Toddler Teeth in a Baby Skeleton: Assessing the reliability for the estimation of non-adult age-at-death using the dentition and long bone length, based on the post/medieval population of St. Bride's Lower, London.

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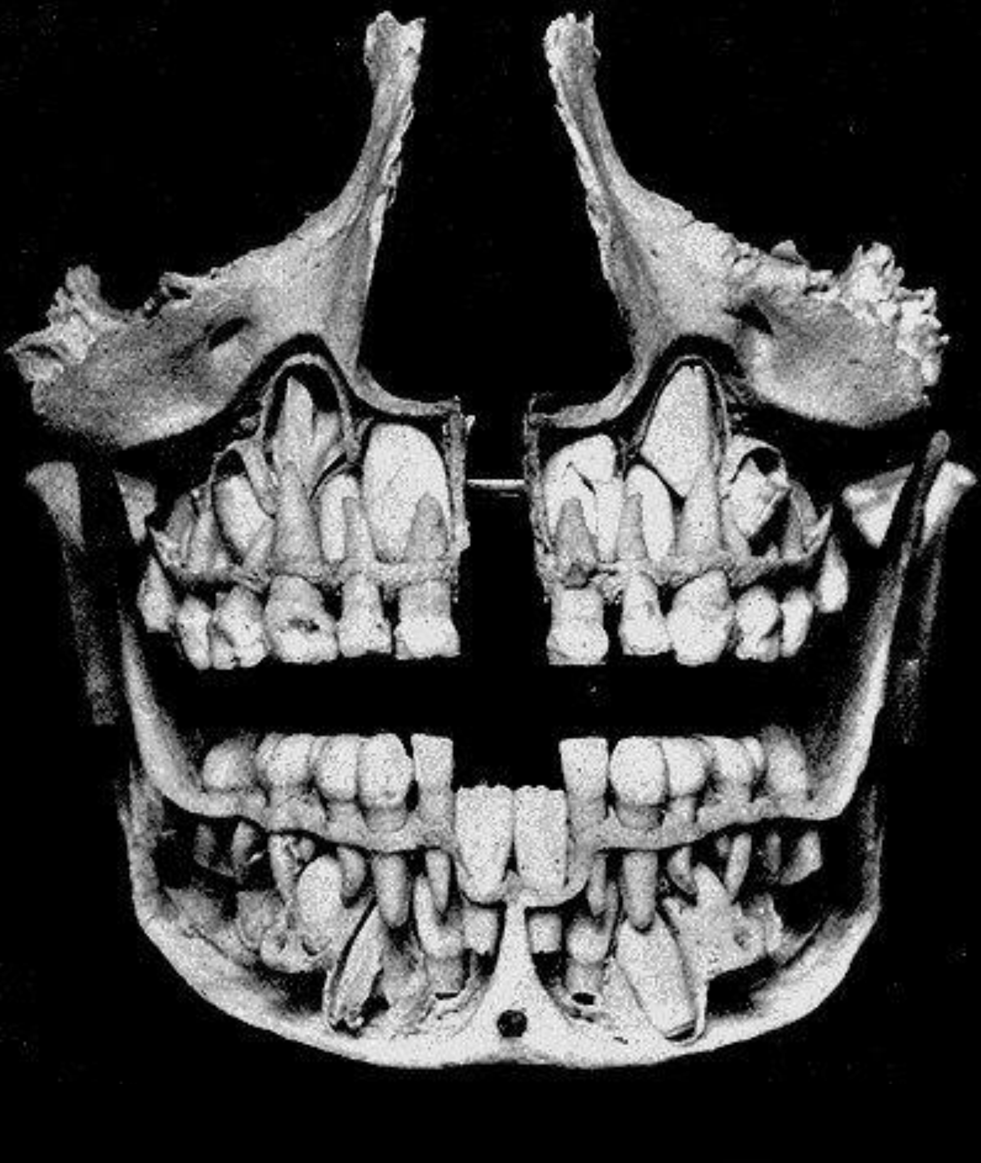

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Toddler Teeth in a Baby Skeleton

Assessing the reliability for the estimation of non-adult age-at-death using the dentition and long bone length, based on the post/medieval population of St. Bride's Lower, London.

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Chapter one: Introduction

One of the first things that is usually done when a skeleton is found in archaeology, is the estimation of age-at-death. Many small details are able to give an indication of the approximate age at which the individual passed away.

Though, what is measured by age-at-death estimation in osteology and why is it important to research it? To understand this, first one should understand the concept of age in science. Anatomical, biological, or physical age (Crampton, 1908) is the age that the skeletal remains appear to be, how far a person is developed during their life. Chronological age (Crampton, 1908), on the other hand is measured in years and months. This is fixed and not open for subjective interpretations: a year is 365 days, if something is two years old, that means it is 730 days old. The day of birth is considered the start of human life and every new day adds to the chronological age of an individual.

The age-at-death estimation is based on features on the bones and dentition that indicate development, so this gives the physical age: the developmental age the individual had at the time of their death (Lewis, 2006). This means an estimate is made based on the elements visible in the skeleton, consequently, an age-at-death estimation can deviate from the chronological age. Especially when taking into account that environmental circumstances can have an impact on growth (Wood et al., 1992)

There are different techniques to estimate an age-at-death in adults and in non-adults (< 18 years). Adult skeletal remains usually have a wide age range of estimated age-at-death, as it focusses more on the ageing process, rather than the growing process (White & Folkens, 2011). For example, in adults the smoothness of the skull or the ends of the ribs are investigated to estimate age-at-death (Cunningham et al., 2016) though this does not always provide the most precise result.

Due to the growing nature of a non-adult skeleton, different techniques need to be applied then with an adult skeleton. In children, or non-adults, this determination of age-at-death is much more precise (Cunningham et al., 2016). Instead of 60-plus years with a reasonably unchanging skeleton for adults, in non-adults, as they are still growing and developing, there is a rapidly changing skeleton over some twenty years which is halted when one comes to perish. Meaning that making an age-at-death estimate can be done quite precisely.

Age-at-death estimations in non-adults

Estimation of age-at-death in non-adults focuses on two major aspects of skeletal development: dental formation and bone maturation and growth (White & Folkens, 2005). The dentition is by many specialists considered to be more reliable as it appears to result the closest approximation of chronological age of the individual. More recent research than when these mentioned techniques were developed shows that teeth will grow at their expected pace, even in the face of harsh circumstances (Cardoso, 2007).

Long bones are the other aspect when it comes to non-adult age-at-death estimation. The growth of these bones is initialised very early on in human development, before it is even born (Ten Cate, 1998). Mainly medical doctors have been very interested in the creation of an overview for how long each bone is at a certain age, such as Maresh (1970). These tables' purpose was to have a baseline for where a child should be when growing up, however, these overviews have become intertwined with archaeology as well.

When long bones are found in archaeological settings, they can be compared to these tables, after which an estimation of age-at-death can be made. All long bones are preferably looked at (Ubelaker, 2005). Each bone can give a different age, the total of these ages is the total estimation of age-at-death for long bones. However, there are techniques which are based on one- or part of a bone.

1.1 Research problem

It is often believed that the long bones underestimate the age-at-death estimation, compared to that of the dentition. Since this believe came into existence, it has been proven that age-at-death estimations based on dentition are quite close to chronological age (Cordoso, 2016). However, this has not yet been tested for long bone age-at-death estimates. Due to the lack of known ages from historical documents in most archaeological populations, this is not a feasible problem to solve.

