <i>et al.</i> (2008)	Isola Sacra, Italy	1 st -3 rd century AD (Roman)	Yes	Possibly elevates slightly from 10 to 12 years, but the projection is not continued.	Began weaning around 1 year, completed weaning around 2-2.5 years.
Nitsch <i>et al.</i> (2011)	Spitalfields, London, UK	18 th and 19 th century	Yes	Yes. Declines during the age bracket of 4-16 years compared to adulthood.	A middle class population. Highly variable infant feeding strategies.
Fuller <i>et al.</i> (2006b)	Modern		Yes	Only considered infants and mothers.	
Dupras and Tocheri (2007)	Kellis, Egypt	100-450 AD (Roman)	Yes. Authors suggest this could be a trophic level effect or indicative of C4	Not obvious.	Completed weaning at 3 years.

			weaning foods being consumed.		
Clayton <i>et al.</i> (2006)	Matjes River Rock Shelter, South Africa	Mid-Holocene	Yes	No	A hunter-gatherer group who regularly consumed marine foods. Breastfed to 1.5 years.
Fuller <i>et al.</i> (2003) and Richards <i>et al.</i> (2002)	Wharram Percy, Yorkshire, UK	Medieval 10 th -16 th century	Yes	Possible indication there is a dip until 8 years old, after which the $\delta^{13}\text{C}$ remains relatively stable.	Breastfeeding finished after 18 months. Large variation within the population.
Eerkens <i>et al.</i> (2011) and Eerkens and Bartelink (2013)	Marsh Creek, Central California	Middle to Late Holocene (4300-3100 BP)	4 out of 6 individual life histories show a tiny elevation, averaging 0.7‰. The others do not.	Individual life histories show 4 out of 6 projections have depleted ^{15}N .	Weaning finished by the end of the 4 th year of life. Large amount of variation in feeding practices.
Beaumont <i>et al.</i> (2012a) and Beaumont <i>et al.</i> (2012b)	Lukin Street, London	Post-Medieval (1843-1854).	No	Some individuals do, others do not.	Breastfeeding terminated around 2 years. Variable breastfeeding strategies, some prolonged.
Pearson <i>et al.</i> (2010)	Aşikli Höyük (AH) and Çayönü Tepesi (CT), Turkey	Early Neolithic (9 th -8 th millennium cal BC)	Not reported	Children over 5 years not included.	At AH the diet was cereals and bovinds. Weaning occurred at 1 year. At CT wild pulses and domesticated pigs were consumed. Weaning occurred around 2 years.
Waters-Rist <i>et al.</i> (2011)	Cis-Baikal, Siberia	Neolithic (8800-5200 cal BP)	No	No	A hunter-gatherer group which consumed freshwater products. Breastfed until 2-3 years, with a difference in infant feeding between the Early and Late Neolithic.
Sandberg <i>et al.</i> (2014)	Kulubnarti, Nubia	Medieval	Yes	Yes	Extended breastfeeding was linked to increased mortality. Variable weaning age, between 2-

					5 years. Animal milk used to supplement diet. C4 and C3 plants both available.
Howcroft <i>et al.</i> (2012)	Bjärby and Trib erga Öland, Sweden	6 th -11 th centuries	No (Bjarby) Yes (Trib erga)	Few older children in study	Terrestrial/freshwater resources available
Howcroft <i>et al.</i> (2014)	Ajvide, Gotland	Middle Neolithic, Pitted Ware Culture	No	Yes, but only slightly	Breastfed until 3 rd /4 th year of life. Longevity of breastfeeding homogenous. Variation in the timing of weaning possibly caused by seasonality.
Kaupová <i>et al.</i> (2014)	Central Europe	Early Medieval, Great Moravian (9 th -10 th century AD)	No	No, but only individuals less than 6 years included	Highly variable infant feeding patterns. Stress not associated with the feeding pattern.
Haydock <i>et al.</i> (2013)	Northampton, UK	Anglo-Saxon	Yes	No	Weaned at 1.75 years, ceased breastfeeding by 3 years.

9.4 Developing the Method and Future Research

The most prominent reservation in the use of the incremental dentine technique is the temporal resolution (see Chapter 3). This problem is not easily rectifiable, but there are several features which show the technique provides information that cannot be gained by other means (such as analyses of a sequence of individuals with varying age-at-death).

The feeding patterns at Zvejnieki and St Saviour's show variability between these two economically different populations. Differences have also been picked up between individuals, which is clear from the large variability in infant feeding practices at St Saviour's and Zvejnieki, including some individuals who were not breastfed at all. Broader differences within the population were also observed, including an isotopic difference between males and females in the St Saviour's population and a difference in childhood diet between those buried with and without pendants at Zvejnieki. The implications of all these trends have been discussed, illustrating the wide ranging questions which the technique has been able to address. This illustrates the ability of the technique to identify patterns in diet and trends in populations.

The results obtained by tracking diet across M1s and M2s in the St Saviour's case study provides further indication that the technique is accurate (Chapter 5). In the crown of any tooth the resolution of the incremental samples is greater than samples taken from the rest of the tooth. This is because the incremental lines are followed more closely in this region (Dean 1985). In the roots the method cuts across the formation lines to a greater degree, decreasing the resolution in this part of the tooth, meaning the samples from the root are more time-averaged than the crown (Eerkens *et al.* 2011). The formation period for the M1 and M2 teeth overlap, which provides a means to compare crown and root samples, thereby testing the accuracy of samples taken from the roots. In theory these overlapping time slices should have similar values and show similar patterns. Between the St Saviour's tooth pairs, there is a small amount of deviation between the overlapping M1 and M2. After taking into account the variability in the formation

time of these teeth and the analytical error, it can be concluded that the same trends are shown by both teeth regardless of which part of the tooth the sample is taken from. This suggests that although the results from the roots are more averaged, they are still reflecting the dietary pattern.

The drawback of the technique is its inability to identify very abrupt changes in an individual's life history, although the fact that some individuals show more gradual dietary transitions than others illustrates this is not completely obscured. Further refinement of the method will increase the resolution. While it is not yet possible to analyse tiny samples of collagen using a mass spectrometer, we can make modifications to the methodology. The next stage in the evolution of the technique will decrease the averaging effect and make the aging of the time slices more accurate. This will involve tracing the lines of growth down the tooth. As these lines are hard to identify by visual inspection, and are impossible to cut around accurately without the tooth being demineralized, the methodology will have to be adapted in other ways. One option is that after a tooth is halved, one half could be stained with a dye to show up the incremental features, while the other half is demineralized. The dyed tooth could be used as a 'map', allowing the features to be followed when cutting around the other half of the tooth. Radiographic and histological techniques would also enhance the aging of the tooth segments (Dean *et al.* 2014).

After some of the time averaging effects are negated, the next phase would be to increase the accuracy with which we can relate the timing of stress to the timing of dietary change. In theory, the best way would be to bypass using the enamel completely and focus solely on the dentine. This would mean the timing of stress events and dietary transitions would be judged using the same tissue. The dentine development, like the enamel, is interrupted during periods of stress. In dentine this occurs when the matrix is poorly mineralized and the resultant structure is referred to as 'interglobular spaces' (Mellanby 1927). These are hard to see compared to enamel hypoplasia and can be patchy (Hillson 1996), but if they could be identified under a microscope

this would allow a better study of infant feeding in relation to stress to be conducted. This would avoid the problem caused by the delay in enamel development compared to the dentine.

Several other lines of research could be pursued, including considering more fully the effects of secondary and tertiary dentine deposits. At St Saviour's, a large number of samples which could have theoretically been used were dismissed on the grounds that they had caries. This is a common problem in any industrial or high-sugar consuming population and has the potential to limit the use of the technique on many populations. Teeth with caries were removed from the sample as a precautionary measure in this study, but an isotopic study on the effects of tertiary dentine deposits would be a useful contribution to the field. This could be done by halving a tooth with a cavity on one side and analysing both halves of the tooth. Secondary dentine could be examined in a similar way.

9.5 Summary

The incremental dentine technique has thrown light on the trends in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ associated with infancy and childhood while the populations selected have added to the pool of groups analysed. Comparing the $\delta^{15}\text{N}$ trends across populations in childhood has shown that declining $\delta^{15}\text{N}$ is a feature of a number of populations, including the St Saviour's almshouse burial ground group and its closest comparison, the Spitalfields population. It was suggested in Chapter 5 that this was related to protein deficiency during a time of growth. This pattern was not observed in the Zvejnieki population, which it is postulated is because of the high levels of protein in the diet from fish. The closest comparable population in the literature is the Lake Baikal hunter-gatherer group, which also do not have declining $\delta^{15}\text{N}$ during childhood. While there are few childhood $\delta^{15}\text{N}$ studies on hunter-gatherer-fisher populations, both Zvejnieki and Lake Baikal support the hypothesis that this decline does not occur in children with a large quantity of protein in their diets. Differences in $\delta^{15}\text{N}$ between children and adults are therefore more likely to be related to physiological changes during childhood, rather than indicative of the trophic level of a child's diet.

The $\delta^{13}\text{C}$ carnivore effect is variable across populations, with both St Saviour's and Zvejnieki not showing this elevation during infancy. The most obvious cause for this pattern is the early introduction of foods prior to weaning or differences in breastfeeding patterns. It is notable that another post-medieval London group, Spitalfields, does have elevated $\delta^{13}\text{C}$. Although breastfeeding patterns were similar, it may indicate a small difference in infant feeding practices. In general, using $\delta^{13}\text{C}$ to track breastfeeding practices must be treated with caution, as the small shift of 1‰ can easily be negated by the introduction of other foods.

Predicting infant feeding patterns based on economy is difficult as there are many factors which affect infant feeding patterns. The two case studies here in some ways conform to the social stereotypes, as the Zvejnieki hunter-gatherer group breastfed slightly longer than the industrial group. The Zvejnieki population is not however typical of hunter-gatherer stereotypes, where breastfeeding is reported for up to 5 years. Relating patterns of infant feeding to the economy of a population is problematic, but it is clear that stereotypes relating hunters and gatherers with extended breastfeeding may not be a true reflection of these people. Variability in infant feeding practices is a feature of all socio-economic groups, suggesting that it is not a valuable way to identify social cohesion. The high frequency of enamel hypoplasia at St Saviour's and the relatively low frequency at Zvejnieki supports the idea that health during industrialized periods was more compromised than that of hunting and gathering groups.

The incremental dentine technique has identified a number of patterns and provided a thorough trophic analysis of infancy and childhood in two populations, further demonstrating the value of a method which is not yet widely used. Future work will help to improve the technique, specifically the resolution.

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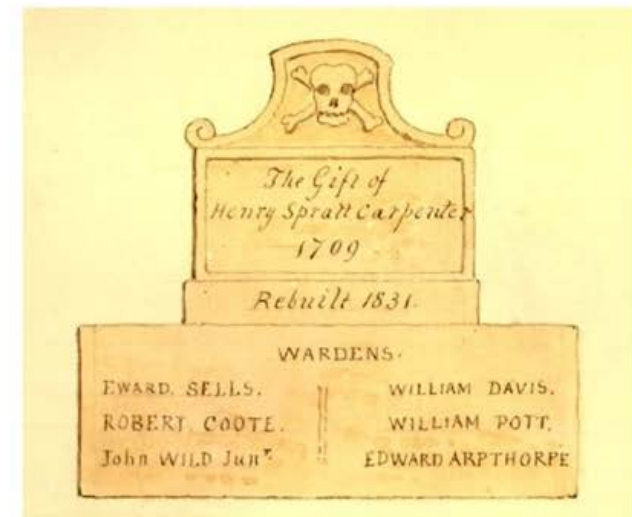
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Appendix A. Pictorial Evidence Providing Information about St Saviour's Almshouse



