UNIVERSITY OF LEIDEN, FACULTY OF ARCHAEOLOGY

The patterns found within the skeletal collection of Alkmaar on Linear Enamel Hypoplasia

A research based on the skeletal remains found at the Franciscan monastery in Alkmaar dating from 1448 to 1572.

Drewes Attema

Figure 1: Illustration of enamel hypoplasia on a young female (Stacey 2019)

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A research based on the skeletal remains found at the Franciscan monastery in Alkmaar dating from 1488 to 1572.

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Table of Contents

1 Introduction

1.1 Linear Enamel Hypoplasia: an Introduction

The teeth are a rich source of information that can provide archaeologists with a lot of information from the past. This data can give information on many different topics such as nutrition and diet, genetics or age at death (Goodman 1991, 279). Data obtained through research on teeth is considered very reliable, due to teeth their resistant nature to taphonomic changes; this resistance causes much of the information ‘stored’ in the teeth to conserve over their individual’s lifetime (Łukasik and Krenz-Niedbała 2014, 297). Studying teeth may reveal stress markers left by diseases, dental wear because of diet and many other aspects of past life. One type of stress markers is called linear enamel hypoplasia, or LEH in short, and this topic will be the focus of this thesis (Goodman 1991, 279).

Linear enamel hypoplasia is a permanent non-specific stress marker that affects the enamel layer of the tooth; this condition arises during the formation of the tooth’s outer enamel layers. LEH causes lines to form on the enamel of teeth; these lines can be seen by the naked eye (see fig. 2.). These lines can form on any of the teeth and can occur multiple times on a single tooth, the frequency of these lines indicate the number of stress moments during the life of an individual. During the development of the enamel a stress episode can cause a deficiency in enamel, this results in the enamel being less thick and is called enamel hypoplasia, when this comes in the form of lines as seen in fig 2 it is called linear enamel hypoplasia (Łukasik and Krenz-Niedbała 2014, 297). The reason it is permanent is because teeth do not undergo any remodeling or regeneration after they are formed, this is what makes them a rich source of information, which undergoes little change (Łukasik and Krenz-Niedbała 2014, 297). There are various different causes for LEH; this is what defines it a non-specific stress marker, since the cause cannot be attributed to anything specific. The main cause for this dental condition is understood to be of nutritional nature (Boldsen 2007, 59), although there are also cases where the dental defect is caused by other things, such as genetics, disease or trauma to the teeth (Goodman 1991, 281).

Figure 2: LEH in a young adult female individual (Łukasik and Krenz-Niedbała 2014, 302).

The linear appearance of the LEH reflects the chronologic nature of the marker, they appear in short episodes and when multiple appear they are able to show systemic stress due to their pattern (Goodman 1991, 281). This systemic show of nutritional stress is very interesting in an archeological setting as it can give insight into the past situation; a high amount of LEH visible in a relatively high amount of the population may give insight into, for instance, possible famine.

The largest restriction when working with LEH is that it can only give indications about health and stress on the period during which the teeth develop, as they do not remodel. The period during which dental development takes place restricts the ages that can be researched; this means that there is only information from the 4th fetal month (formation of the first tooth) to a maximum of 12 years old (completion of the enamel on the third molars)(Logan and Kronfield 1933, 384). Although it might seem backwards to look at adults instead of children, by looking at adults we research the fully developed teeth, which makes it possible to recognize when childhood stress occurred. Looking at actual children themselves actually makes this process more difficult since tooth development can differ and aside from dentition sex estimation on children is a difficult task as well.

This lack of remodeling is however one of its strengths as it can be used to determine the age at which the stress takes place. A method proposed by Reid and Dean combines the knowledge of the crown formation with the location of the LEH on the tooth to determine the age of an individual at these specific stress intervals (Reid and Dean 2000, 135). In doing so a more precise representation of an individual's biological profile can be made which in in turn helps other kinds of research. Linear enamel hypoplasia has been the most widely used stress marker and is still an import asset when it comes to the recreation of the biological profile (Łukasik and Krenz-Niedbała 2014, 297).