The closest thing to comparing chronological to developmental age, would then be to compare the age-at-death estimates based on dentition and on long bones. To do so a population with enough non-adult remains need to be available, which is why the dataset from the Museum of London is used to gain access to the measurements taken on the St. Bride's Lower population from London. The research question for this is:

How does the estimation of age-at-death based on dentition compare to the estimation of age-at-death based on long bones in non-adults in the St. Bride's Lower skeletal population?

To be able to answer the main question, I will also address the following sub-questions.

- ☐ What is the mean age of the sample group estimated using the dentition?
- ☐ What is the mean age of the sample group estimated using the long bones?
- ☐ What differences can be seen between the different non-adult age groups, and how can these be explained?

1.2 Approach

This research will be conducted using the population from St. Bride's Lower in London. This site was excavated in the 1900's, after which thorough analysis have been performed on all remains (Milne, 1997). During the postmedieval period, from which this population comes, St. Bride's Lower buried the remains of the lowest socioeconomic people in London (Milne, 1997).

The age-at-death estimates for both the dentition and the long bones from the British population have been published by the Museum of London (museumoflondon.org.uk), hereafter known as MOLA (Museum of London Archaeology department). To initially focus on the differences in estimated age between techniques, the dataset needs to be filtered on different methods, and age categories. MOLA has already performed all these steps on the dataset, which was then published. This is the data that was available for this research. MOLA used all types of age-at-death estimation techniques, of which I have selected two: Maresh (1970) for bone length and Gustafson & Koch (1974) for dentition. MOLA has also divided their dataset into age groups. Instead of an estimated range of age-at-death, it gives an age group. This will provide the answers to both the research question, as well as the sub-questions.

The flaw in these abovementioned methods for age-at-death estimation, however, is that it is based on living children and not specifically for osteological research. This might be a problem as this research does not deal with modern children.

1.3 Thesis outline

This thesis will be based upon both literature research, as well as comparative research between previously collected data. In chapter two a more in-depth description will be given on the topic of estimation of age-at-death in non-adults, focusing specifically on dental development and bone growth. Chapter three will give more background information of the archaeological context of the site and will describe the methods used to collect, order, and research the acquired data. The following chapter, chapter four, will contain the results from this research. Chapter five will discuss these results, after which the thesis will be concluded in chapter six.

Chapter two: Non-adult age-at-death estimation: dental and bone development

This thesis's broad focus is on dental and long bone development in archaeological skeletal remains of non-adults. Though before understanding how archaeological specimen are examined, it is convenient to understand how the preceding processes work. These processes have been thoroughly investigated in living persons, such as by Ten Cate (1998) for dental development and Maresh (1949, 1970) for long bone development.

2.1 Dental development

The use of teeth in osteoarchaeology is a commonly used practice (White & Folkens, 2005). They explain that the reason for this is easily explained; teeth preserve very nicely as they are made from a more resilient material than bone.

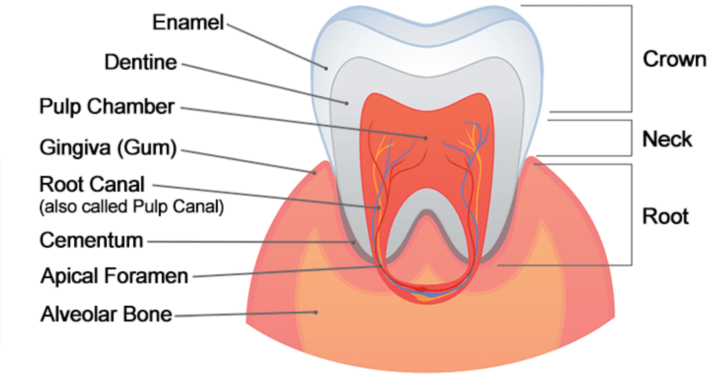


Figure 2.1 Dental structure.

Note. From VCdental.com (2011)

Teeth are constructed in three layers (Ten Cate, 1998). Ten Cate (1998) explains that there is a very tough, though brittle, highly mineralised outside layer, which is known as enamel. The layer beneath the enamel is dentine, an elastic tissue, which supports the enamel and keeps it from breaking. The third layer is known as pulp, this area houses the vessels and nerves that are connected to the teeth. As osteologists deal solely with the teeth from skeletal remains, and thus dried teeth, they will only come across empty pulp chambers.

The development of teeth is a process starting at about 15 weeks gestational age, also referred to as intra-uterine life or duration of pregnancy (Lewis, 2006), and teeth continue to develop until the individual reaches' maturity (Liversidge, 2003). When estimating age using dentition, it is important to keep in mind that humans, alike most other mammals, have two sets of teeth (Hillson, 2014). The first of these sets are the deciduous teeth, also known as 'milk teeth' (Hillson, 2014). The second set are the permanent teeth, although in between there is a period in which both deciduous and permanent teeth are visible

(Hillson, 2014). As this process takes up the entire non-adult phase of human life, it is a good referencing point when estimating age-at-death.

When estimating the age-at-death of a non-adult using dental development, there are two important aspects: dental mineralisation and eruption (Ubelaker, 1978). Ubelaker (1978) specifically adds that with dental eruption is meant the eruption from the gum, not the bone, nor the reaching of the final position, also known as the occlusal plane.

2.1.1 Mineralisation

Mineralisation of the teeth takes place in two phases: pre-eruptive and post-eruptive mineralisation (Giacman et al., 2016). The pre-eruptive process occurs because of the cells in the teeth that are there to mineralise the teeth, ameloblasts. The second phase occurs after the teeth have erupted and takes place because of the contact with the mineral ions that can be found in saliva, they continue to mineralise (Giacman et al., 2016).

The mineralisation process that occurs in the enamel and dentine of teeth is the reason why the visible part of the teeth in the mouth is hard (Giacaman et al. 2016). The first stages of tooth development are the bud stage, cap stage and bell stage (Hillson, 2010). These stages are the formative steps of the crown and it is during the bell stage that a clear distinction between enamel and dentine appears (Hillson, 2010). This bell stage starts in approximately the third month of intra-uterine development for deciduous teeth. The mineralisation process for the permanent teeth starts two to three months later (Caruso et al., 2016).

Permanent teeth have approximately the same developmental stages they go through (Ten Cate, 1998), only at a later timeframe. Permanent teeth begin their development be-tween the twentieth week of intra-uterine life and the tenth month of extra-uterine life, so after the child is born (Ten Cate, 1998). The first molar starts development at the same time as the rest of the permanent teeth, although the third molar only starts developing around the time the child is five years old, the second molar develops in the time in between (Ten Cate, 1998).

2.1.2 Dental eruption

Around the time of birth, all deciduous teeth crowns have fully mineralised and even the enamel formation of some of the permanent teeth is completed (Kendall et al., 2018). Teeth have been programmed to form and erupt in a certain order (Kendall et al. 2018). The eruption of a tooth also occurs at a predetermined moment, as is visible in figure 2.2. Researchers such as Ubelaker (1978) and Moorrees (1963) have researched this eruption pattern in both living children and archaeological samples.