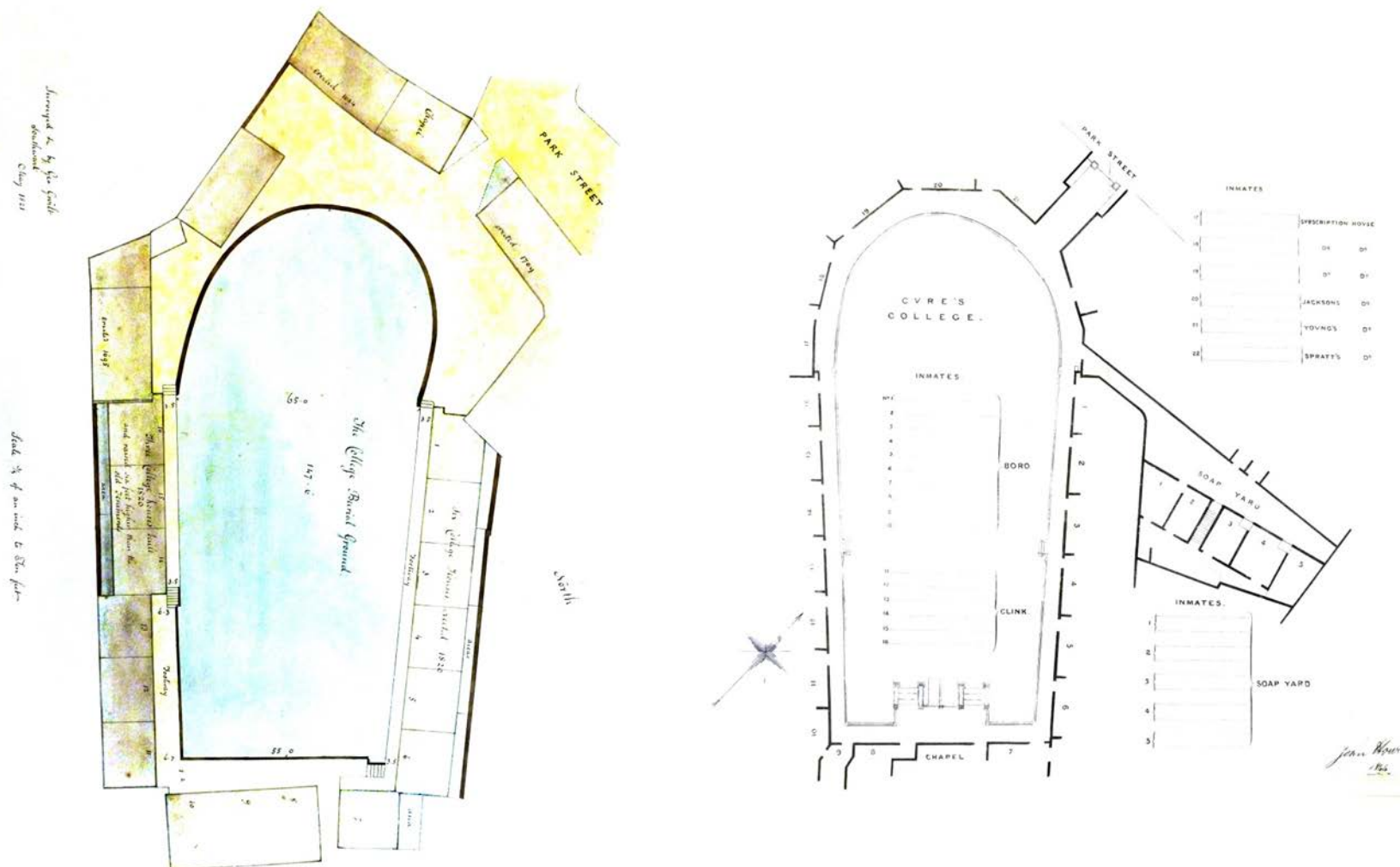
Images of St Saviour's Almshouse and Burial Ground. 1) Chapel and almshouse 1852 by Thomas Hosmer Shephard 2) North side of the almshouses 3) College yard 1851 by Thomas Hosmer Shephard 4) College yard 1851 by Thomas Hosmer Shephard 5) Section of almshouses 1825 by G. Yates 6) Almshouses 1808 by George Smith 7) Section of almshouses 1825 by G. Yates 8) almshouse and burial ground by G. Yates 1825. 9) Interior view of the chapel at the almshouse 1825 by G. Yates. Images 1, 3 and 4 are curated by the British Museum, all others by the London Metropolitan Archives.



Illustrations of three plaques originally adorning the St Saviour's almshouses. The inscriptions cite the benefactors, Henry Jackson, Henry Young and Henry Spratt. Images from the London Metropolitan Archive.



Effigy of Thomas Cure, benefactor of St Saviour's almshouses. Situated in Southwark cathedral. Author's own image 2013.



Two plans of the St Saviour's Almshouses. (Left) Survey by Gwilt 1821. (Right) survey by Howe (1844). Note the extension called 'Soap Yard' in the later plan. Held by the London Metropolitan Archives.

Appendix B. St Saviour's Almshouse Incremental Dentine Results

Sample	Age (years)	Sex	$\delta^{15}\text{N}$ AIR	$\delta^{13}\text{C}$ VPDB (cal)	C:N ratio	% collagen
921	>18	Female				
First Molar (M1)						10.3
0-6 months			13.9	-19.5	3.3	
6-12 months			14.4	-18.9	3.3	
1 year-20 months			13.4	-19.0	3.3	
20 months-28 months			13.2	-18.9	3.3	
28 months-3 years			12.4	-19.2	3.2	
3-4 years			11.9	-19.2	3.3	
4-5 years			11.6	-19.5	3.3	
5-6 years			12.1	-19.2	3.2	
6-7 years			11.8	-19.2	3.3	
7-8 years			11.6	-19.4	3.3	
3rd molar (M3)			13.2	-18.8	3.2	11.9
949	6-12	Unknown				
First Molar (M1)						9.6
0-6 months			13.5	-19.1	3.3	
6-12 months			13.8	-18.9	3.3	
1 year-20 months			10.9	-19.8	3.2	
20 months-28 months			12.0	-18.5	3.2	
28 months-3 years			12.0	-18.3	3.2	
3-4 years			11.3	-18.7	3.2	
4-5 years			11.4	-18.8	3.2	
5-6 years			11.2	-18.8	3.2	
6-7 years			11.0	-19.4	3.3	
7-8 years			11.5	-19.2	3.3	
2272	6-12	Unknown				
First Molar (M1)						9.3
0-6 months			16.7	-17.6	3.2	
6-12 months			14.9	-17.7	3.2	
1 year-20 months			15.2	-17.8	3.2	
20 months-28 months			14.0	-18.0	3.2	
28 months-3 years			13.4	-18.6	3.3	
3-4 years			13.2	-17.9	3.2	
4-5 years			12.5	-18.1	3.2	
5-6 years			12.5	-18.1	3.3	
6-7 years			11.9	-19.1	3.3	
7-8 years			12.5	-19.5	3.4	
895	6-12	Unknown				
First Molar (M1)						16.8

0-6 months	13.8	-19.4	3.2
6-12 months	12.5	-19.6	3.2
1 year-20 months	12.7	-19.0	3.2
20 months-28 months	12.0	-18.7	3.2
28 months-3 years	11.7	-18.9	3.2
3-4 years	11.4	-18.9	3.2
4-5 years	12.2	-18.3	3.2
5-6 years	12.5	-18.2	3.2
6-7 years	12.7	-18.2	3.2
7-8 years	12.2	-18.5	3.2

2151 >18 Female

First Molar (M1) 12.6

0-6 months	12.1	-18.8	3.3
6-12 months	10.5	-19.0	3.2
1 year-20 months	10.1	-19.1	3.2
20 months-28 months	10.2	-19.0	3.2
28 months-3 years	10.0	-18.9	3.2
3-4 years	9.6	-18.0	3.2
4-5 years	9.4	-19.5	3.2
5-6 years	10.2	-19.0	3.2
6-7 years	10.4	-19.0	3.3
7-8 years	11.2	-18.6	3.2

661 18-25 Male

First Molar (M1) 14.1

0-6 months	12.3	-19.4	3.2
6-12 months	12.3	-18.7	3.2
1 year-20 months	12.0	-18.6	3.2
20 months-28 months	11.7	-18.7	3.2
28 months-3 years	11.3	-18.6	3.2
3-4 years	11.4	-18.4	3.2
4-5 years	11.2	-18.5	3.2
5-6 years	11.9	-17.9	3.2
6-7 years	11.5	-18.4	3.2
7-8 years	11.0	-18.7	3.2

843 13-17 Unknown

First Molar (M1) 15.6

0-6 months	10.0	-21.2	3.2
6-12 months	9.9	-19.9	3.2
1 year-20 months	7.5	-20.1	3.2
20 months-28 months	9.4	-20.0	3.2
28 months-3 years	9.1	-20.4	3.2
3-4 years	10.4	-19.6	3.2
4-5 years	10.2	-20.0	3.2

5-6 years	9.6	-19.8	3.2
6-7 years	7.6	-20.9	3.2
7-8 years	8.7	-20.3	3.2

607	36-45	Female	
First Molar (M1)			16.5
0-6 months	13.6	-18.8	3.3
6-12 months	13.0	-18.6	3.2
1 year-20 months	10.8	-19.0	3.2
20 months-28 months	9.6	-19.3	3.2
28 months-3 years	9.4	-19.8	3.3
3-4 years	8.9	-19.8	3.2
4-5 years	9.0	-19.8	3.2
5-6 years	9.7	-19.3	3.3
6-7 years	10.6	-18.9	3.3
7-8 years	12.0	-18.9	3.2

809	18-25	Male		
First Molar (M1)				11.7
0-6 months	15.4	-19.0	3.2	
6-12 months	14.3	-19.3	3.2	
1 year-20 months	13.9	-19.1	3.2	
20 months-28 months	13.6	-19.0	3.2	
28 months-3 years	13.4	-18.7	3.2	
3-4 years	11.8	-19.3	3.2	
4-5 years	12.8	-18.3	3.2	
5-6 years	13.4	-19.4	3.2	
6-7 years	13.9	-18.9	3.2	
7-8 years	12.0	-20.4	3.2	
3rd molar (M3)	13.4	-19.4	3.2	11.5

4005	18-25	Female	
First Molar (M1)			15.9
0-6 months	14.9	-17.8	3.1
6-12 months	14.2	-18.0	3.2
1 year-20 months	12.5	-18.5	3.2
20 months-28 months	11.1	-18.2	3.2
28 months-3 years	10.7	-18.5	3.2
3-4 years	11.0	-18.5	3.2
4-5 years	10.8	-18.3	3.2
5-6 years	11.3	-18.4	3.2
6-7 years	10.9	-18.6	3.2
7-8 years	12.2	-18.2	3.2

4052	18-25	Male	
First Molar (M1)			10

0-6 months	12.2	-17.8	3.3
6-12 months	11.8	-17.9	3.3
1 year-20 months	12.3	-17.5	3.3
20 months-28 months	11.8	-17.7	3.2
28 months-3 years	11.9	-17.5	3.2
3-4 years	10.0	-18.9	3.2
4-5 years	11.5	-18.0	3.3
5-6 years	10.4	-18.8	3.2
6-7 years	12.0	-17.6	3.3
7-8 years	11.6	-18.1	3.3

823 18-25 Female

First Molar (M1) 12.9

0-6 months	14.1	-19.0	3.2
6-12 months	12.3	-20.1	3.2
1 year-20 months	11.0	-20.5	3.2
20 months-28 months	11.9	-19.5	3.2
28 months-3 years	10.0	-20.6	3.2
3-4 years	11.4	-19.4	3.2
4-5 years	11.6	-18.7	3.2
5-6 years	11.4	-19.4	3.2
6-7 years	11.7	-19.0	3.2
7-8 years	11.6	-19.3	3.2

885 >18 Female

First Molar (M1) 9.8

0-6 months	12.7	-20.3	3.3
6-12 months	13.6	-19.5	3.2
1 year-20 months	12.7	-19.6	3.2
20 months-28 months	13.4	-19.9	3.2
28 months-3 years	13.2	-20.1	3.2
3-4 years	10.8	-21.4	3.2
4-5 years	13.6	-19.4	3.2
5-6 years	13.2	-19.9	3.3
6-7 years	13.5	-19.7	3.2
7-8 years	13.5	-19.8	3.2

629 18-25 Female

First Molar (M1) 14.4

0-6 months	14.8	-18.8	3.3
6-12 months	13.7	-19.5	3.3
1 year-20 months	14.0	-19.2	3.3
20 months-28 months	14.1	-19.1	3.3
28 months-3 years	12.6	-20.5	3.2
3-4 years	13.7	-19.0	3.3
4-5 years	13.9	-19.5	3.2

5-6 years	12.7	-20.4	3.2
6-7 years	13.8	-19.3	3.2
7-8 years	13.3	-20.0	3.2

677	18-25	Female		
First Molar (M1)				10.1
0-6 months	14.1	-18.9	3.3	
6-12 months	12.4	-19.2	3.2	
1 year-20 months	11.8	-19.6	3.2	
20 months-28 months	11.4	-19.2	3.2	
28 months-3 years	11.9	-19.0	3.2	
3-4 years	11.5	-19.3	3.2	
4-5 years	11.8	-19.1	3.2	
5-6 years	11.9	-18.5	3.3	
6-7 years	11.8	-18.7	3.3	
7-8 years	11.9	-19.1	3.3	
Second Molar (M2)				14
3-4 years	11.9	-19.5	3.2	
4-5 years	11.9	-19.1	3.2	
5-6 years	12.1	-19.3	3.2	
6-7 years	11.7	-19.4	3.2	
7-8 years	11.4	-19.3	3.2	
8-9 years	11.4	-19.0	3.2	
9-10 years	11.6	-19.2	3.2	
10-11 years	11.6	-19.1	3.3	
11-12 years	11.9	-19.0	3.2	
12-13 years	12.1	-18.9	3.2	

799	>18	Female		
First Molar (M1)				13.9
0-6 months	10.6	-25.8	7.2	
6-12 months	11.4	-17.8	3.2	
1 year-20 months	10.8	-18.9	3.2	
20 months-28 months	10.6	-18.8	3.3	
28 months-3 years	10.8	-18.6	3.2	
3-4 years	10.6	-17.7	3.2	
4-5 years	11.3	-17.3	3.3	
5-6 years	11.2	-17.2	3.2	
6-7 years	11.1	-18.1	3.3	
7-8 years	11.0	-18.0	3.2	
3rd molar (M3)	14.1	-17.9	3.2	12.5

2417	18-25	Female		
First Molar (M1)				16.1
0-6 months	12.9	-24.5	13.6	
6-12 months	13.2	-19.3	3.2	

1 year-20 months	12.0	-19.1	3.2
20 months-28 months	10.8	-19.2	3.2
28 months-3 years	10.5	-19.3	3.2
3-4 years	10.5	-19.7	3.2
4-5 years	11.1	-19.0	3.2
5-6 years	10.5	-19.1	3.2
6-7 years	10.8	-18.9	3.2
7-8 years	11.2	-19.1	3.2
2097	6-12	Unknown	
First Molar (M1)			12.3
0-6 months	13.4	-19.9	3.3
6-12 months	13.5	-18.8	3.2
1 year-20 months	11.7	-19.3	3.3
20 months-28 months	12.0	-19.6	3.3
28 months-3 years	12.4	-19.0	3.2
3-4 years	12.5	-19.4	3.2
4-5 years	13.1	-18.3	3.3
5-6 years	13.0	-18.3	3.2
6-7 years	11.5	-19.0	3.2
7-8 years	13.5	-18.4	3.3
962	13-17	Unknown	
First Molar (M1)			16.1
0-6 months	12.6	-18.8	3.2
6-12 months	12.3	-18.7	3.2
1 year-20 months	11.6	-18.8	3.2
20 months-28 months	12.0	-18.2	3.2
28 months-3 years	11.7	-18.6	3.2
3-4 years	11.6	-18.4	3.2
4-5 years	11.2	-18.6	3.2
5-6 years	11.8	-18.4	3.2
6-7 years	11.8	-18.3	3.2
7-8 years	12.0	-18.0	3.2
659	>18	Male	
First Molar (M1)			15.9
0-6 months	8.2	-20.9	3.3
6-12 months	10.0	-19.1	3.2
1 year-20 months	9.6	-19.3	3.2
20 months-28 months	9.1	-19.7	3.2
28 months-3 years	9.7	-19.2	3.2
3-4 years	9.9	-19.4	3.2
4-5 years	8.6	-19.9	3.3
5-6 years	9.5	-19.6	3.2
6-7 years	9.7	-19.7	3.3