1.2 Thesis Aims

The goal of the research is to study if there are patterns recognizable in the linear enamel hypoplasia present in the skeletal collection of Alkmaar in order to add to the previous research done in the area. By identifying the patterns this research aims to gain more insight into this skeletal collection and to find correlations between the presence of linear enamel hypoplasia and the age of death. The hypothesis for the thesis is that nutritional stress during childhood can have an impact on the longevity of life; this stress can be indicated by the presence of LEH. This research aims to see if individuals that have a higher amount of LEH in their dentition would have a lower mean age of death; the correlation between these two would indicate that nutritional stress in early stages of life causes complications at a later age (Brickley and Ives 2008, 9).

Doing so this thesis also aims to add to the research already conducted on LEH and its usefulness when compiling an accurate biological profile. Since LEH is a common occurring stress marker and teeth are among the most commonly found bones a correlation like this would provide a more in-depth look into past living circumstances for many datasets. Additionally adding context to a non-specific stress marker might help add data in order to understand the specific causes and distribution of these varying causes. Adding knowledge on the implications of this non-specific stress marker could be significant as its usefulness archaeologically is mainly hindered by the lack of specificity.

1.3 What are the recognizable patterns of LEH within the skeletal collection of Alkmaar?

Whether there is a distinguishable pattern to be found in the occurrence of LEH is a multi-layered question, so before this thesis is able to answer this question it has to divide it into smaller sub-questions. These sub-questions will be used to answer this main question while highlighting the different aspects of a question like this while also aiming to find smaller correlations within this topic. Analyzing the different aspects of LEH individually allows for a more careful analysis, this might prevent certain patterns and other differences to be overlooked.

1.3.1 What differences in LEH prevalence can be observed between men and women?

The first pattern to distinguish is done by looking at the presence or absence of LEH, e.g., is there a high prevalence of the condition in this particular collection? In doing so, the research aims to identify whether there is a higher prevalence than what normally would be expected. While looking at the occurrence of LEH a distinction should be made between men and women, this should be done to see whether there might be a significant difference between these groups.

The reason for this distinction is that the way men and women respond to some diseases and stress physiologically has been different in many cases, this does not directly have to do with sex but and can be due to workload or other social and cultural differences of the past. It is interesting to see whether there is recognizable variation within the research group, and the skeletal distinctions between men and women are both reliable and available.

1.3.2 What patterns can be observed regarding the age of individuals when LEH episodes occur and what differences can be observed between men and women?

Another aspect that will be studied within the skeletal collection is the age/ages at which LEH occurs. The way this can be recognized is by looking at the dental record of the collection and identifying which teeth have linear enamel hypoplasia. As stated previously, the specific age at which certain teeth develop allows for the identification of the age at which the condition occurs. Additionally more teeth with LEH present in an individual indicates multiple episodes of stress as well as strengthens the case for malnutrition. After the identification of the age at which this occurs, a distinction will once more be made between men and women to see if one is more prone to suffer from the condition at a specific age.

1.3.3 What is the correlation between LEH and longevity of life?

The last aspect this thesis aims to recognize is whether the individuals of the collection in which LEH occurs have a significant variation in age-at-death in comparison to those in which LEH is absent. Another comparison that will be made is the number of LEH to see if individuals with higher occurrence of LEH have a lower age-at-death. Men and women will again be analyzed separately. In doing so this research aims to identify whether there is an indication for the correlation between LEH and longevity of life.

1.4 Approach

To answer these questions a dataset will be used that was compiled from a skeletal collection excavated in Alkmaar. This data is from the burial site belonging to the Franciscan Monastery that stood in the city between 1448 and 1572. The skeletal remains from this collection have been analyzed and used in previous research. In this research by Dr. Schats (2016), a common stress marker found was LEH (Schats 2016, 137). For this research, dental data as well as data on sex and age will be entered into a database to make the data more accessible and easier to use. After this, the digitized database can easily be used to run statistical tests in order to identify possible significant differences that can be derived from the data.