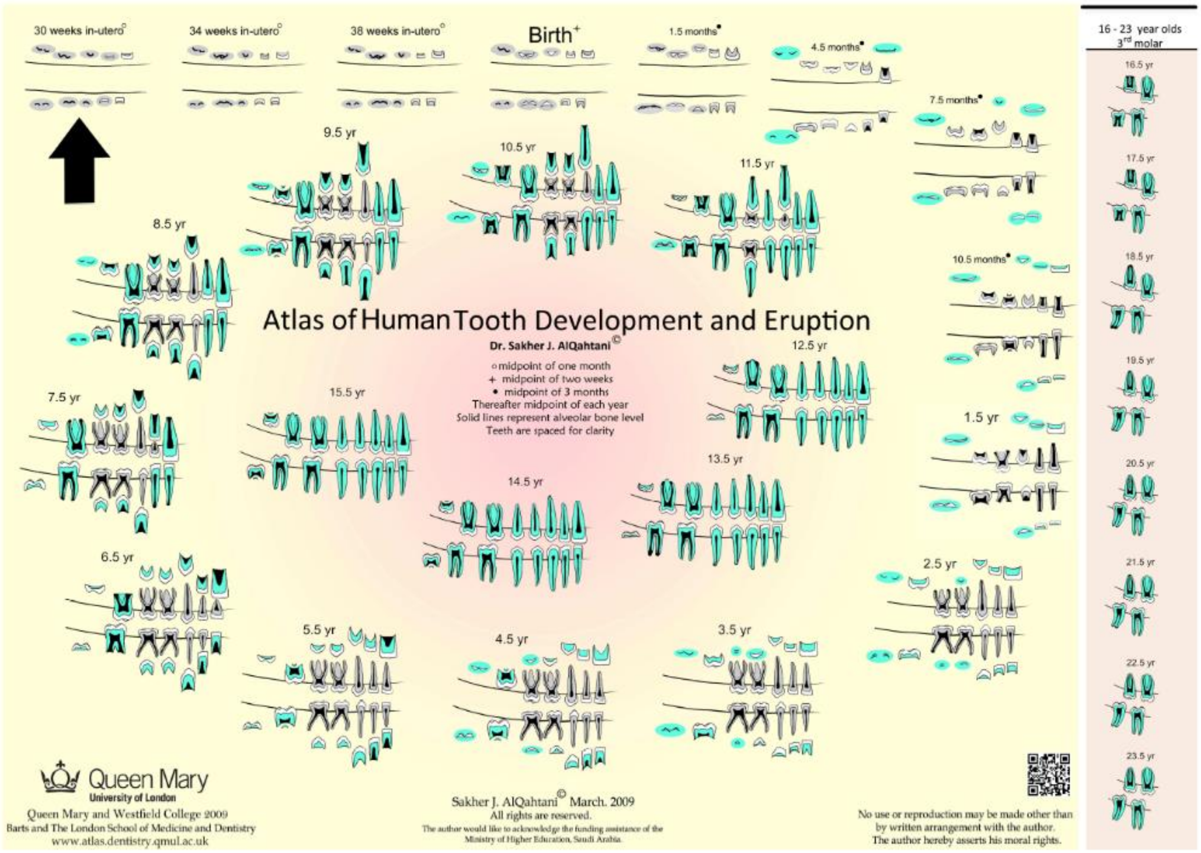


Figure 2.2 Atlas of Human Tooth Development and Eruption.

Note. From AlQahtani, Hector & Liversidge (2010). Brief Communication: The London Atlas of Human Tooth Development and Eruption. *American Journal of Physical Anthropology* 142. pp. 481-490.

As eruption of the teeth is such a clearly defined moment in living children, it is not unexpected that so much research has focussed on this occurrence. What makes it difficult for archaeologists, as Ubelaker (1978) states, is that dental eruption is the moment the tooth erupts from the gum, not the bone. As archaeologists usually only deal with the skeletal remains, this can cause some discrepancies between the outcomes of the methods.

2.1.3 Reliability of dentition

Age-at-death estimation in non-adults based on dentition is considered to be one of the most reliable techniques (Ubelaker, 1978). One of the many reasons for this, is that teeth tend to grow in a more stable pace than any other part of the body, even when confronted with difficult circumstances (Ubelaker, 1978). However, severely bad circumstances, such as continuous malnutrition from very early on, can cause some delay in the development of teeth or can impact how teeth develop (Ubelaker, 1978).

Secondly, not every ancestry group has the same pace of dental development, a discrepancy of five percent may occur (Kendall et al., 2018). However, five percent usually means only a couple of months in non-adults, which means that estimations are usually still within approximately the same year.

2.2 Long bone development

To understand how bones develop, it is necessary to first understand the difference between intramembranous and endochondral ossification. Which type of bone development takes place, is determined by the locality and function of the bone (Steiniche & Hauge, 2003).

2.2.1 Intramembranous ossification

This type of ossification, formation of bone, occurs on the surface of, for example, the flat bones of the skull (Steiniche & Hauge, 2003). Bone development starts when a foetus is about twelve weeks old (Lewis, 2006). Lewis (2006) explains that, before bone occurs, there is a cartilage outline of the shape of the bone. This cartilage outline is covered by the perichondrium, which is the connection between cartilage and joints. To ossify this cartilage, osteoblasts come in, the cells that initiate the creation of bone which form and are responsible for the formation of the bone matrix (Steiniche & Hauge, 2003). Osteoblasts are the cells that initiate the creation of bone (Steiniche & Hauge, 2003). This bone matrix will mineralise, after which the osteoblasts turn into osteocytes, the active, living bone cells, whilst other osteoblasts keep being added to the bone matrix.

2.2.2 Endochondral ossification

Endochondral ossification allows bones to grow both in length and diameter (Steiniche and Hauge, 2003). This process forms bone by transforming cartilage into bone and continues until all growth is completed (Mackie et al., 2008). In addition to osteoblasts, other cells are also involved in endochondral ossification, this allows the bone to grow in multiple direc-tions (Kronenberg 2006), as well as at a rapid pace (Steiniche & Hauge, 2003).

2.2.3 Reliability of bone growth

Bone growth is highly susceptible to environmental circumstances (Lewis, 2006). Meaning that poor hygiene, bad health care, malnutrition, and more circumstances like it, will have an impact on how fast a child grows. Infants are dependent on their mother’s milk for nutrition, although when a child does not receive this, or there is something wrong with the mother’s internal system, young children can already show a halt in bone development (Lewis, 2006). Short periods of poor circumstances are not visible on the skeletal remains, though when it is longer than five days, it will be visible (Lewis, 2006).

It has also been proven, that humans living in environmentally poor circumstances have smaller statures than their contemporaries living in better circumstances (Lewis, 2006). She explains that one possibility for this is that human bodies adapt themselves to living with less nutrients, by having a smaller body that needs less nutrients to survive. Though, she also discusses the possibility that these populations might have a low level of genetic diversity, meaning that a short mother and a short father produce a short child. Without the introduction of taller people to the population they will simply stay shorter as a population.

Populations living in poor circumstances are usually shorter, due to the chronic nature of the poor circumstance (Maat, 2005). If a child would be mover to a richer environment, then the growth process could still be caught up (Maat, 2005).

Overall, there is much variability between bone growth, not just in archaeological specimen. Just look at someone from Asian decent in comparison to someone from European decent, the hight difference can be substantial. When estimating an age-at-death of a non-adult using long bones, it is therefore important to know from which background an individual came to make a correct estimation.

Chapter three: Methods and Materials

This thesis focuses specifically on two methods used in estimation of age-at-death, one for dental age estimates and one for long bone age estimates. The age estimates have been made by MOLA using these techniques, according to their method statement (Museum of London Archaeology Service, 2008**)**. They are responsible for excavating the site which the used population comes from. As this is a statistical research topic, statistical analysis will be performed. How this research will be performed, will be presented in this chapter.