7-8 years	10.4	-19.0	3.3
767	13-17	Male	
First Molar (M1)			13.3
0-6 months	14.2	-19.4	3.2
6-12 months	13.6	-19.2	3.2
1 year-20 months	13.0	-19.5	3.2
20 months-28 months	13.0	-18.3	3.2
28 months-3 years	12.2	-18.9	3.3
3-4 years	11.8	-18.7	3.2
4-5 years	11.4	-18.2	3.2
5-6 years	12.0	-19.1	3.2
6-7 years	12.4	-18.6	3.2
7-8 years	12.2	-18.7	3.3
956	>45	Male	
First Molar (M1)			15.1
0-6 months	15.8	-18.4	3.3
6-12 months	15.0	-18.9	3.2
1 year-20 months	14.4	-18.8	3.3
20 months-28 months	13.8	-18.5	3.2
28 months-3 years	12.9	-19.3	3.3
3-4 years	12.0	-18.7	3.2
4-5 years	11.8	-19.4	3.2
5-6 years	11.9	-18.5	3.2
6-7 years	12.5	-18.1	3.2
7-8 years	12.2	-18.8	3.2
2127	36-45	Unknown	
First Molar (M1)			15.5
0-6 months	9.3	-16.9	3.1
6-12 months	9.8	-17.2	3.1
1 year-20 months	8.2	-17.9	3.1
20 months-28 months	8.8	-16.5	3.3
28 months-3 years	8.7	-16.7	3.2
3-4 years	8.7	-17.3	3.2
4-5 years	9.6	-16.5	3.2
5-6 years	9.7	-16.5	3.2
6-7 years	10.2	-17.2	3.2
7-8 years	11.2	-17.6	3.3
681	13-17	Unknown	
First Molar (M1)			11.3
0-6 months	14.5	-16.8	3.3
6-12 months	13.6	-17.4	3.2
1 year-20 months	13.3	-17.3	3.2

20 months-28 months	11.9	-17.9	3.2
28 months-3 years	12.0	-17.0	3.2
3-4 years	11.7	-17.3	3.3
4-5 years	12.2	-17.0	3.2
5-6 years	12.1	-17.5	3.2
6-7 years	12.3	-17.3	3.2
7-8 years	12.4	-17.3	3.2

785	26-35	Male		
First Molar (M1)				13.5
0-6 months	13.5	-17.0	3.2	
6-12 months	12.0	-17.5	3.2	
1 year-20 months	12.0	-16.8	3.2	
20 months-28 months	11.5	-16.8	3.2	
28 months-3 years	9.7	-17.8	3.2	
3-4 years	11.2	-16.8	3.2	
4-5 years	9.9	-17.4	3.2	
5-6 years	11.0	-17.0	3.2	
6-7 years	10.2	-17.6	3.2	
7-8 years	11.7	-16.8	3.2	
Second Molar (M2)				13
3-4 years	10.9	-19.2	3.2	
4-5 years	10.6	-19.2	3.2	
5-6 years	10.9	-19.1	3.2	
6-7 years	10.9	-19.3	3.2	
7-8 years	11.1	-19.4	3.2	
8-9 years	11.2	-19.3	3.2	
9-10 years	11.1	-19.3	3.2	
10-11 years	11.3	-19.2	3.2	
11-12 years	11.3	-19.2	3.2	
12-13 years	12.1	-19.2	3.2	
3rd molar (M3)	13.5	-18.0	3.2	12.6

2362	18-25	Female		
First Molar (M1)				14.8
0-6 months	12.2	-17.9	3.2	
6-12 months	13.0	-17.9	3.2	
1 year-20 months	12.7	-18.9	3.3	
20 months-28 months	12.7	-18.3	3.2	
28 months-3 years	13.0	-18.0	3.2	
3-4 years	11.9	-18.6	3.2	
4-5 years	12.1	-19.0	3.2	
5-6 years	12.6	-18.2	3.3	
6-7 years	11.7	-19.3	3.2	
7-8 years	13.1	-18.0	3.2	
3rd molar (M3)	13.2	-18.7	3.2	15.2

3065	13-17	Female		
First Molar (M1)				9.3
0-6 months			14.1	-19.6 3.2
6-12 months			13.4	-19.6 3.1
1 year-20 months			11.9	-19.4 3.1
20 months-28 months			11.5	-19.5 3.1
28 months-3 years			11.5	-19.1 3.2
3-4 years			10.4	-19.8 3.2
4-5 years			11.8	-18.2 3.1
5-6 years			12.0	-18.7 3.1
6-7 years			11.8	-19.1 3.2
7-8 years			10.6	-20.7 3.2
889	26-35	Female		
First Molar (M1)				15.4
0-6 months			14.9	-18.0 3.2
6-12 months			13.0	-18.9 3.2
1 year-20 months			13.1	-18.2 3.2
20 months-28 months			9.7	-20.9 3.4
28 months-3 years			12.8	-19.1 3.2
3-4 years			12.4	-18.5 3.2
4-5 years			12.6	-18.4 3.2
5-6 years			12.6	-19.3 3.2
6-7 years			13.1	-18.7 3.2
7-8 years			13.5	-18.7 3.2
Second Molar (M2)				12.9
3-4 years			13.3	-19.7 3.2
4-5 years			12.7	-19.5 3.2
5-6 years			13.1	-19.4 3.2
6-7 years			13.2	-19.5 3.2
7-8 years			13.2	-19.5 3.2
8-9 years			13.2	-19.4 3.2
9-10 years			13.0	-19.4 3.2
10-11 years			13.0	-19.5 3.2
11-12 years			13.5	-19.2 3.2
12-13 years			13.3	-19.3 3.2
3rd molar (M3)			13.5	-18.3 3.2 13.4
603	13-17	Female		
First Molar (M1)				12.2
0-6 months			15.2	-18.3 3.2
6-12 months			13.5	-18.3 3.3
1 year-20 months			12.8	-18.4 3.2
20 months-28 months			12.3	-18.8 3.2
28 months-3 years			12.4	-18.8 3.2

3-4 years	12.3	-19.0	3.2
4-5 years	12.0	-18.8	3.2
5-6 years	12.4	-18.2	3.2
6-7 years	12.4	-19.3	3.2
7-8 years	12.4	-18.8	3.2
Second Molar (M2)			14.1
3-4 years	13.0	-19.3	3.2
4-5 years	12.5	-19.4	3.3
5-6 years	12.6	-19.2	3.2
6-7 years	12.3	-19.3	3.2
7-8 years	12.1	-19.3	3.2
8-9 years	11.9	-19.0	3.2
9-10 years	12.0	-19.0	3.2
10-11 years	12.2	-19.1	3.2
11-12 years	12.5	-19.2	3.2
12-13 years	12.8	-19.0	3.2
801	13-17	Unknown	
First Molar (M1)			8.3
0-6 months	14.0	-19.1	3.3
6-12 months	13.6	-19.3	3.3
1 year-20 months	12.5	-19.3	3.2
20 months-28 months	13.0	-18.3	3.2
28 months-3 years	12.2	-19.1	3.2
3-4 years	12.2	-18.9	3.2
4-5 years	11.8	-19.0	3.2
5-6 years	11.9	-19.4	3.3
6-7 years	12.3	-18.6	3.2
7-8 years	13.0	-17.7	3.3
813	13-17	Unknown	
First Molar (M1)			11.3
0-6 months	16.4	-17.6	3.2
6-12 months	16.0	-16.8	3.2
1 year-20 months	13.8	-19.3	3.2
20 months-28 months	13.0	-18.6	3.2
28 months-3 years	13.5	-17.9	3.2
3-4 years	14.3	-17.9	3.2
4-5 years	13.5	-18.2	3.2
5-6 years	13.0	-18.1	3.2
6-7 years	12.5	-18.7	3.2
7-8 years	13.2	-18.2	3.2
2350	18-25	Male	
First Molar (M1)			9.9
0-6 months	14.9	-17.7	3.3

6-12 months	13.1	-17.5	3.2	
1 year-20 months	11.7	-18.3	3.2	
20 months-28 months	11.6	-18.5	3.3	
28 months-3 years	11.6	-18.4	3.2	
3-4 years	12.9	-17.1	3.2	
4-5 years	12.1	-16.9	3.2	
5-6 years	11.2	-18.4	3.2	
6-7 years	12.2	-17.5	3.2	
7-8 years	12.9	-17.6	3.3	
Second Molar (M2)				7.5
3-4 years	13.0	-19.3	3.2	
4-5 years	12.7	-19.0	3.2	
5-6 years	12.5	-19.0	3.2	
6-7 years	12.3	-19.3	3.2	
7-8 years	12.1	-19.4	3.2	
8-9 years	12.4	-19.5	3.2	
9-10 years	12.8	-19.6	3.2	
10-11 years	12.9	-19.5	3.2	
11-12 years	12.8	-19.6	3.2	
12-13 years	13.1	-19.4	3.2	
3rd Molar (M3)	13.3	-19.2	3.3	7.3

4044	13-17	Unknown		
First Molar (M1)				9.9
0-6 months	12.8	-18.6	3.3	
6-12 months	12.8	-18.9	3.3	
1 year-20 months	13.7	-18.9	3.2	
20 months-28 months	13.2	-18.5	3.2	
28 months-3 years	13.8	-18.1	3.2	
3-4 years	13.5	-18.6	3.2	
4-5 years	13.6	-18.5	3.2	
5-6 years	13.5	-19.0	3.2	
6-7 years	13.9	-18.5	3.2	
7-8 years	13.7	-17.4	3.3	

709	18-25	Male		
First Molar (M1)				15.5
0-6 months	15.3	-17.7	3.2	
6-12 months	13.9	-18.1	3.2	
1 year-20 months	12.7	-18.5	3.2	
20 months-28 months	12.3	-18.4	3.2	
28 months-3 years	11.9	-18.0	3.3	
3-4 years	12.0	-17.9	3.2	
4-5 years	12.2	-18.1	3.2	
5-6 years	12.4	-17.8	3.2	
6-7 years	12.1	-18.0	3.2	

7-8 years	12.9	-17.5	3.2	
Second Molar (M2)				12.4
3-4 years	12.9	-19.7	3.2	
4-5 years	12.3	-19.6	3.2	
5-6 years	12.1	-19.6	3.2	
6-7 years	11.9	-19.4	3.2	
7-8 years	12.4	-19.4	3.3	
8-9 years	12.6	-19.2	3.2	
9-10 years	12.3	-18.9	3.2	
10-11 years	12.6	-19.1	3.2	
11-12 years	12.5	-19.1	3.2	
12-13 years	12.5	-18.9	3.2	
3rd molar (M3)	13.0	-18.4	3.2	13.4

2408	13-17	Male		
First Molar (M1)				14.4
0-6 months	11.8	-19.3	3.2	
6-12 months	11.1	-19.0	3.2	
1 year-20 months	11.0	-19.0	3.2	
20 months-28 months	10.6	-19.4	3.2	
28 months-3 years	10.4	-18.8	3.2	
3-4 years	9.6	-19.1	3.2	
4-5 years	9.4	-19.1	3.2	
5-6 years	9.8	-18.6	3.2	
6-7 years	10.6	-18.2	3.2	
7-8 years	11.2	-18.1	3.3	

2423	36-45	Female		
First Molar (M1)				12.9
0-6 months	10.6	-18.4	3.3	
6-12 months	10.7	-18.5	3.2	
1 year-20 months	11.2	-17.7	3.2	
20 months-28 months	11.7	-17.3	3.2	
28 months-3 years	10.6	-17.5	3.2	
3-4 years	10.5	-18.2	3.2	
4-5 years	11.0	-18.4	3.2	
5-6 years	12.4	-17.5	3.2	
6-7 years	11.8	-17.6	3.2	
7-8 years	12.8	-17.2	3.3	

4084	13-17	Male		
First Molar (M1)				11.3
0-6 months	12.4	-18.0	3.3	
6-12 months	11.0	-18.3	3.2	
1 year-20 months	11.1	-17.6	3.2	
20 months-28 months	9.4	-18.2	3.2	