The specific data point that were extracted from the previous archaeology forms were basic things like the site code, feature numbers and find numbers. The more important data from the forms that could be used in the statistical analyses were the age, sex, number of teeth recovers, the teeth types, presence of LEH, number of teeth with LEH, type of teeth with LEH, and lastly total number of LEH episodes.

1.5 Thesis Outline

In the second chapter, this thesis will provide background information and other contextual information on the formation of enamel and LEH. This will include the enamel formation, LEH formation, causes of LEH, and archaeological possibilities with LEH and lastly provide archaeological examples in which LEH provided context for the biological profile.

The third chapter will provide context on the site where the skeletal material was recovered from and the skeletal collection itself. The composition of the skeletal collection will be presented in addition to the selection criteria in order to show what skeletal material was considered usable for further research. This chapter will also talk about the differences between this research and the previous research, and will show how their data was translated into the database. Lastly it will show what methods were used when analyzing the data and how the statistical tests were chosen and used.

The fourth chapter will deal with the results found after analyzing the dataset and will address the different sub questions in order to be able to answer the main question. This chapter will consist mainly out of statistical tables, significance tests and correlational strength between different data points.

The fifth chapter will dive deeper into this data and will function as the discussion of the research. This will include both the interpretation of the data and comparisons between the found results and other research done. The research questions will be answered and further consideration will be given in order to improve future research and address the accuracy of this one.

The sixth chapter will be the final one and will present the conclusions drawn throughout the thesis. All the different research questions will be presented and the patterns found in the skeletal collection of Alkmaar will be shown. Finally, the thesis will present ideas on the focus of future research based on the results that came out of this one.

2 Linear Enamel Hypoplasia

Using studies conducted by multiple different archeologists and anthropologists, this chapter will present the essential background information on the processes behind linear enamel hypoplasia. First, the process of regular enamel formation in a case where there are no complications will be presented. This will allow for a better understanding of the next paragraph, which focuses on the formation and types of enamel hypoplasia. After this, the specific causes for enamel hypoplasia are explained in order to understand what it can imply archaeologically. Lastly, the chapter will highlight some of the work done in the field that forms the background for this and much of the other research conducted regarding LEH. Research conducted on LEH, timing of dental growth and its implications towards longevity and general health.

2.1 An introduction to enamel formation

There are many steps in the dental formation process, the earliest step is the formation of tooth buds and the process ends with the completion and eruption of the wisdom teeth in adulthood (Logan and Kronfield 1933, 384). A large part of the dental formation is the production of enamel, since both the deciduous teeth and the permanent teeth are protected by enamel. The enamel is the layer that forms around the tooth as seen in fig. 3; this layer protects the dentine of the tooth. The thicker parts of the layer can reach a 2mm thickness and slim down to 1mm or even less when the enamel wears down over time (Hillson 1996, 148).

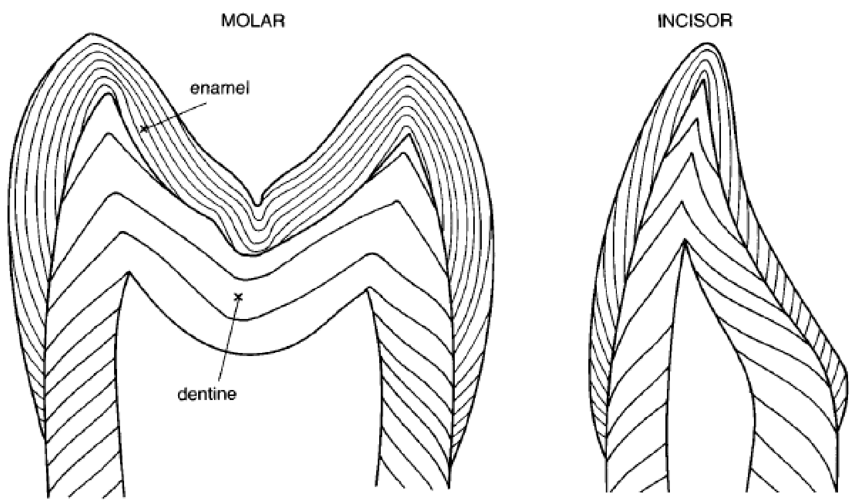


Figure 3: Enamel and dentine layers for a molar and an incisor (Hillson 1996, 120).