3.1 Gustafson & Koch (1974)

As indicated in chapter 2, this thesis focuses on the method developed by Gustafson & Koch (1974). This method scores individual teeth using four stages of development: commencement of mineralisation, completion of crown, eruption, completion of root (see table 3.2). This method is designed to be applied on two quadrants of teeth in both the deciduous (primary) and the permanent dentition. In both sets of teeth, they make use of the left maxillary quadrants and the right mandibular quadrants. These teeth are identified using the FDI numbering system on the horizontal axis.

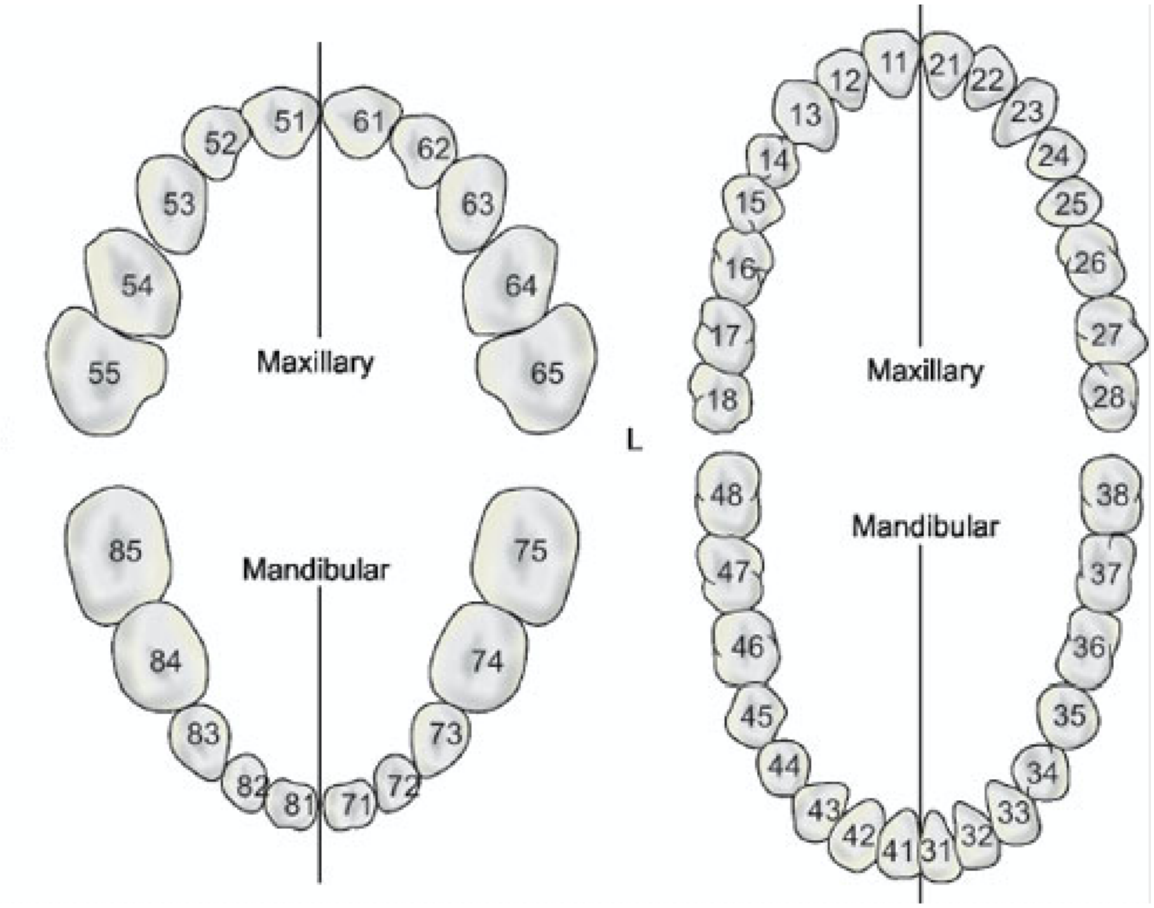


Figure 3.1 Deciduous and permanent dentition, numbered according to the FDI numbering system.

Note. From dentistconsultationhub.com (2004)

The FDI numbering system classifies teeth in their quadrant and their location. Quadrants one through four identify the permanent dentition, whilst five through eight identify the deciduous dentition. The second number identifies which teeth in the quadrant is referred to, with the medial incisor holding the number one up to the third molar holding the number eight in the permanent dentition. In the deciduous dentition there are no premolars and only two molars, coming to a total of five teeth per quadrant (see figure 3.1).

The image below (figure 3.2) shows the developmental stage and associated ages per tooth included in the Gustafson and Koch (1974) system. The graph is made using triangles to indicate individual differences. The lowest point of the triangle is the earliest recorded occurrence and the highest point the latest recorded occurrence. The peak of the triangle indicates the frequency at which the stage completion occurs on average. The graph is visible in below in figure 3.2. The vertical axis describes the age in months during the first year and in years for the ages two through fifteen.

Table 3.1 after Gustafson & Koch (1974)

Group	Age
A-B	Intrauterine life
B-C	First year of life
C-D	2-16 years

Table 3.2 after Gustafson & Koch (1974)

Stage	
I	Commencement of Mineralisation
II	Completion of crown
III	Eruption
IV	Completion of root

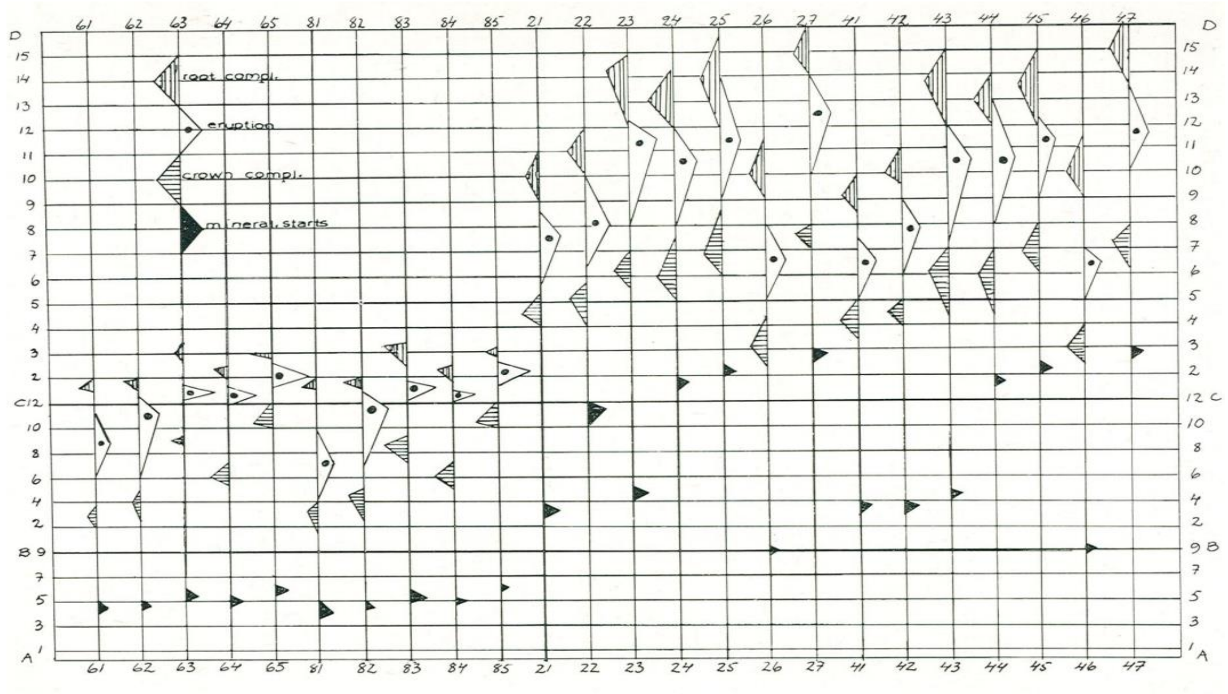


Figure 3.2 Gustafson & Koch (1974) age-estimation table.