28 months-3 years	10.3	-18.0	3.2	
3-4 years	9.8	-18.8	3.3	
4-5 years	9.9	-18.7	3.2	
5-6 years	9.1	-19.0	3.2	
6-7 years	10.2	-18.3	3.2	
7-8 years	12.6	-16.9	3.3	
2199	36-45	Female		
First Molar (M1)				12.1
0-6 months	17.3	-17.4	3.0	
6-12 months	15.5	-18.5	3.0	
1 year-20 months	12.9	-18.9	3.0	
20 months-28 months	12.0	-19.3	3.0	
28 months-3 years	11.9	-18.7	3.0	
3-4 years	11.5	-18.5	3.0	
4-5 years	11.7	-18.1	3.0	
5-6 years	11.4	-18.1	3.0	
6-7 years	11.4	-18.5	3.0	
7-8 years	12.6	-17.9	3.0	
2406	36-45	Female		
First Molar (M1)				11.4
0-6 months	14.5	-18.8	3.0	
6-12 months	14.3	-17.9	3.0	
1 year-20 months	12.7	-18.3	3.0	
20 months-28 months	11.9	-18.0	3.0	
28 months-3 years	10.7	-18.3	3.0	
3-4 years	10.7	-18.1	3.0	
4-5 years	10.9	-18.4	3.0	
5-6 years	11.6	-17.9	3.0	
6-7 years	11.5	-18.0	3.0	
7-8 years	10.7	-18.7	3.0	
3rd molar (M3)	13.8	-18.4	3.2	13.9
3011	18-25	Male		
First Molar (M1)				15.2
0-6 months	14.5	-18.6	3.0	
6-12 months	13.7	-18.7	3.0	
1 year-20 months	14.6	-17.4	3.0	
20 months-28 months	12.3	-18.5	3.0	
28 months-3 years	12.6	-17.4	3.0	
3-4 years	12.7	-17.8	3.0	
4-5 years	10.9	-18.8	3.0	
5-6 years	10.5	-19.3	3.0	
6-7 years	12.8	-16.6	3.1	
7-8 years	10.6	-19.5	3.0	

3rd molar (M3)	12.4	-18.8	3.2	14.8
4050	>18	Male		
First Molar (M1)				14.5
0-6 months	14.7	-18.7	3.1	
6-12 months	13.7	-17.8	3.0	
1 year-20 months	11.6	-18.7	3.0	
20 months-28 months	11.2	-18.8	3.0	
28 months-3 years	11.5	-18.7	3.0	
3-4 years	11.3	-19.0	3.0	
4-5 years	11.5	-18.7	3.0	
5-6 years	11.3	-18.8	3.0	
6-7 years	11.5	-18.5	3.0	
7-8 years	11.9	-18.2	3.0	
2079	18-25	Male		
First Molar (M1)				16
0-6 months	11.0	-20.0	3.3	
6-12 months	11.9	-19.7	3.3	
1 year-20 months	9.5	-20.4	3.3	
20 months-28 months	8.5	-21.2	3.2	
28 months-3 years	9.6	-18.7	3.2	
3-4 years	11.7	-19.5	3.2	
4-5 years	11.0	-19.1	3.2	
5-6 years	12.5	-18.5	3.3	
6-7 years	11.6	-19.0	3.2	
7-8 years	11.8	-18.6	3.2	

Appendix C. St Saviour's Almshouse Incremental Enamel Results

Sample	Tooth	Age Bracket	$\delta^{13}\text{C} \text{ ‰}$ VPDB	$\delta^{18}\text{O} \text{ ‰}$ PDB
661	First Molar	0-6 months	-12.6	-4.8
		6-12 months	-12.5	-4.9
		1 year-20 months	-12.3	-4.8
		20 months-28 months	-12.5	-4.7
		28 months-3 years	-12.2	-4.5
709	First Molar	0-6 months	-13.4	-6.1
		6-12 months	-13.3	-6.1
		1 year-20 months	-13.1	-6.3
		20 months-28 months	-12.9	-6.3
		28 months-3 years	-12.7	-6.1
	Second Molar	3-4 years	-12.9	-6.3
		4-5 years	-13.1	-6.2
		5-6 years	-12.9	-6.2
		6-7 years	-12.3	-5.8
	First Molar	7-8 years	-12.4	-5.7
		8-9 year	-13.4	-6.5
		9-10 years	-13.3	-6.4
		10-11 years	-13.1	-6.4
		11-12 years	-13.1	-6.4
		12-13 years	-13.2	-6.1
785	First Molar	0-6 months	-13.2	-5.1
		6-12 months	-13.0	-5.2
		1 year-20 months	-12.8	-5.0
		20 months-28 months	-12.6	-5.1
		28 months-3 years	-12.6	-5.1
	Second Molar	3-4 years	-13.5	-5.1
		4-5 years	-13.3	-5.0
		5-6 years	-13.3	-4.9
		6-7 years	-12.9	-4.5
	Third Molar	7-8 years	-12.7	-4.5
		8-9 year	-13.3	-5.8
		9-10 years	-13.4	-5.8
		10-11 years	-13.4	-5.5
		11-12 years	-13.4	-5.4
		12-13 years	-13.3	-5.1
799	First Molar	0-6 months	-13.7	-5.5
		6-12 months	-13.5	-5.7
		1 year-20 months	-13.6	-5.3
		20 months-28 months	-13.6	-4.7
		28 months-3 years	-13.4	-4.9

809		0-6 months	-14.1	-5.7
		6-12 months	-13.9	-5.6
		1 year-20 months	-13.5	-5.7
		20 months-28 months	-12.9	-5.4
		28 months-3 years	-12.4	-5.0
889	First Molar	0-6 months	-12.7	-5.9
		6-12 months	-12.4	-5.7
		1 year-20 months	-12.3	-5.5
		20 months-28 months	-12.3	-5.6
		28 months-3 years	-13.0	-6.1
	Second Molar	3-4 years	-12.9	-5.4
		4-5 years	-13.2	-5.4
		5-6 years	-12.8	-5.2
		6-7 years	-12.8	-5.1
		7-8 years	-12.9	-5.3
	Third Molar	8-9 year	-13.5	-6.6
		9-10 years	-13.3	-6.4
		10-11 years	-13.1	-6.4
		11-12 years	-13.0	-6.2
		12-13 years	-13.6	-6.5
2079	First Molar	0-6 months	-14.6	-6.0
		6-12 months	-14.1	-5.8
		1 year-20 months	-13.9	-5.8
		20 months-28 months	-13.8	-5.7
		28 months-3 years	-13.7	-5.5
2350	First Molar	0-6 months	-12.7	-6.3
		6-12 months	-12.3	-6.1
		1 year-20 months	-11.8	-6.2
		20 months-28 months	-11.7	-6.1
		28 months-3 years	-11.6	-5.5
	Second Molar	3-4 years	-11.9	-5.5
		4-5 years	-12.1	-5.3
		5-6 years	-12.1	-5.5
		6-7 years	-11.7	-5.4
		7-8 years	-11.9	-5.5
	Third Molar	8-9 year	-13.1	-7.1
		9-10 years	-12.8	-7.1
		10-11 years	-12.6	-7.0
		11-12 years	-12.6	-6.7
		12-13 years	-12.4	-6.3
2417	First Molar	0-6 months	-14.5	-4.5
		6-12 months	-14.4	-4.7

		1 year-20 months	-14.3	-4.8
		20 months-28 months	-13.8	-5.3
		28 months-3 years	-13.6	-4.8
3065	First Molar	0-6 months	-13.8	-5.0
		6-12 months	-13.5	-5.0
		1 year-20 months	-13.4	-5.2
		20 months-28 months	-12.9	-5.1
		28 months-3 years	-12.7	-4.9
603	First Molar	0-6 months	-12.5	-6.6
		6-12 months	-12.2	-6.2
		1 year-20 months	-12.1	-6.0
		20 months-28 months	-12.3	-6.2
		28 months-3 years	-12.5	-6.1
	Second Molar	3-4 years	-13.0	-6.1
		4-5 years	-13.1	-6.3
		5-6 years	-12.7	-6.1
		6-7 years	-12.4	-5.8
		7-8 years	-12.6	-5.9
659	First Molar	0-6 months	-13.2	-5.5
		6-12 months	-13.0	-5.2
		1 year-20 months	-13.2	-5.2
		20 months-28 months	-13.2	-4.8
		28 months-3 years	-13.5	-4.8
2272	First Molar	0-6 months	-13.1	-4.9
		6-12 months	-12.5	-4.4
		1 year-20 months	-12.3	-4.5
		20 months-28 months	-12.1	-4.5
		28 months-3 years	-11.7	-4.5
677	Second Molar	3-4 years	-12.9	-4.4
		4-5 years	-12.8	-4.0
		5-6 years	-12.2	-4.0
		6-7 years	-12.1	-3.9
		7-8 years	-12.4	-4.3

Appendix D. Published Article Summarizing Chapters 4 and 5.

AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 154:585–593 (2014)

Early Life Histories of the London Poor Using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ Stable Isotope Incremental Dentine Sampling

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KEY WORDS post-medieval; teeth; diet; health

ABSTRACT High resolution incremental isotopic analysis of the dentine from early forming teeth, especially first molars (M1s), provides a means to assess the effects of poor childhood nutrition and healthcare on individuals in an assemblage where there are no infants to study. This approach is applied to an 18th and 19th century cemetery population associated with St Saviour's Almshouse burial ground in Southwark, London, to assess whether, or how, early dietary history, including weaning age, influenced health and nutritional status. The results show a general pattern in which non-breast milk foods were introduced before or by 6 months of age, as indicated by elevated $\delta^{15}\text{N}$ during this period. Almost all individuals for which we also have second molar (M2) records, showed lower $\delta^{15}\text{N}$ values from a

very young age (>1 year) until approximately 8–10 years, compared to adult values. The overall results show a significant difference in $\delta^{13}\text{C}$ ($p = 0$ to 4sf, $F = 17.327$) and a weaker statistical difference in $\delta^{15}\text{N}$ between males and females ($p = 0.019$, $F = 5.581$). One possible cause of this is a difference in the diet of males and females early in life, or alternatively, a greater susceptibility of males to nutritional deprivation compared to females. The latter argument is strengthened by a significant difference in the incidence of enamel hypoplasia between the males and females, with 7.7% of male teeth showing defects, compared to 3.9% of females. *Am J Phys Anthropol* 154:585–593, 2014. © 2014 Wiley Periodicals, Inc.

The survival of an infant in the past was strongly dependent on breast milk as a buffer against pathogens (Lönnerdal, 2000), as a source of essential nutrients and generally as a long term assurance of health into adulthood. More broadly, breastfeeding duration is related to birth spacing and parity because it inhibits the fertility of the mother. Prolonged breastfeeding generally reduces the number of children per female (Anderson et al., 1986) and thus, combined with the effects it has on infant mortality, it affects both population numbers and the age profile of a population (Knodel, 1977). Infant feeding practices can be influenced by many variables, including education (Howie et al., 1990), religion (Ineichen et al., 1997), subsistence strategy, mobility, availability of suitable infant foods (Schurr and Powell, 2005), work requirements (Fildes, 1995), social ideals, class and status. There is, therefore, a high degree of variability between societies and within social groups. A shorter breastfeeding duration is often associated with agricultural or industrialized societies and a longer duration with hunting and gathering societies. An example of this difference is shown by the Bofi foragers of central Africa who practice more prolonged breastfeeding than do the Bofi farmers (Fouts, 2004).

As other foods are added to the infant's diet, in the "weaning" period or process, a child is introduced to new dietary sources, as well as to new pathogens. The removal of the immunologically protective breast milk and the introduction of foreign foods are, therefore, often associated with an increased incidence of illness, especially diarrhoea (Motarjemi et al., 1993; Quigley et al., 2007). This kind of incidence is common in societies undergoing economic development.

Historical sources show that, in general, the Post-medieval industrial period is characterized by a decline in breastfeeding as a result of the employment of women in industry from the 19th century (Wickes, 1953). Children not breastfed, or those being weaned, were commonly given foodstuffs called "pap" (bread soaked in butter or milk) or "panada" (cereals cooked in broth) (Stevens et al., 2009). Foods likely to have formed part of the weaning diet include broths, pre-chewed meat, bread, rusks, cereals, pulses, and fruit. However, historical records referring to childhood diet after milk is withdrawn are sparse (Fildes, 1986).

STABLE ISOTOPES, TEETH AND INFANT FEEDING

Several studies have applied stable isotope analysis to understand infant diet. They are based on the observation that a child feeding from its mother's or wet-nurse's

Additional Supporting Information may be found in the online version of this article.

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milk is effectively a trophic level above its mother. This is reflected in a 2–3‰ enrichment in bone collagen $\delta^{15}\text{N}$ (Fogel et al., 1989). Later, $\delta^{15}\text{N}$ values decrease, a pattern which is believed to be associated with cessation of breastfeeding and the introduction of other solid foods. A 1‰ enrichment in $\delta^{13}\text{C}$ may also be associated with a trophic level effect (Fuller et al., 2006).

Researchers have used these observations to study weaning and infant feeding practices, first by comparing the isotopic composition of the bones from infants and children of known age, for example, Katzenberg et al. (1993), Schurr (1998), Prowse et al. (2008), and Pearson et al. (2010). The approach using individuals of different ages, however, is problematic because of the difficulties of aging infant and juvenile skeletons, their underrepresentation in the archaeological record and perhaps most importantly, the physiology of the bone. Bone is dynamic and is remodeled throughout an individual's life. The isotopic composition is thus a reflection of diet over a prolonged, rather than a discrete period (Richards et al., 2002). The study of teeth counteracts some of these issues, as they develop in early life and are retained into adulthood, allowing the early life histories of adult survivors to be studied. Unlike bone, teeth are less susceptible to remodeling once formed and they are robust enough to often survive in the archaeological record (Hillson, 2005).

Several studies have compared teeth between individuals or teeth belonging to the same individual by taking the approximate developmental age of the teeth and comparing isotope values. A fairly coarse sequence of events can be constructed using this methodology. Wright and Schwarcz (1999) conducted a study on the first molars, premolars, and third molars from the same individuals, which develop at different ages throughout childhood. Enamel carbonate $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values from individuals at Kaminaljuyú were used to identify the duration of breastfeeding and the introduction of solid foods. It was found that $\delta^{13}\text{C}$ values increased from the first molar to the premolar, leading the authors to suggest the introduction of maize gruel as a weaning food. $\delta^{18}\text{O}$ differed little between the first molar and premolar, but declined from the premolar to the third molar, which was interpreted as a weaning age of up to 6 years (Wright and Schwarcz 1999).