The enamel is produced in layers that are formed one by one in the infoldings of the enamel organ (Hillson 1996, 121). The enamel layers are composed of a non-cellular material, which is an inorganic compound, however its formation process is caused by cells, and these are called ameloblasts. These ameloblasts are created by the enamel organ (Hillson 1996, 118). The ameloblasts produce the enamel within the enamel organ, and in the first stage the enamel is still partly organic. In the second stage the enamel matrix matures and the organic component is broken down resulting in leaving only the inorganic component which is the finalized enamel that is almost entirely mineral (Hillson 1996, 148). However, complications often arise in the production of enamel, and one type of the disturbances that is frequently found is enamel hypoplasia. This condition emerges when the ameloblasts stop forming enamel, resulting in permanent stress-markers on the teeth. This is why enamel hypoplasia literally means the underdevelopment of enamel.

2.2 Formation and types of enamel hypoplasia

Enamel hypoplasias are a common occurrence and have been categorized in three separate groups; these defects have their own causes and characteristics. The short answer to the cause of linear enamel hypoplasia would be that the ameloblasts, the enamel producing cells, cease enamel production. At its core, this is the cause for all three types of enamel hypoplasia, in the next subchapter the causes will be explained in more detail (Goodman and Rose 1991, 106).

The first type of hypoplasia is plane-type defects, which cover large parts of a tooth with brown marks along with pitting (see fig. 4). The second type are called pit-type defects, these pits have a varying size and are found along with the third furrow-type, their size and patterning largely depends on the size of the furrows. The last type of enamel hypoplasia is the furrow-type, more commonly known as linear enamel hypoplasia (Hillson 1996, 167) and is the most common of the three types of enamel hypoplasia. These stress-markers can vary depending on the severity and the duration of the growth disruption. Commonly only one of these markers is found per tooth, but there are many examples where multiple episodes occur, causing more than one furrow/line to be observable on the crown of multiple teeth (Hillson 1996, 167).

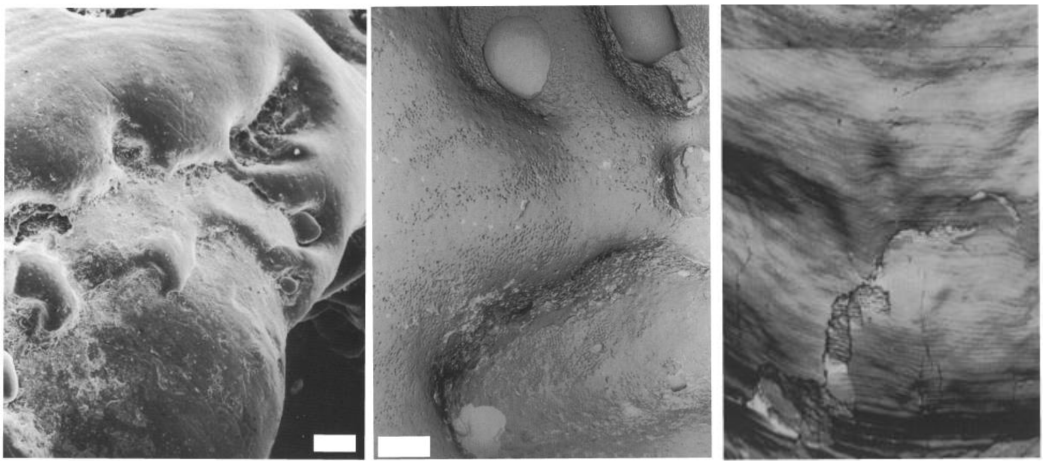


Figure 4: Plane-type, pit-type and furrow type enamel hypoplasia (from left to right) (After Hillson 1996, 168-170).