Note. From Gustafson, G. & Koch, G. (1974). Age estimation up to 16 years of age based on dental development. Odontologisk Revy 25(3), 297-306.

3.2 Maresh (1970)

The Maresh (1970) technique in archaeology is used to estimate age-at-death of an individual based on the length of their bones. As an individual's bones no longer grow when adulthood is reached, this technique only applies to non-adults. In the article, Maresh (1970) has published measurements of healthy, modern-day children from middle-to-upper class. She does not specifically focus on bone, though rather on all measurements in growing children, also including muscles and fat. The aim for this research was to document complete growth of a person from birth onwards, meaning that it was not designed for archaeological purposes. However, it is one of the most used techniques for estimating age-at-death in non-adults (Cunningham et al., 2000). They also add, that having the diaphyseal length with and without the epiphysis between the ages of ten and twelve, also contributes to age-at-death estimation as one can then see the stage of fusion.

To use this technique, one needs the length of the bone in centimetres and the formula for the corresponding bone. Maresh (1970) has formulae for the six major bones: humerus, ulna, radius, femur, tibia, fibula, and the clavicle. These formulae can be found in table 3.3. As sex estimates are not usually made on non-adults, the six formulae can be applied on both sexes. Once the bone length is measured one can insert it in the formula.

Depending on the completeness of the skeletal remains, one is left with one or multiple age estimates. Each bone provides its own age estimate, so for accuracy more bones with estimates are better. When these have been calculated, one can use the standard error to find the lower and higher bound of the age estimate that has been calculated for an individual.

3.3 St. Brides Lower

St. Brides is a church in London, on Fleet Street, which dates to de post-medieval period (Milne, 1997). It has been the subject of archaeological research since the 1950's, starting after the Blitz (Milne, 1997). Milne (1997) explains that all parts of the church have been excavated, this includes the areas inside the church, as well as the churchyards. More interestingly, he explains the socioeconomical stratification within the burial distribution: one can find the higher-class citizens inside the church, or close to it, in contrast to the lower-class citizens, whom are to be found outside.

The population under study in this thesis comes from the St. Bride's Lower cemetery, an additional graveyard, created to deal with the overpopulation of the cemetery (Miles & Conheeney, 2005). Kausmally (2008) explains that the buried individuals likely came from the Bridewell workhouse and Fleet prison, as documented in the parish records. This confirms their low socioeconomic status. However, individuals were not accurately identified as only a couple of them had coffin plates.

3.4 Data analysis

The data is analysed as a group and individually. R (open source) is used for the statistical analysis done for this thesis; these scripts can be found in appendix 5. R (open source) is a program in which statistical analysis can be done by writing in code.

3.4.1 Distribution of data

How datasets are distributed determines which tests are and are not possible (Elliott & Woodward, 2011). Elliott & Woodward (2011) explain that a dataset with a normal distribution results in a graph with a bell shape, if this graph takes any other form, the dataset is not normally distributed. They continue to explain that one needs to establish hypotheses for these tests, the first one being the null hypothesis, which is in any case the assumption that the data is distributed normally. In the case this hypothesis is rejected, the alternative hypothesis is that the data is not distributed normally. For this dataset, the Shapiro-Wilkes test was used to test for normality.

3.4.2 Comparative statistical analysis

After having determined the distribution of the dataset, it is key to determine what type of comparative research is being done. In this case the dataset, as visible in [appendix nr.], comprises of an individual with two measurement variables. As it is still unknown how the data is distributed, there are two options: a paired T-test or the Wilcoxon signed-rank test.

A paired T-test is used when data is paired in some sort of way, which Is the case when the dataset is comprise of a subject with two measurements, like is the case in this thesis (Elliot & Woodward, 2007). For the test the one sample is subtracted from the other sample. These results will be analysed as a one-sample T-test. A one-sample T-test, aims to check the dataset against a specified value (Elliot & Woodward 2007).

For the dataset in appendix 4, this means that the bone length age estimate is subtracted from the dental age estimate. The difference between these two will then be compared to the specified value of zero. Having zero as a specified value means that the assumed hypothesis assumes that there is no difference between the samples.

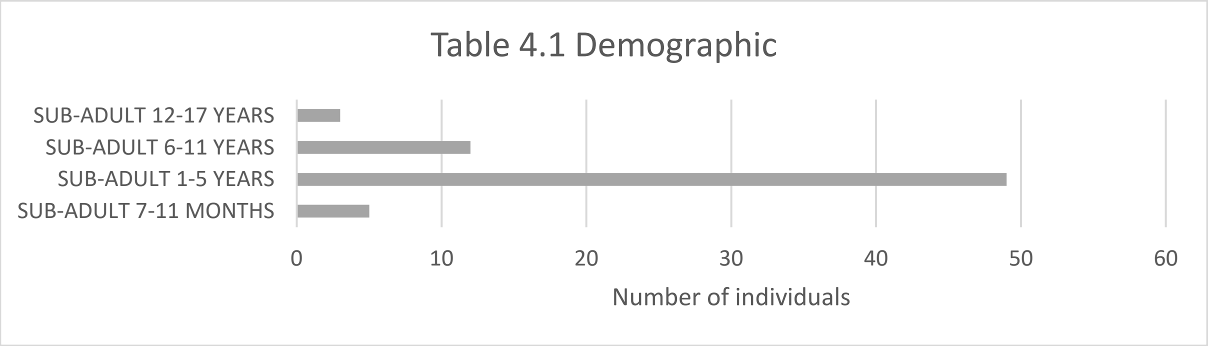
The Wilcoxon signed-rank test has the same aim as the paired T-test, though does not assume a normal distribution of the dataset (Elliot & Woodward, 2007). The Wilcoxon signed-rank test also has more depth to it as it also takes into account the magnitude of the difference of the data. If there is a large difference between the dental age estimate value and that of the bone length age estimate value, the Wilcoxon signed-rank test will show this. The Wilcoxon signed-rank test always assumes that both groups of values have the same deviation. If this is not the case, it means that one of the values deviates much more than the other value

Chapter four: Results

This chapter presents the results based on the dataset found in appendix 4, in combination with the R-scripts found in appendix 5. I will start with a general presentation of the population, after which I will discuss the general statistics of the population. I will end with presenting the individual statistical results.

4.1. Demography

This research is limited to the number of subjects available from the assemblage from St. Brides Lower, which have both a dental age and long bone age assigned. After having removed all individuals which did not adhere to the predetermined standards, a group of 69 individuals total remains. This group largely consists of non-adults between one and five years old, as can be seen in figure 4.1. When looking at the remainder of the individuals, which have not been selected for this research, the non-adult 1-5 years group still stands out.



4.2. Dental development vs. long bone length: Mean age-at-death

The initial analysis comparing the means of the different methods already gives important insights into the dataset. Their value is to get a better sense in understanding the data that has been researched and to understand how some outcomes have been established based hereon.

4.2.1 Age-at-death estimation based on dental development (Gustafson & Koch, 1974)

Based on the dental development, the assemblage in its entirety is estimated 6.3 years at the moment of death, in an age group ranging between seven months and seventeen years. More interesting, however, is to see the averages in each of the groups, as is visible in figure 4.2. The average dental score for individuals who have overall been scored to seven and eleven months, is one year. This is higher than the value of the overall age group. The group that has an overall estimation of one to five years old, has an average age of 2.6 years old. This is more towards the lower end of the spectrum, in contrast to the younger group. The third group, with an overall age estimate between six and eleven, has an average age of eight years. The oldest group, ranging between twelve and seventeen, has an average age of 13.7 years old.