More recently, temporal resolution has been increased by focusing on higher resolution sampling and analyses within a single tooth. Fuller et al. (2003) suggested that infant feeding strategies could be inferred by comparison of the isotopic composition of dentine from the crown, cervical root and apical root of different teeth. The number of intratooth samples has since been increased to over 10 from each tooth, refining the resolution of such longitudinal studies (Eerkens et al., 2011; Beaumont et al., 2012b). We have applied this approach, with some minor modifications, to obtain early life history nutritional information in a group who likely suffered deprivation in the form of poor nutrition and a high incidence of disease during childhood.

Unlike enamel, which is laid down in two phases—rapid formation followed by a slower maturation phase that results in smoothing of sequential information (Suga, 1982)—dentine is not remodeled (Hillson, 2005). As a result the isotopic composition of the protein component represents a series of discrete periods during the formation of the dentine. This makes it ideal for methods requiring fine temporal resolution. Teeth with severe

caries or advanced attrition are unsuitable for this approach. As the dentine forming cells, odontoblasts, do not die, there is the potential for dentine to be laid down later in life as a reaction to caries or attrition (Arana-Chavez and Massa, 2004). Such samples can be excluded during the selection process. Dentine is also laid down around the pulp cavity slowly throughout life, so older individuals are more likely to have time-averaged isotopic signals within their teeth (Hillson, 1996). In this study, most individuals died as young adults and results from the first molars of older individuals, such as 956 and 2199, still produce infant feeding patterns, suggesting time-averaging is not affecting our ability to track their early life histories.

A major methodological issue with dentine sampling is the problem of how to assign developmental ages to subsamples. Although the outline of tooth development is known, there is considerable interindividual variability (Garn et al., 1958; Tompkins, 1996). Moreover, the majority of studies are concerned with the eruption sequences of teeth, rather than the formation sequences, because eruption data can be obtained relatively unobtrusively (Smith, 1991). It is also difficult to establish ages for the incremental structures within the dentine. As the dentine develops early in life, periodic von Ebner and Andresen lines are laid down at a constant, but as yet undetermined, rate (Dean and Scandrett, 1995). Estimates for periodicity of the Andresen lines in the literature range from 5 (Kawasaki et al., 1980) to 8 days (Dean et al., 1993). Thus, although there is potential to count these lines and use them to age the dentine at periodic intervals within a tooth for use with incremental sampling, there is a large degree of uncertainty, particularly toward the roots. It is also not currently possible to collect enough dentine for conventional isotope measurements at such a small scale. Therefore, we adopted a compromise solution building on the work of Eerkens et al. (2011) and Beaumont et al. (2012b), who demonstrated the feasibility of sampling dentine incrementally at moderately high resolution, details of which are provided in the methods section below. In both studies, dietary changes were identified, including breastfeeding and weaning signals.

ALMSHOUSE BURIAL GROUND, PARK STREET, SOUTHWARK, LONDON

The material for this study was recovered during a program of archaeological excavation ahead of redevelopment by Network Rail at Park Street, the site of College Yard or St Saviour's Alms house burial ground in London (Teague et al 2013). During the 18th and 19th centuries, Southwark was part of the parish of St Saviour's, situated outside the walls of the city of London. In comparison with other parishes, St Saviour's was a deprived area and historical sources point toward a high incidence of disease and nutritional deprivation affecting the inhabitants (Brickley et al., 1999). With the industrial revolution and improving transport links, the area became a region for migration and settlement, which fueled the expansion of Southwark's population, raising it from 35,000 in 1700 to 85,000 by 1831 (Reilly, 1998). The crowded conditions exacerbated health problems within the population, and outbreaks of disease were common. In 1832, an outbreak of cholera resulted in the death of 10% of the Southwark population (Boast, 1997). Living conditions were crowded and drinking water was

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sourced from the unsavoury River Thames where sewage was discharged (Brickley et al., 1999).

The burial ground associated with the almshouse first opened around 1730 when St Saviour's churchyard became full (Holmes, 1897). Following its closure in the 1850s, it was purchased by Charing Cross Rail Company in 1860, when railway arches were built over the ground (Holmes, 1897). This resulted in the removal of some of the burials to municipal cemeteries, with the remainder lying undisturbed in areas that were used as a builder's yard and the Borough Market until the present day redevelopment. The skeletal remains were well-preserved, and the industrial working class background of the population makes this material an important source of information about the relationship between health and diet.

SAMPLING AND METHODS

The selection of the teeth was based on a number of criteria. Each first molar in the collection was scored according to Brothwell's (1981) chart, to record the level of attrition and the incidence of caries. Only those which displayed limited attrition, no caries and no damage were selected, resulting in a final sample size of 42 individuals. Six suitable second molars and 10 third molars from the same individuals were also selected according to the same criteria. Of the 42, 16 were identified as female and 14 as male, the rest being of unknown sex. The samples are biased towards young adults. This is partly due to our exclusion of older individuals with the higher incidences of attrition and partly because of a preference in the burial of young individuals at this site. The reason for this demographic bias in the burial population is unclear (Teague et al 2013). A list of selected samples is given in Table 1. First, molars were chosen to investigate infant feeding strategies because they develop from birth until the root apices close at approximately 8 years old, thus spanning a large portion of an individual's childhood (Massler et al., 1941). The second molars represent approximately the age span of 3 to 13 years. Ten third molars were selected to examine the adult patterns. In this case, only the root tips were analyzed, thus representing the late teens/early 20's. There is a larger variability in the development timing of the third molar than the other teeth (Mincer et al., 1993).

Each molar was cleaned using aluminium oxide air abrasive to remove adhering dirt. The tooth was halved using a Buehler Isomet with diamond-tipped blade. Collagen was extracted from one half of the tooth by demineralizing it in 0.5 M HCl. Demineralization time varied substantially between teeth, from just over a week to 3 weeks. Thereafter, the demineralized, but still intact dentine was cut into 10 strips horizontally from the tip of the crown to the root apex using a scalpel, following Beaumont et al. (2012b). Five of the sections originated from the crown, which in the first molar represents approximately the first 0 to 3 years, while the other five sections originated from the cemento-enamel junction to the root tip, representing approximately the years 3–8. In the second molar, the strips from the crown represent approximately the years 3–8 and the strips from the root the years 9–13. The method used in this study cuts through the Andresen lines, making horizontal sections down a tooth from crown to root. In the crown of the tooth the angle of the lines is roughly followed, although due to the size of the samples required each section rep-

TABLE 1. List of individuals sampled, including their age, sex and which teeth were analyzed

Individual	Age (years)	Sex	Teeth sampled
603	13–17	Female	M1, M2
607	36–45	Female	M1
629	18–25	Female	M1
659	>18	Male	M1
661	18–25	Male	M1
667	18–25	Female	M1, M2
681	13–17	Unknown	M1
709	18–25	Male	M1, M2, M3
767	13–17	Male	M1
785	26–35	Male	M1, M2, M3
799	>18	Female	M1, M3
801	13–17	Unknown	M1
809	18–25	Male	M1, M3
813	13–17	Unknown	M1
823	18–25	Female	M1
843	13–17	Unknown	M1
885	>18	Female	M1
889	26–35	Female	M1, M2, M3
895	6–12	Unknown	M1
921	>18	Female	M1, M3
949	6–12	Unknown	M1
959	>45	Male	M1
962	13–17	Unknown	M1
2079	18–25	Male	M1
2097	6–12	Unknown	M1
2127	36–45	Unknown	M1
2151	>18	Female	M1
2199	36–45	Female	M1
2272	6–12	Unknown	M1
2350	18–25	Male	M1, M2, M3
2362	18–25	Female	M1, M3
2406	36–45	Female	M1, M3
2408	13–17	Male	M1
2417	18–25	Female	M1
2423	36–45	Female	M1
3011	18–25	Male	M1, M3
3065	13–17	Female	M1
4005	18–25	Female	M1
4044	13–17	Unknown	M1
4050	>18	Male	M1
4052	18–25	Male	M1
4084	13–17	Male	M1

Sex and age provided by Oxford Archaeology (Teague et al 2013).

resents many of these histological features. Toward the root there is an increased deviation from the histological features as they become more angled, meaning the samples are more time averaged (Fig. 1).

Each strip of demineralized dentine was rinsed in distilled water three times and heated at 70°C in pH3 H₂O for 2 days, following a modified Longin (1971) method. Where the root tips of third molars were sampled, extraction of collagen followed the same procedure. Following filtration and freeze drying, the resulting collagen was weighed into tin capsules. Samples were measured in duplicate, using a continuous flow mass spectrometer (Sercon 20–22). A laboratory standard, Alanine, was used to monitor data quality, check for drift and to calculate C/N ratios. The results were calibrated using a two-point calibration based on multiple aliquots of international standards, IAEA6 and USGS40 which were included in the sample runs as well as multiple aliquots of the internal standard. Analytical

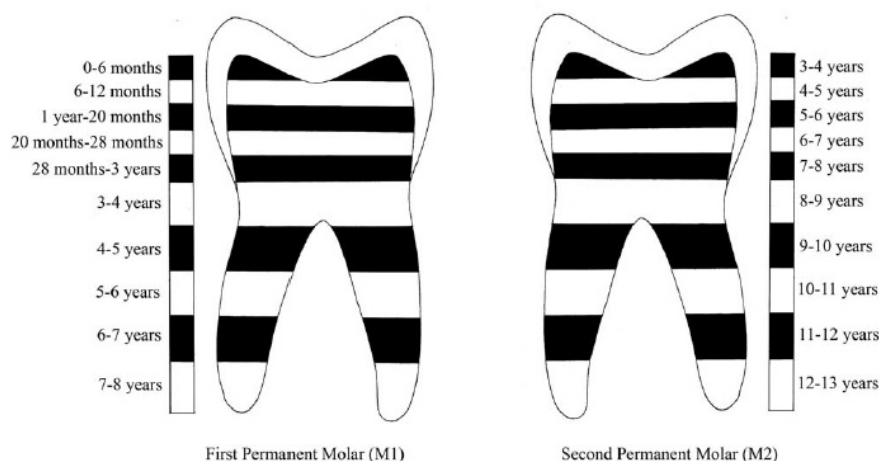


Fig. 1. Position of incremental samples taken from first and second molars with approximate age assigned to each strip.

reproducibility is $\pm 0.1\text{‰}$ and $\pm 0.2\text{‰}$ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively, based on multiple replicates of the internal laboratory standard.

The collagen samples obtained from each tooth strip were allocated an age range based on a developmental chart (Massler et al., 1941). The chart serves as a general indication of timing, although it is recognized that these ranges are approximate and that they are complicated by differences in development rates between individuals and populations. There is some evidence for differences in dentine development between males and females, with females showing slightly faster formation than males after the age of approximately 5 or 6 years (Demirjian and Levesque, 1980). Because the sections made are approximate time intervals, we have not attempted any adjustments.

RESULTS

The average yield of collagen was 12.9%, reflecting good preservation. All samples had C/N ratios within the acceptable range of 2.9 and 3.6 (DeNiro, 1985) with the exception of the 0–6 months sample from individual 2417 and the 0–6 months sample from individual 799. The high C/N ratio obtained from these individuals may have been the result of contamination or poor preservation that was not identifiable by eye. These teeth were omitted from subsequent data analysis. The full set of data is reported in the Supporting Information (Table 1).

The $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ data for tooth sections from all individuals were combined according to tooth section, and shown as box and whisker plots plotted against estimated age for each increment (Fig. 2). These data show that, on average, $\delta^{15}\text{N}$ values peaked during the earliest sample of 0 to 6 months, with an average value of $13.6 \pm 1.9\text{‰}$ (1 standard deviation) and a range of 8.2–17.3‰. Greater variability is observed between individuals in these earlier time slices compared to later increments. The $\delta^{15}\text{N}$ of individuals at the lower end of this range can be consistent with the absence of breastfeeding. This is shown by $\delta^{15}\text{N}$ which is similar to or lower than that of subsequent segments, from the same individual, which represent the diet throughout the rest of

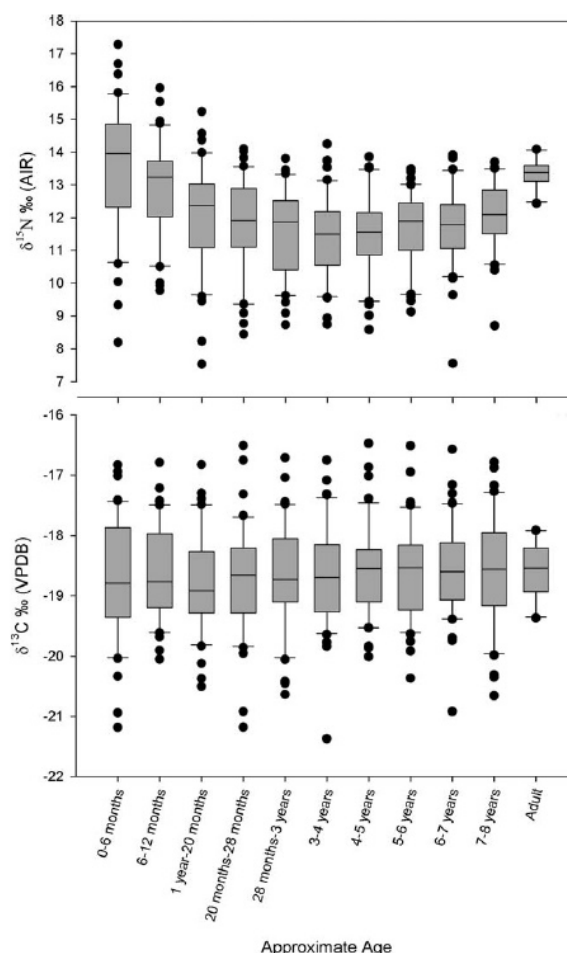


Fig. 2. Box and whisker plots showing the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results from the first molars of all forty individuals and the third molar results from 10 adults.

the childhood. After the initial peak, $\delta^{15}\text{N}$ values decline, to an average of $11.4 \pm 1.3\text{‰}$ for the segment representing approximately the years 3–4. These averaged results suggest supplementation of non-breast milk foods at or before 6 months of age for the majority of individuals.

The smaller sample of second and third molars provides an indication of the entire childhood trajectory, into adulthood. The six second molars show, after a decline in $\delta^{15}\text{N}$ during earlier childhood, a steady increase in $\delta^{15}\text{N}$ during the later childhood and teenage years from approximately 8–9 years (Fig. 3). As before, there is some variability between individuals, with 889 and 709 showing less of a trend toward increasing adult $\delta^{15}\text{N}$ than the others. There is a general upward trend in $\delta^{15}\text{N}$ throughout later childhood, entering the adult range of $13.3 \pm 0.5\text{‰}$ (range 12.4–14.1‰), as represented by the 10 third molars. These are taken as representing a mean “adult” value.

The $\delta^{13}\text{C}$ values are consistent over the entire period. For the 0 to 6 months section, the average $\delta^{13}\text{C}$ value is $-18.69 \pm 1\text{‰}$, ranging from -16.8‰ to -21.2‰ . There is little change over the rest of the childhood as all subsequent sections had a combined mean of $-18.64 \pm 0.84\text{‰}$, ranging between -16.5 and -21.4‰ . The M3 average value of $-18.6 \pm 0.5\text{‰}$ does not represent a notable dietary difference from childhood to adulthood.

A general linear model was used to test for the effects of age and sex on first molar $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in the sequential tooth segments using QED Statistics (Pisces Conservation Ltd) (Table 2). The 29 individuals whose sex is known were initially tested to ensure there was no age/sex interaction. No significant age effect was found for $\delta^{13}\text{C}$ ($p = 0.961$ at a 95% significance level, $F = 0.342$), unlike the $\delta^{15}\text{N}$ which shows a highly significant age effect ($p = 0$ to 4sf at a 95% significance level, $F = 10.163$). Although the number of sexed individuals was modest, a comparison of $\delta^{13}\text{C}$ from first molars showed a subtle but significant difference between males and females throughout the first 8 years of life ($p = 0$ to 4sf, $F = 17.327$). Females had lower $\delta^{13}\text{C}$ on average ($-18.9 \pm 0.9\text{‰}$, compared to the male average of $-18.5 \pm 0.8\text{‰}$). A weaker statistical difference was found in $\delta^{15}\text{N}$ between males and females, with females on average having slightly higher $\delta^{15}\text{N}$ than males ($p = 0.019$, $F = 5.581$) (Fig. 4). The female $\delta^{15}\text{N}$ average is $12.1 \pm 1.2\text{‰}$, while the male average is $11.8 \pm 1.3\text{‰}$. Given the lack of interaction between age and sex a simple linear regression of the effects of age on $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ were also undertaken, which included the previously excluded unsexed individuals. The $\delta^{15}\text{N}$ showed a significant difference with age ($p = 0$ to 4sf, $F = 9.941$), while the $\delta^{13}\text{C}$ did not show a significant age effect ($p = 0.977$, $F = 0.291$). There were too few M2s and M3s to make a viable study of differences between the sexes after the age of 8 years.

DISCUSSION

General trends

The results suggest breastfeeding was being practiced and weaning foods were introduced at or before 6 months of age for most individuals. This observation demonstrates that the 18th century trend of dry-feeding infants from birth without any initial provision of breast milk (Fildes, 1995) was not practiced by the majority of this population and, as a general practice, solid foods were introduced at around 6 months of age or before,

replacing breast milk shortly afterward. While there are some ambiguous feeding patterns, an estimated 83% of individuals were breastfed. The greater variability in $\delta^{15}\text{N}$ up to roughly 2 years of age could indicate variable breastfeeding and weaning practices between nursing mothers. The $\delta^{15}\text{N}$ results from some individuals, such as 843 and 885 may even point to a complete lack of breastfeeding. These individuals have low $\delta^{15}\text{N}$ values for the first two dentine sections that are consistent with those of the first 5 years of life, suggesting that breast milk played a minimal role. Similar variability in infant feeding practices was demonstrated in an isotopic study of Post-medieval individuals from the Spitalfields crypt, using the known age skeletal remains approach (Nitsch et al., 2011). The small number of individuals analyzed from the 19th century Lukin Street cemetery in London makes comparison of variability difficult to judge, but those data hint that variable practices were followed. In the Lukin Street study, only one out of five individuals displayed an obvious breastfeeding and weaning signal (Beaumont et al., 2012b).

Our data show a general pattern of elevated $\delta^{15}\text{N}$ in infancy, dropping to below adult values until 6–8 years, before increasing into early adulthood. The M2 results from individuals 603, 677, 2350, and 785 suggest that the more elevated $\delta^{15}\text{N}$ values occur after 8–9 years in these samples. The consistent decrease before this age may reflect the higher nutrient requirements of growing children, which can be higher than those of fully grown adults, and may lead to a nitrogen deficit and reduced isotope fractionation (Schurr, 1998). This explanation follows the idea that if nitrogen (protein) is limiting, fractionation of $^{15}\text{N}/^{14}\text{N}$ is less expressed, and thus the body's nitrogen pool has lower $\delta^{15}\text{N}$. This pattern is not unique to the St Saviour's population; the relationship between growth rates and isotopic composition has been reported in animals (Trueman et al., 2006) and it has been demonstrated that weight gain in pregnant women is inversely related to their hair $\delta^{15}\text{N}$ (Fuller et al., 2004). The pattern is also reflected by some individuals in the Lukin Street cemetery, (Beaumont et al., 2012b) as well as in some individuals at the hunter-gatherer Marsh Creek Site in California (Eerkens et al., 2011). Observations of a similar pattern across populations from a variety of backgrounds suggest a physiological mass balance cause, but it is also possible the lower $\delta^{15}\text{N}$ during childhood could be related to diet, if children happened to consume lower trophic level food sources during this period of their lives. The interaction of diet and physiology would also be a reasonable explanation for the patterns.

A sex linked difference in stable isotopes

Although $\delta^{13}\text{C}$ values throughout the growth period are very similar, there is a small but significant offset in $\delta^{13}\text{C}$ between males and females (the average male value is $-18.5 \pm 0.8\text{‰}$ and female value $-18.9 \pm 0.9\text{‰}$) (Table 2). A small difference in $\delta^{15}\text{N}$ can also be recognized statistically (the average male value is $11.8 \pm 1.3\text{‰}$ and female value $12.1 \pm 1.2\text{‰}$). The isotopic differences are difficult to explain. It is unlikely to be caused by a difference in the rate of dentine formation, because the small male/female differences are expressed over a period of many years. The variation could reflect dietary differences, with female children consuming a subtly different diet compared to males throughout most of the first 8

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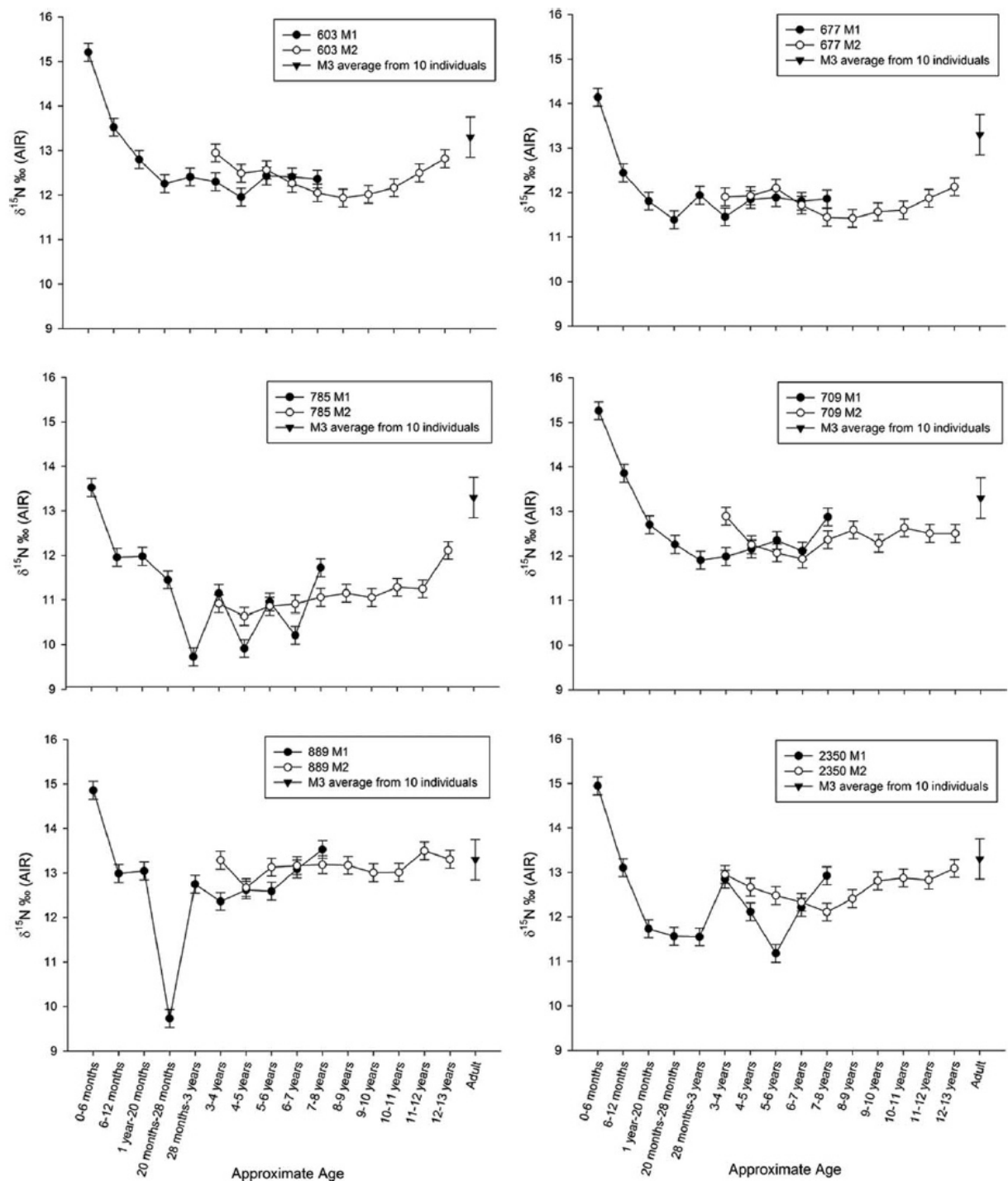


Fig. 3. $\delta^{15}\text{N}$ results for six individuals with first and second molar pairs. Each graph represents an individual. The average third molar result is plotted in each graph to show the adult value. Error bars on the first and second molar plots represent the analytical error. Error bars on the third molar plot represent 1 standard deviation.

years. It's difficult to conceive of a social environment in which such a scenario would occur. Historical documentation relating to a difference in male and female early diets is lacking. Humphrey et al. (2012) do report variation between male and female infant mortality at various

intervals throughout the Post-medieval period, oscillating at some points between greater male or female survival. They suggest one possible cause of increased infant mortality was a change in infant feeding practices and maternal health, variably affecting one sex more than the other

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TABLE 2. Results of the general linear model statistical analysis for all sexed individuals

Source	DF1	DF2	Inc. SS	Adj. SS	MS	F	Prob
$\delta^{15}\text{N}$ output							
Sex	1	270	9.30655	9.30655	9.30655	5.58144	0.0188614
Age	9	270	153.401	152.509	16.9454	10.1627	9.00512E-014
Age/sex interaction	9	270	3.61533	3.61533	0.401703	0.240914	0.988144
Error	270		450.201		1.66741		
Total	289		616.524				
$\delta^{13}\text{C}$ output							
Sex	1	270	11.2221	11.2221	11.2221	17.3273	4.23644E-005
Age	9	270	1.95159	1.99189	0.221321	0.341727	0.960298
Age/sex interaction	9	270	2.81962	2.81962	0.313291	0.483732	0.885076
Error	270		174.866		0.647653		
Total	289		190.86				

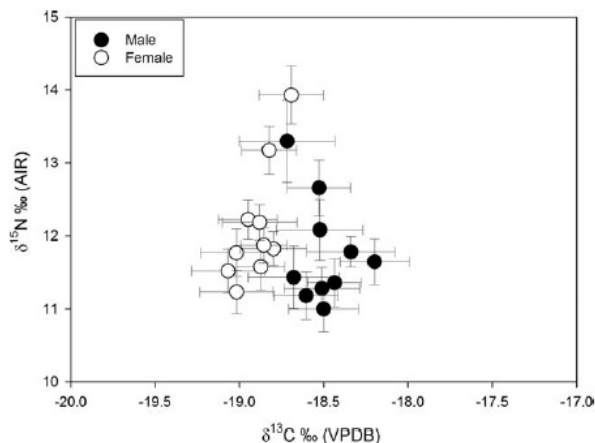


Fig. 4. Scatterplot showing the average value of each first molar incremental segment for all sexed individuals. Each plot represents the average of a tooth segment and therefore a specific age bracket. The segment averages of the males and females have been plotted separately to illustrate the difference in isotopes between the two, 10 plots for the female segments and 10 for the male segments. Error bars represent the standard error.

throughout the Post-medieval period. Still, this does not imply dietary differences between male and female infants in the different periods.

An alternative explanation involves physiological differences between males and females. It is known that male children are more susceptible to stress and infant mortality than females (Naeye et al., 1971). In a review of the effects of sex hormones on the immune system, Bouman et al. (2005) report that females have a greater immune response and resistance to pathogens than males. These observations demonstrate that physiological differences can account for differences in infant mortality (as observed in Humphrey et al. 2012) but it is not yet clear how they might impact on the subtle differences observed in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. One possible explanation is that such physiological differences only become apparent under conditions of nutritional or biological stress during childhood. One of the effects could be on efficiency of metabolism (or possibly digestion) of limited proteins, with females outcompeting the males.