It seems that it is only the youngest group in which the average age lies higher than that of the age category. In all of the other groups, the average age of the group is at the lower end of the age group.

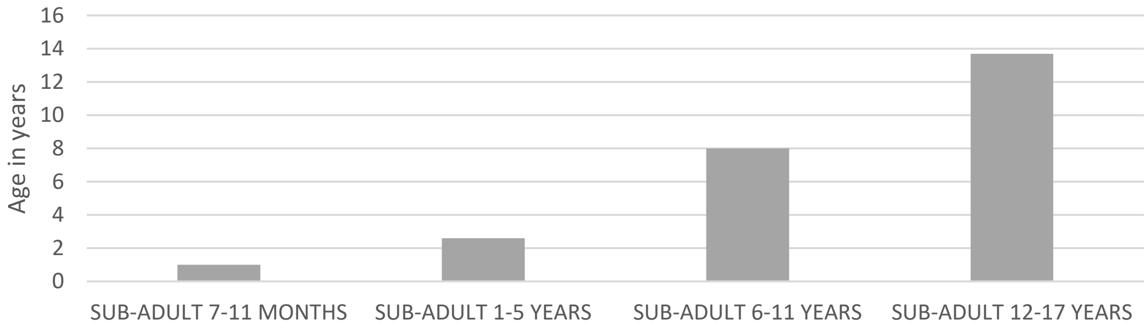


Table 4.2 Average age per age group based on dental remains in years

4.2.2. Age-at-death estimation based on long bone development (Maresh, 1970)

Using the exact same assemblage as for the estimations based on dental development, the average age estimate has also been calculated using the long bone development method. This average age in years of the entire dataset is 4.5 years old.

The youngest group, ranging between seven and eleven months has an overall average of 4.5 months old. This is lower than the lower boundary of the age group. Individuals with an overall age estimate ranging between one and five years old, have an average age of 1.7 years, which is just within the age range. The third group, with an overall age estimate between six and eleven years old, has an average age of 5.6 years old. This is, again, below the lower bound of the age category. The oldest group also demonstrates this occurrence: having an age group ranging from twelve to seventeen, the average age is 10.2. It appears that, except for the second group, all age estimation averages are below the lower bound of the age group.

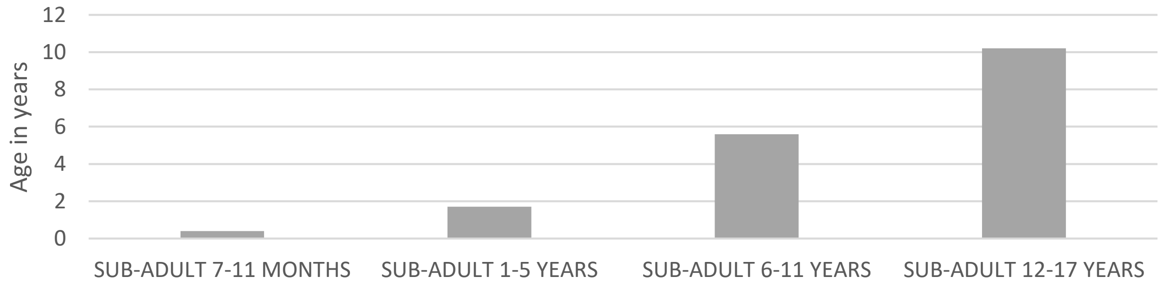
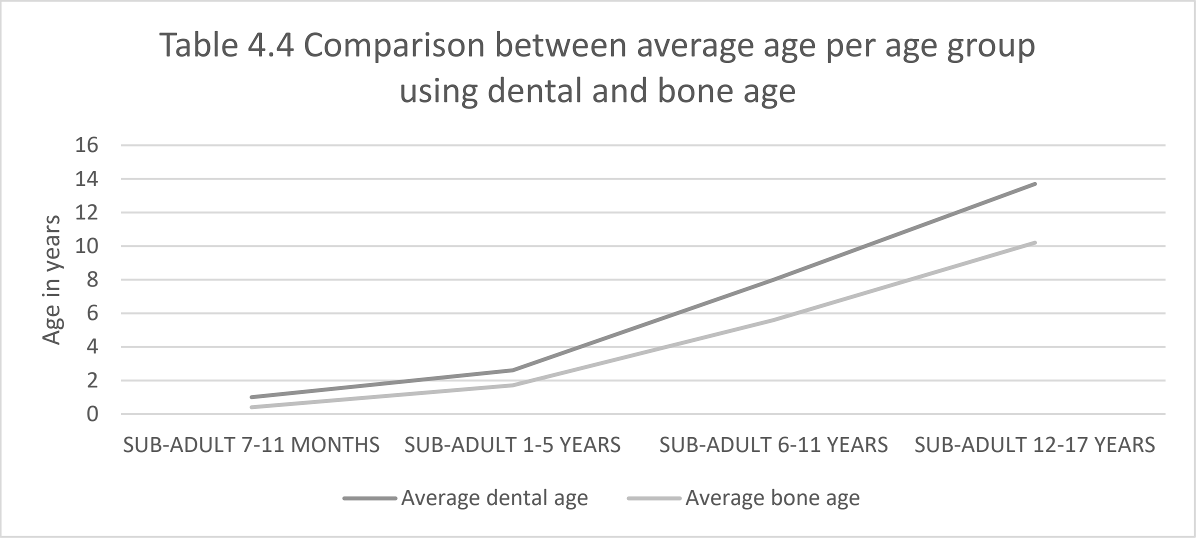


Table 4.3 Average age per age group based on long bone remains in years

4.2.3. Comparing mean age-at-death estimations for both methods

When looking at the average ages for the entire assemblage using both methods, an age gap of almost two years becomes visible. Also, when comparing the average ages for each of the groups, such differences become apparent. This is visible in table 4.4.



The youngest groups show a difference between the two methods of approximately eight months. In an age group of three months, that is quite a significant difference. The age group ranging between one and five years old shows an average difference of approximately one year. The third group, ranging between six and eleven years old, has an average difference of approximately two and a half years. In the last age category this difference based on average increases even more, to approximately three and a half years.

Age group	Average dental age	Average bone age	Difference	Difference %
SUB-ADULT 7-11 MONTHS	1.0	0.4	0.6	60%
SUB-ADULT 1-5 YEARS	2.6	1.7	0.9	35%
SUB-ADULT 6-11 YEARS	8.0	5.6	2.4	30%
SUB-ADULT 12-17 YEARS	13.7	10.2	3.5	26%

4.3 Dental development vs. long bone length: Individual differences in age-at-death estimations

The statistical analysis of this research focuses on individuals, rather than groups. Its value is to better understand each individual in the population, rather than looking at groups or averages.

4.3.1. Distribution of data

The Shapiro-Wilke test was applied to the dataset of dental ages as well as to the dataset of bone length ages. For both datasets the null hypothesis is that the data is normally distributed. The Shapiro-Wilke test on the dental age estimations has resulted in a W-value of 0.81324 and a p-value of less than 0.001.

As the p-value is below the 0.05 border, the null hypothesis has been rejected, meaning that the dental age dataset is not normally distributed.

Running the same Shapiro-Wilke test on the long bone age dataset has resulted in a W-value of 0.76722 and a p-value of less than 0.001. As is the case with the dental age dataset, this dataset too has a p-value below the 0.05 border. Based on this, the null hypothesis has been rejected, which means that this dataset is also not normally distributed.

4.3.2. Wilcoxon signed-rank test

The Wilcoxon signed-rank test is performed to compare the dental age and the long bone age on an individual level. The null hypothesis in this scenario is that dental age and long bone age are identical to each other. The p-value which has been established with this test is less than 0.001. As this is lower than 0.05, this rejects the null hypothesis. The alternative hypothesis is therefore accepted. Meaning that dental age and long bone age are statistically significantly different for all the individuals.

Chapter 5: Discussion

Within the discussion I aim to make an interpretation of the results, as they were provided in the previous chapter. Using other sources to justify my own interpretations, the goal is to find a critically established answer to the research questions.

6.1 Comparison on a group level

The data that was used for this research was already divided into different age groups; each individual was assigned an age range in which most closely resembled their age-at-death estimation. When looking at those groups, the one to five years old group really stands out. Though, one explanation for this is that between the ages of one and five, mothers usually stop weaning (Fildes, 1986). Due to the harsh living circumstances, such as malnutrition and physical labour, young children would need to start adapting to eating solid foods if there were any. Going from a nutritionally rich diet to a diet with likely little nutritional value, is a possible explanation for the high mortality rate in the age group between one- and five-year-olds. The younger group would still be weaned and receive a higher nutritious intake. Both of the older groups would have already adapted to this different lifestyle. Though it would be interesting to see if these same trendlines occur in richer populations, or if they show a completely different mortality age range.

On a group level, it seems that the difference in age estimation grows the older the child is. In the youngest group, this difference between dental and long bone age-at-death estimation is a few months, to the eldest group where this difference grows to be almost four years, on average. Concluding from this, there are two likely scenarios:

1. Maresh (1970) linearly underestimates age-at-death based on long bone lengths, in comparison to Gustafson & Koch (1974). Or the other way around, that Gustafson & Koch (9174) overestimates age-at-death based on dentition.
2. The growth development of the children in this population is continuously delayed, resulting in a linear incline in the difference between age-at-death estimation based on dentition or long bones.

Based on the data gathered from the group analysis, there is already a great difference visible between both techniques that were used. In most cases, the difference is already clear on an average level. Logically speaking, this means that there is such a tremendous difference on an individual level, that the average of each group is severely impacted.

However, the non-transparency with which the measurements of both techniques were performed there is some space for discrepancies. Not knowing how certain measurements were taken and which samples were used for the age-at-death estimation is not optimal, though it does not make it impossible to use the dataset. Both techniques are still reliable and widely used in archaeology **(juvenile skeleton?)**.

6.2 Comparison on an individual level

Within the entire dataset there are just two individuals, 1981 and 1446, who have a higher age-at-death estimation using the Maresh (1970) method than the age-at-death estimation based on the Gustafson & Koch (1974) method. All other individuals are equal, though usually lower, estimated in age-at-death using the Maresh (1970) method in comparison to the Gustafson & Koch (1974) method. Meaning that individual variation is usually between underestimation of the age-at-death and gravely underestimation of the age-at-death.

In each age group there is at least one individual, who really shows a large difference between age-at-death estimation based on dental and long bone remains. The youngest group has an individual, 2173, whose dentition estimates them to be one year old, whilst the long bones suggest that the individual is just born. There are several individuals (1153, 1189, 2013, 1463, 1551) in the second group that have an age-at-death estimation of one or maybe two years old, according to their long bones, whilst their dentition suggests that they were around four or five years old. The third group, ranging between six and eleven, has an individual (1791) who has a three-and-a-half-year age gap between their estimated age-at-death methods. All other individuals in this group show a remotely similar difference between their estimated age-at-death results. The last group has the smallest sample, though does contain the individual with the largest difference in age-at-death estimation. Individual 1789 shows a six-year difference! They have a dental age-at-death estimation of fifteen and an age-at-death estimation based on long bones of nine.

These results on an individual level can support the same two statements as the comparison on a group level does. It still remains true that the dental age-at-death estimations are higher than the long bone age-at-death estimations. That this is not just done by a few outliers, and rather by almost the entire population. The possible reason behind it though, is only speculation.

6.3 Gustafson & Koch (1974) vs. Maresh (1970)

Concluding that either one or the other method is over- or underestimating the age-at-death in non-adults is not possible form the results that were obtained in this research. However, it is possible to say, with certainty, that they show a real discrepancy between the two. To circle back to the research question: the dental age-at-death estimation and the long bone age-at-death estimation do not match.

Though recent research has been done in the reliability of age-at-death estimation using the Gustafson & Koch (1974) method in archaeological context (Brandon, 2018). This research found that the use of dentition is a very reliable source of age estimation (Brandon, 2018). Taking this into account, I tend to believe that it is the Maresh (1970) technique which underestimates age-at-death.

As has been previously stated, both of these methods were designed on living children for living children, their intent was not to be used in estimating age-at-death of archaeological individuals. Working with the bone or tooth itself is different than getting data from an X-ray. This could be a possible reason for the discrepancy between the results. However, Brandon (2018) proved that dentition is still a reliable technique for estimating age-at-death, even though the Gustafson & Koch (1974) method was designed on living children.

Also, I have questioned the validity of both of the methods. As I did not perform my on skeletal analysis, I did not choose the methods, and was dependent on the data that MOLA provided. These two methods showed the largest group of individuals that were available to research. To state that a different method for estimation of age-at-death in non-adults would provide different results is also not true. As this has not yet been researched, I am proposing it as a possible explanation for the conclusion of my research.

Lastly, it could be entirely possible that the age-at-death estimations according to these techniques were true to what the skeletal remains showed. And that the earlier proposed explanation of socioeconomic standing has had such an impact on this assemblage. That would mean that a new method should be developed for every type of social standing, which would then be able to estimate age-at-death correctly for each individual. Though this is not (yet) the case, which means that it could be possible that age-at-death estimation in non-adults underestimates the age of individuals from lower socioeconomic status.

Chapter six: Conclusion

As this thesis is comparative research, this chapter is divided in the different levels of comparison. This follows the same structure as in which the results were given, to avoid confusion. This will be followed by the comparison between the methods, in order to answer the research question, as this is the intended goal. This chapter will end with several suggestions for future research, these are mainly based on the outcome of this research and the options that came up in the discussion.

Using the dentition, the mean age of the entire group is 6.3 years, whilst it is only 4.5 when basing it on long bones. This shows a difference of almost two years, when considering that this concerns the same group of people younger than eighteen, this is quite a large difference.

When comparing the different age-at-death estimations between the age groups, it seems that Maresh (1970) is always lower than Gustafson & Koch (1974). And that this difference is much larger in the lowest two age groups, compared to the highest age groups, though this might be due to the limited range.

Standing out remains the group between one and five years estimated age, this is much larger than any other group and makes up the largest part of the sample. This increase in child mortality is likely due to the discontinuity of breastfeeding and the lack of a nutritious diet.

Thus, age-at-death estimations based on long bones underestimate the age-at-death estimation based on dentition in the St. Brides Lower skeletal population. This is based on the much lower age-at-death estimates from the Maresh (1970) method compared to the Gustafson & Koch (1974) method. With the assumption based on Brandon (2018), that Gustafson & Koch (1974) is a reliable method to use when performing an age-at-death estimation.