A study of the linear enamel hypoplasia of the Park Street skeletons points towards a significantly higher incidence of stress in males than females during the first

5 years of life. 7.7% of male teeth were affected, compared to 3.9% of the female teeth. A chi-squared test shows this is statistically significant ($p = 0.001$) (Teague et al 2013). The etiology of enamel hypoplasia is nonspecific, but it is generally considered to reflect stress in some form, including illness and starvation (Hillson, 1996). In this case, we know that these were poverty-stricken individuals from the circumstances of their deaths and burial in a cemetery attached to an almshouse. There is good reason to assume generally high levels of stress, but apparently it affected the males more than the females.

Our data has shown a significant, yet small, difference between males and females during their childhood development. We are unable, at present, to pinpoint the most reasonable explanation for this observation in the almshouse individuals. It would seem to us, however, that some form of differential response to stress might account for the observation amongst this group, given their constrained circumstances. Application of this approach to individuals from other populations could establish whether this sex-linked difference is observable in other groups, whether similarly deprived or not. This would help establish whether dietary differences may have played a role in the observations made, a possibility which cannot be discounted.

CONCLUSIONS

Sequential analyses of the M1 dentine of sexed individuals from an almshouse cemetery reveal a small but statistically significant sex difference in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for males and females during their childhood. This difference may be indicative of male/female childhood dietary differences or their physiological responses to stress. Previously observed differences in immune responses, and to infant mortality rates, may be consistent with the latter explanation, but this has yet to be substantiated. What is clear is that this subtle difference is unlikely to have been picked up by standard isotopic approaches, even if infants' and childrens' skeletons had been available.

Elevated $\delta^{15}\text{N}$ in early life shows the contribution of breast milk declined and weaning commenced at or before 6 months of age, on average, for this population. This is the age at which modern health care practitioners recommend introducing other foods to an infant. Since the popular practice in the 18th century was for "dry feeding" of infants, the general pattern shown here for weaning at about 6 months may represent a shift

towards more people breastfeeding compared to the previous century, or may indicate the practice of dry feeding infants was not universal. Our data also show that children aged up to about 8 years had $\delta^{15}\text{N}$ values lower than those of adults as reflected in their M3 dentine values. This may be due to greater nitrogen demands during this period of growth. Adult $\delta^{15}\text{N}$ values are similar to other London inhabitants measured so far, for example, Nitsch et al. (2010) and Beaumont et al. (2012a).

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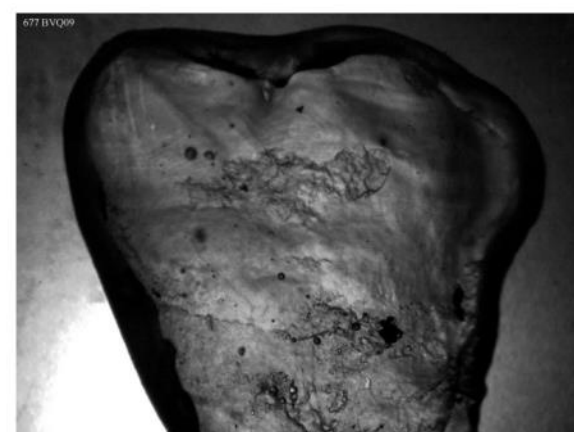
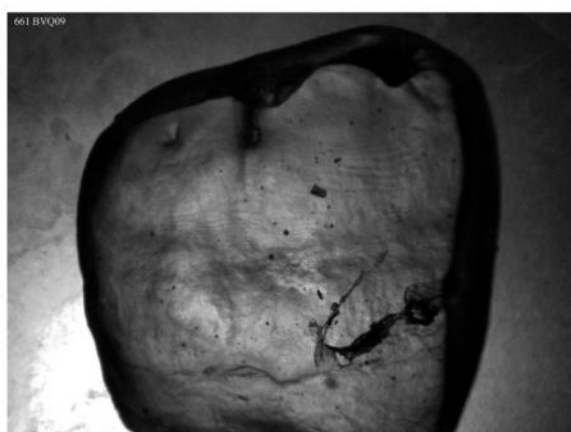
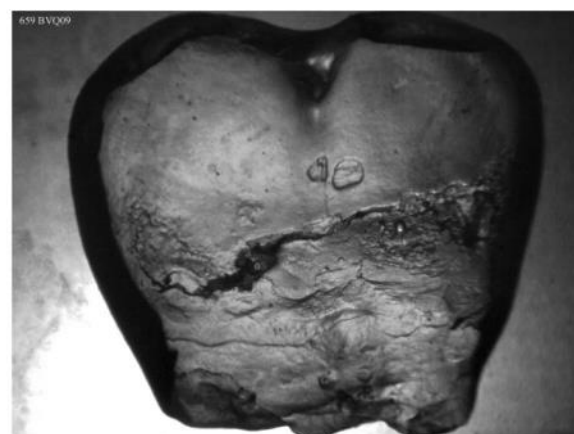
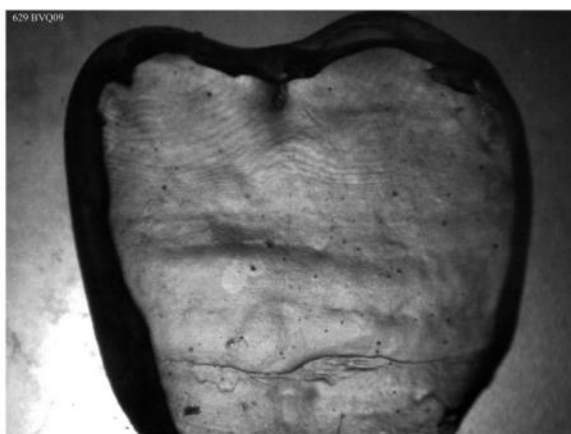
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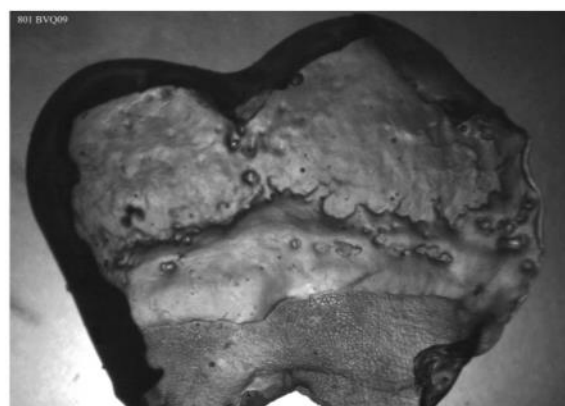
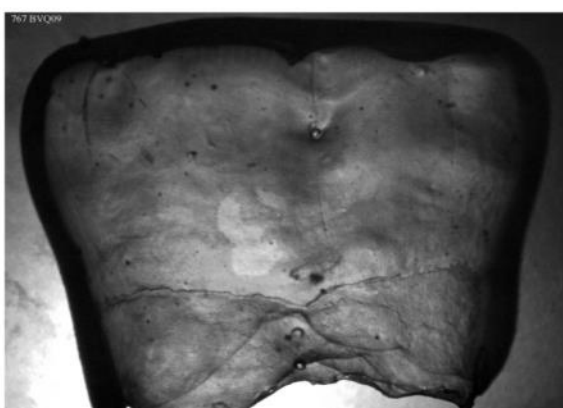
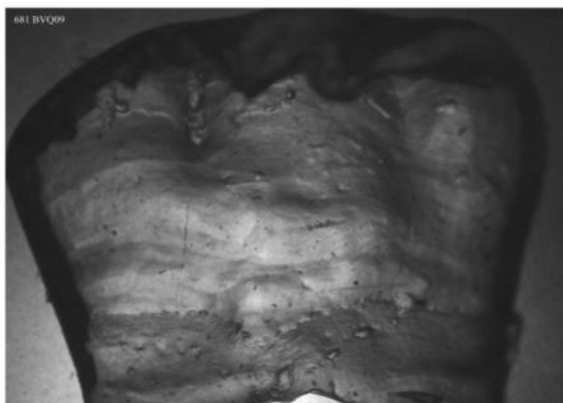
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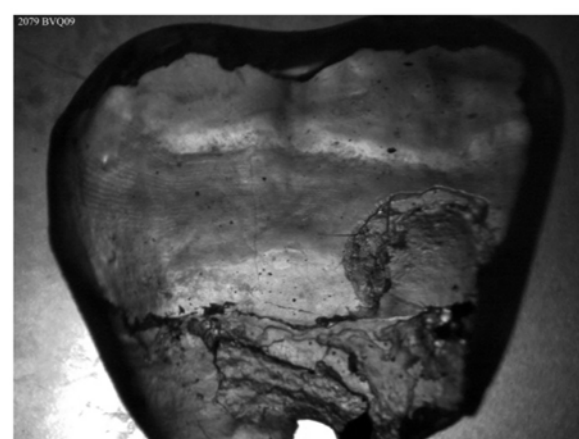
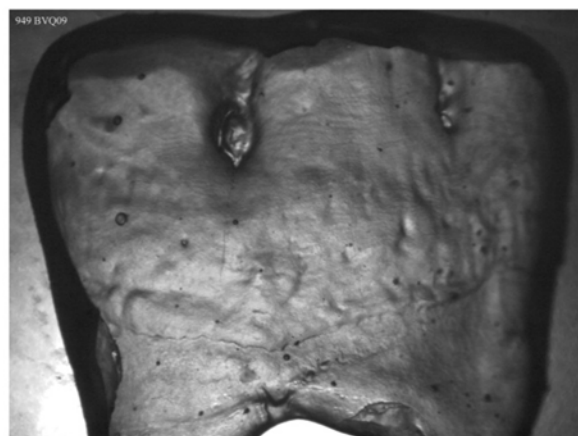
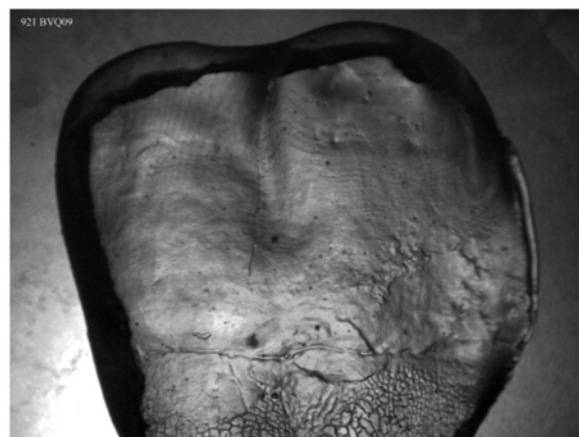
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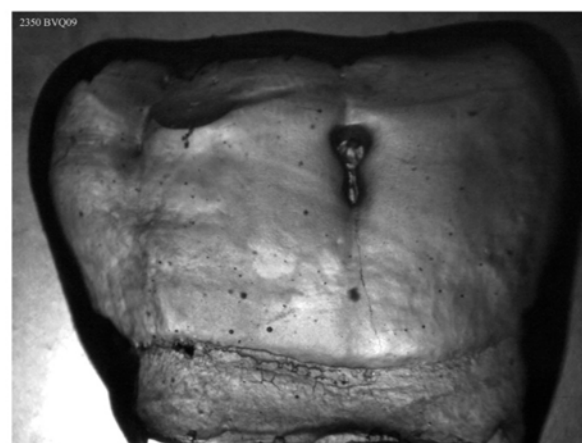
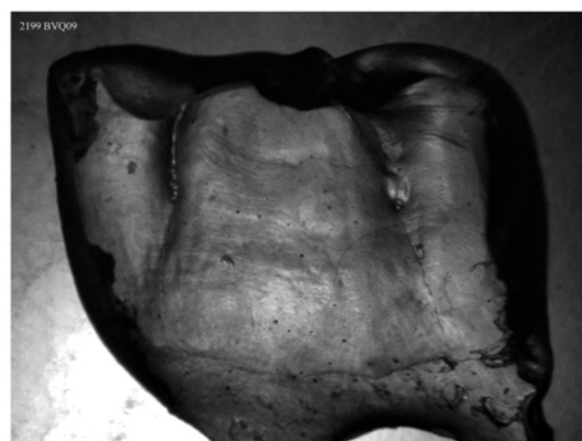
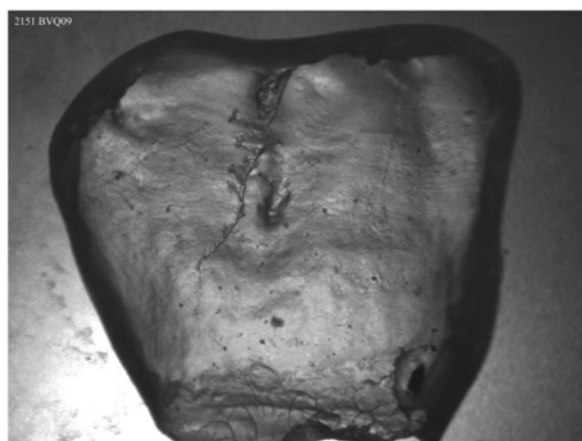
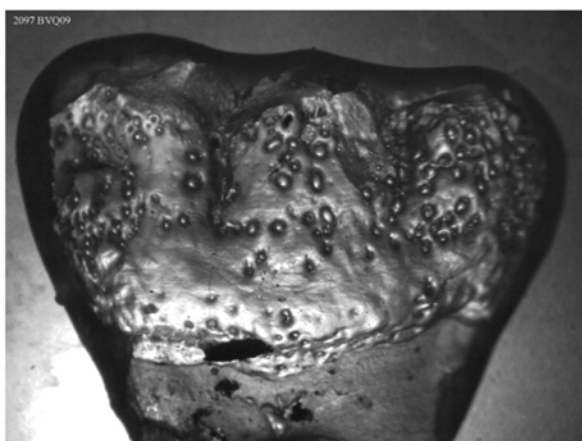
Appendix E. Photographs from the First Molar Casts of Individuals from St Saviour's Almshouse.