6.1 Future research

One of the possible scenarios that I have proposed is that the Maresh (1970) method does not underestimate age-at-death because the method is faulty, alternatively, it is the individual that is misleading. I have speculated this to be because of the socioeconomic circumstances of the individuals of the assemblage I investigated. By doing this same research on contemporary assemblages from a kinder environment, one could compare if the estimation of age-at-death using dental and long bone results. If those match my results, then it would be possible to conclude that it actually is the Maresh (1970) method that does the underestimation.

Another option would be to find an assemblage from which the chronological age is known. By then comparing the age-at-death estimates of dentition and long bones, is will become clear which type of remains most closely resembles the age the person really was when they died.

Thirdly, it would be possible to use other techniques to do the same age-at-death estimation. Using, for example, newer methods or those that were designed for archaeological purposes, rather than for living children. To include the previously mentioned option too, having all these results and being able to compare them to the real age of the individual would be another way to settle the argument of which method is the best.

Alternatively, specifically for the St. Bride's Lower site, it would be an option to look at adult statures. If it were the case that bone growth was stunted because of the environment and malnutrition, surely the adults would also show some sort of evidence of this. If the St. Bride's Lower adult individuals' statures are much lower than individuals from a different social standing, than it would be safe to say that the results which were drawn from this research are because of the environment, and not the methods that were applied.

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Appendices

Appendix 1: Dataset, adapted from mola

Appendix 2: R script

Appendix 1

Table of the dataset, adjusted from MOLA (2008).

SITE-CODE	ESTIMATION OF AGE	GUSTAFSON & KOCH (1974) in years	MARESH (1970) in years	TOTAL
2173	SUB-ADULT 7-11 MONTHS	1	0.1	5
1121	SUB-ADULT 7-11 MONTHS	1	0.3	
1442	SUB-ADULT 7-11 MONTHS	1	0.3	
1843	SUB-ADULT 7-11 MONTHS	1	0.3	
1443	SUB-ADULT 7-11 MONTHS	1	0.8	
1149	SUB-ADULT 1-5 YEARS	1	1	49
1236	SUB-ADULT 1-5 YEARS	1	1	
1584	SUB-ADULT 1-5 YEARS	1	1	
1847	SUB-ADULT 1-5 YEARS	1	0.7	
1864	SUB-ADULT 1-5 YEARS	1	0.8	
2069	SUB-ADULT 1-5 YEARS	1	0.7	
1981	SUB-ADULT 1-5 YEARS	1.3	1.5	
1179	SUB-ADULT 1-5 YEARS	1.5	1.5	
1394	SUB-ADULT 1-5 YEARS	1.5	1.3	
1562	SUB-ADULT 1-5 YEARS	1.5	1.5	
1566	SUB-ADULT 1-5 YEARS	1.5	1	
1616	SUB-ADULT 1-5 YEARS	1.5	0.5	
1623	SUB-ADULT 1-5 YEARS	1.5	1	
2218	SUB-ADULT 1-5 YEARS	1.5	1	
2286	SUB-ADULT 1-5 YEARS	1.5	1.5	
*1659	SUB-ADULT 1-5 YEARS	1.6	1	
1484	SUB-ADULT 1-5 YEARS	1.6	1.3	
1187	SUB-ADULT 1-5 YEARS	2	1.5	
1276	SUB-ADULT 1-5 YEARS	2	0.5	
1379	SUB-ADULT 1-5 YEARS	2	0.7	
1437	SUB-ADULT 1-5 YEARS	2	1.5	
1528	SUB-ADULT 1-5 YEARS	2	1.5	
1601	SUB-ADULT 1-5 YEARS	2	1.5	
1773	SUB-ADULT 1-5 YEARS	2	1.5	
2169	SUB-ADULT 1-5 YEARS	2	1.5	
1384	SUB-ADULT 1-5 YEARS	2.5	1	
1137	SUB-ADULT 1-5 YEARS	3	1.5	
1242	SUB-ADULT 1-5 YEARS	3	2.5	
1358	SUB-ADULT 1-5 YEARS	3	1.5	
1367	SUB-ADULT 1-5 YEARS	3	1.5	
1434	SUB-ADULT 1-5 YEARS	3	2	
1507	SUB-ADULT 1-5 YEARS	3	1.5	

1560	SUB-ADULT 1-5 YEARS	3	2.5	
1629	SUB-ADULT 1-5 YEARS	3	1.5	
2128	SUB-ADULT 1-5 YEARS	3	2	
1498	SUB-ADULT 1-5 YEARS	3.5	2.5	
1153	SUB-ADULT 1-5 YEARS	4	1	
1189	SUB-ADULT 1-5 YEARS	4	1.5	
1318	SUB-ADULT 1-5 YEARS	4	2.5	
1447	SUB-ADULT 1-5 YEARS	4	3	
1533	SUB-ADULT 1-5 YEARS	4	3.5	
1815	SUB-ADULT 1-5 YEARS	4	3	
2013	SUB-ADULT 1-5 YEARS	4	2	
2087	SUB-ADULT 1-5 YEARS	4	3.5	
1238	SUB-ADULT 1-5 YEARS	5	2.5	
1413	SUB-ADULT 1-5 YEARS	5	4	
1463	SUB-ADULT 1-5 YEARS	5	1	
1478	SUB-ADULT 1-5 YEARS	5	3.5	
1551	SUB-ADULT 1-5 YEARS	5	2	
1154	SUB-ADULT 6-11 YEARS	6	5	12
1431	SUB-ADULT 6-11 YEARS	6	4	
1539	SUB-ADULT 6-11 YEARS	6	4	
1218	SUB-ADULT 6-11 YEARS	7	5.5	
1490	SUB-ADULT 6-11 YEARS	7	6	
1124	SUB-ADULT 6-11 YEARS	8	5	
1296	SUB-ADULT 6-11 YEARS	8	4	
1393	SUB-ADULT 6-11 YEARS	8	5	
1168	SUB-ADULT 6-11 YEARS	9	7	
1682	SUB-ADULT 6-11 YEARS	10	7.5	
1791	SUB-ADULT 6-11 YEARS	10	6.5	
1446	SUB-ADULT 6-11 YEARS	11	11.5	
1693	SUB-ADULT 12-17 YEARS	12	11	3
1204	SUB-ADULT 12-17 YEARS	14	10.5	
1789	SUB-ADULT 12-17 YEARS	15	9	
				69

* Individual 1659 was placed in the 6-11 category by MOLA, though all age estimates given in this table and the data posted by MOLA suggests that this individual belongs in the 1-5 group, which is where I have placed them for this research.

Appendix 2

```
> install.packages("dplyr")
> install.packages("ggpubr")
> my_data <- read.delim(file.choose(DATA.txt))
> my_data <- Age_Estimates
```

Shapiro-Wilkes normality test

Dental data

```
> library("dplyr")
> library("ggpubr")
> set.seed(1234)
> dplyr::sample_n(my_data, 10)
> library("ggpubr")
> ggdensity(my_data$DENTAL_AGE, main = "Density plot of dental age",xlab = "Dental Age")
> shapiro.test(my_data$DENTAL_AGE)
```

Long bone data

```
> library("dplyr")
> library("ggpubr")
> ggdensity(my_data$BONE_AGE, main = "Density plot of bone age",xlab = "Bone Age")
> shapiro.test(my_data$BONE_AGE)
```

Mann-Whitney test to compare averages

```
>par(mfrow=c(1,2))
wilcox.test(88, 99, data=my_data)
        88=dental data
        99=bone data
```

Wilcoxon signed-rank test

```
> library(MASS)
> head(my_data)
> wilcox.test(my_data$DENTAL_AGE, my_data$BONE_AGE, paired=TRUE)
```