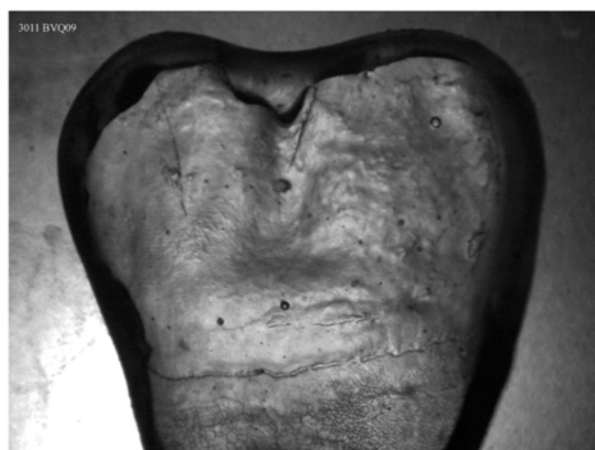
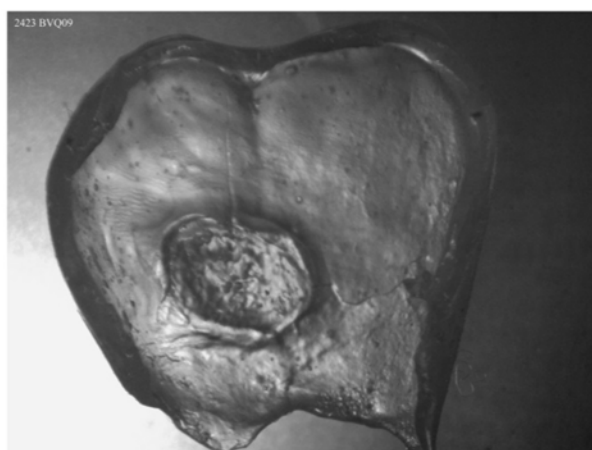
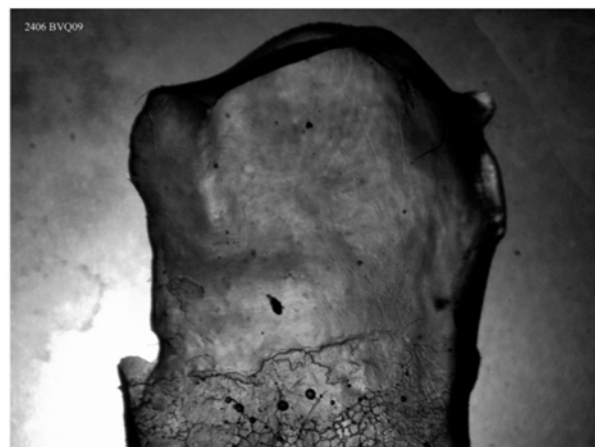


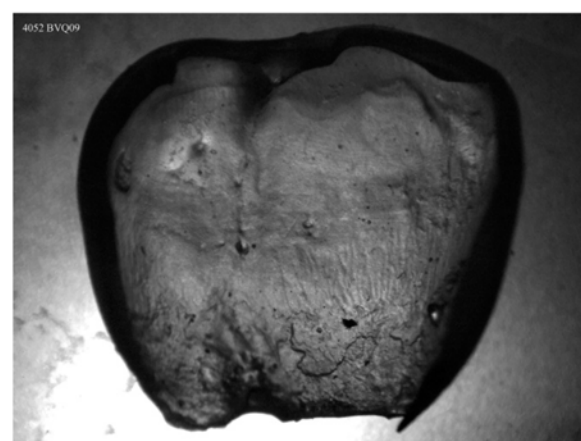
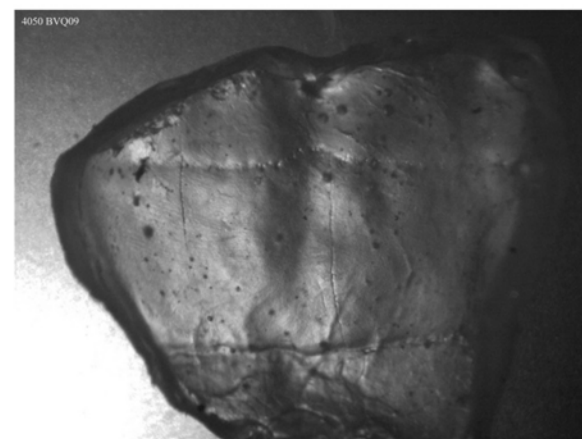
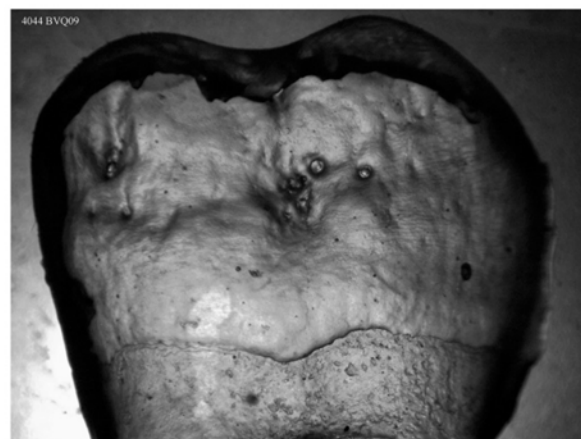
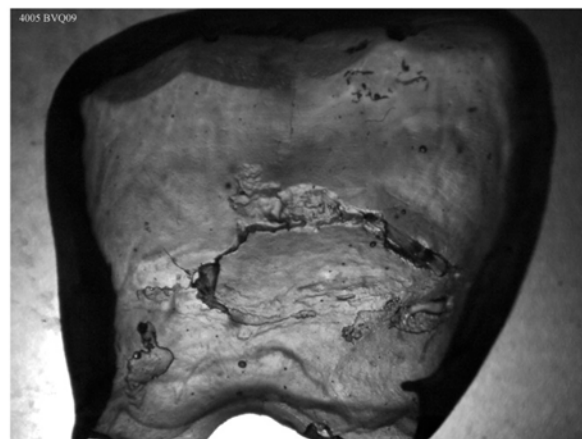












All images were taken under a dissecting microscope, magnification x5.

Appendix F. Zvejnieki Results

Sample	Age	Sex	Radiocarbon date	$\delta^{15}\text{N}$ (AIR)	$\delta^{13}\text{C}$ (VPDB) (cal)	C:N Ratio	‰ collagen
137	Adult	Female	4280±60				35.6
0-6 months				11.9	-22.0	3.2	
6-12 months				11.1	-22.0	3.2	
1 year-20 months				9.9	-21.4	3.2	
20-28 months				10.1	-21.3	3.2	
28 months-3 years				10.5	-21.2	3.2	
3-4 years				10.5	-21.3	3.2	
4-5 years				10.3	-21.6	3.2	
5-6 years				10.7	-21.8	3.3	
6-7 years				10.5	-21.9	3.3	
7-8 years				10.7	-21.8	3.3	
123	Child	Male	6395±60				14.8
6-12 months				13.2	-22.4	3.2	
1 year-20 months				12.9	-22.6	3.2	
20-28 months				12.3	-23.1	3.3	
28 months-3 years				11.2	-23.0	3.2	
3-4 years				10.5	-22.9	3.3	
4-5 years				10.8	-23.1	3.5	
319	Child (6±2)	Unknown	7635±60				9.2
20-28 months				12.5	-23.3	3.2	
207	Adult (12-16)	Unknown	4850±60				20.2
0-6 months				15.5	-22.8	3.3	
6-12 months				16.9	-23.5	3.2	
1 year-20 months				16.6	-24.0	3.2	
20-28 months				16.0	-24.5	3.2	
28 months-3 years				13.9	-24.0	3.2	
3-4 years				13.5	-23.9	3.2	
4-5 years				12.8	-23.7	3.2	
5-6 years				12.8	-23.8	3.2	
6-7 years				13.7	-24.3	3.2	
7-8 years				12.0	-23.0	3.2	
208	Adult	Male	5345±60				11.1
0-6 months				18.4	-21.1	3.3	
6-12 months				15.1	-21.0	3.2	
1 year-20 months				13.6	-22.4	3.2	

20-28 months	14.0	-22.5	3.2
28 months-3 years	14.7	-22.5	3.2
3-4 years	13.6	-22.3	3.2
4-5 years	13.3	-21.9	3.2
5-6 years	12.5	-21.8	3.2
6-7 years	13.8	-22.4	3.2
7-8 years	15.1	-22.8	3.2

170	Adult	Female	8150±80			5.8
6-12 months			16.3	-21.7	3.3	
1 year-20 months			15.6	-22.0	3.4	
20-28 months			15.4	-22.2	3.5	
28 months-3 years			15.7	-21.4	3.4	
3-4 years			15.8	-21.6	3.5	
4-5 years			15.7	-21.2	3.4	
5-6 years			15.7	-21.5	3.5	
6-7 years			15.6	-21.2	3.4	
7-8 years			15.5	-20.9	3.4	

162	Adult (30-35)	Male	5635±65	6.2	
0-6 months			15.0	-23.3	3.3
6-12 months			12.7	-22.7	3.3
1 year-20 months			12.0	-22.6	3.3
20-28 months			12.1	-22.5	3.3
28 months-3 years			12.0	-22.5	3.3
3-4 years			12.0	-22.6	3.3
4-5 years			10.6	-22.1	3.3
5-6 years			10.5	-22.1	3.4
6-7 years			11.0	-22.1	3.4
7-8 years			12.3	-22.6	3.4

124	Adult	Male	5280±55			8.8
0-6 months				13.2	-23.8	3.3
6-12 months				13.6	-24.0	3.3
1 year-20 months				14.7	-24.3	3.3
20-28 months				16.7	-25.2	3.3
28 months-3 years				12.5	-23.7	3.3
3-4 years				12.6	-23.4	3.2
4-5 years				11.5	-22.7	3.2
5-6 years				10.8	-23.0	3.2
6-7 years				11.1	-23.1	3.2
7-8 years				14.0	-24.5	3.3

92	Adult	Male	6510±50			10.1
0-6 months				13.0	-21.1	3.2

6-12 months				12.3	-20.9	3.3
1 year-20 months				11.6	-21.0	3.3
3-4 years				10.5	-21.6	3.3
5-6 years				10.5	-21.2	3.3
6-7 years				10.8	-20.8	3.3
7-8 years				11.6	-22.5	3.3
121	Adult	Female	6145±80			22.5
0-6 months				14.3	-22.7	3.3
6-12 months				14.3	-22.6	3.2
1 year-20 months				13.6	-22.9	3.2
20-28 months				12.2	-23.3	3.2
28 months-3 years				11.7	-24.0	3.2
3-4 years				11.8	-23.5	3.2
4-5 years				11.2	-22.9	3.2
5-6 years				11.4	-22.7	3.2
6-7 years				11.5	-22.4	3.2
7-8 years				11.9	-22.6	3.2
173	Adult	Male	5895±65			8.1
6-12 months				17.0	-24.4	3.4
1 year-20 months				15.1	-24.0	3.4
20-28 months				14.0	-23.2	3.4
28 months-3 years				13.2	-23.3	3.4
3-4 years				13.2	-23.4	3.4
4-5 years				14.2	-24.6	3.3
5-6 years				13.9	-24.3	3.3
6-7 years				14.5	-24.9	3.4
7-8 years				15.3	-24.9	3.3
313	Adult	Female	7525±60			20.1
20-28 months				14.6	-24.3	3.3
164	Adult (25-35)	Male	5230±95			5.9
0-6 months				14.3	-22.7	3.3
6-12 months				13.9	-23.2	3.3
1 year-20 months				12.7	-23.5	3.3
20-28 months				11.9	-23.4	3.3
28 months-3 years				11.8	-23.3	3.4
3-4 years				11.9	-23.0	3.3
4-5 years				11.8	-22.9	3.3
5-6 years				11.9	-23.1	3.3
6-7 years				11.8	-22.4	3.3
7-8 years				10.8	-22.5	3.4

179	Adult	Male	5895±70			11.7
0-6 months				12.5	-22.8	3.3
6-12 months				13.4	-24.9	3.2
1 year-20 months				14.7	-25.9	3.2
20-28 months				14.8	-23.3	3.2
28 months-3 years				12.8	-23.4	3.2
3-4 years				11.5	-23.7	3.2
4-5 years				12.1	-23.9	3.2
5-6 years				13.0	-24.3	3.3
6-7 years				12.5	-23.8	3.2
7-8 years				12.6	-22.9	3.3
154	Adult (40-45)	Male	7730±70			16.7
6-12 months				14.8	-22.5	3.3
1 year-20 months				13.9	-23.0	3.2
20-28 months				13.8	-23.4	3.2
28 months-3 years				14.6	-23.8	3.2
3-4 years				14.3	-23.5	3.3
4-5 years				13.6	-23.4	3.2
5-6 years				13.7	-23.7	3.2
6-7 years				14.5	-24.5	3.2
7-8 years				14.9	-24.4	3.3
206	Child (7-14)	Unknown	5285±50			19.7
0-6 months				17.3	-23.6	3.3
6-12 months				17.4	-23.9	3.2
1 year-20 months				17.3	-24.8	3.2
20-28 months				15.6	-24.4	3.2
28 months-3 years				14.2	-24.3	3.2
3-4 years				13.4	-23.9	3.2
4-5 years				12.3	-23.6	3.2
5-6 years				11.4	-23.3	3.2
6-7 years				9.6	-22.5	3.2
7-8 years				10.4	-22.4	3.2