These furrows and lines will be visible in the dentition as long as the teeth do not deteriorate further; this is because there is a difference between teeth and other inorganic materials in the body. Unlike bone, the inorganic components of teeth are unable to repair or remodel after completion, this causes disturbances in the ameloblasts enamel production to remain visible. The permanence of these stress markers are thus an excellent source of data for bio-archaeologists to study as the cause of these stress markers can help reconstruct a person's biological profile. These disturbances can be retraced to an individual's infancy (when dealing with deciduous teeth) or their childhood (for most of the permanent teeth), the enamel of the wisdom tooth can grow up until twelve years old (Łukasik and Krenz-Niedbała 2014, 297).

2.3 The causes of linear enamel hypoplasia

The cause for these disruptions of enamel production is mostly thought to come from illness and nutritional stress during the formative years of these teeth (Martin *et al.* 2008, 362). The problem is that after the stress-markers have been created it is nearly impossible to retrace which specific factors lead to the ameloblasts ceasing production. This causes the enamel hypoplasias to be classified as non-specific stress markers, even though multiple probable causes are known. When analyzing the individual's teeth this means that determining the cause of LEH is near impossible, but studies have proven that in larger groups, the condition can statistically indicate which cause or causes were most likely (Boldsen 2007, 59).

Globally, systemic nutritional stress is the main cause of hypoplasias (Goodman and Rose 1991, 291) and only one of the three; the other two are hereditary anomalies and localized traumas. Hereditary enamel hypoplasia is generally not of the furrow-type, and affects the whole tooth. This form of hypoplasia is both the most severe and very rare and only affects less than a percent of the cases (Goodman and Rose 1991, 281). Tooth trauma is thought to be more common, but again less commonly observed in the form of LEH. In addition, local trauma usually only effects one tooth or teeth adjacent to the main trauma point, this makes it very distinguishable (Goodman and Rose 1991, 281). The last possible cause is systemic metabolic stress, most likely caused by either malnourishment or illnesses that cause metabolic stress. This type of enamel hypoplasia is most commonly observed alongside LEH, but in order for it to become visible, the nutritional stress must be systemic. There is even a linear correlation visible between the degree of malnourishment and the prevalence and severity of LEH (Hillson 1996, 166). Statistically this makes a strong case for LEH as indicator for nutritional stress and generally bad living conditions, while still being a non-specific stress marker (Goodman and Rose 1991, 291).

2.4 Timing of linear enamel hypoplasia

An important difference between the three types of hypoplasia is that the furrow-type/LEH is the only type where the location of the stress-marker directly reflects the period during which the episode occurred. Since teeth follow a systemic growth pattern, it can estimate the age of an individual at the time of the episode by looking at the location of LEH on the specific tooth (Goodman and Rose 1991, 281). The theory behind this has been in development for an extended period and there are a few different methods to time LEH.

LEH only reflects the period during which the teeth develop, any episode of LEH can only happen between the formative years of enamel. A lot of research has been done into the age at which teeth develop and this has led to age groups during which individual teeth grown (Read and Dean 2006, 329). Combining this with the presence of LEH this indicates a specific age group during which a possible nutritional stress episode occurred.

The crown of every single permanent tooth has a similar growth pattern as seen when looking at figure 5 and figure 6. The largest difference between the teeth is that they erupt and are grown at different moments, speeds and location (maxillary versus mandibular) (Hillson 1996, 128).

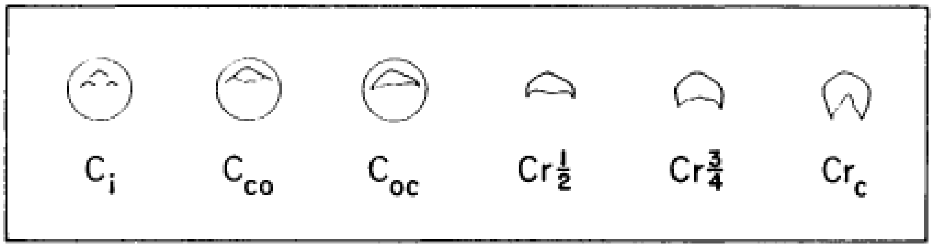


Figure 5: The stages of crown development of a single rooted tooth (after Hillson 1996, 128).

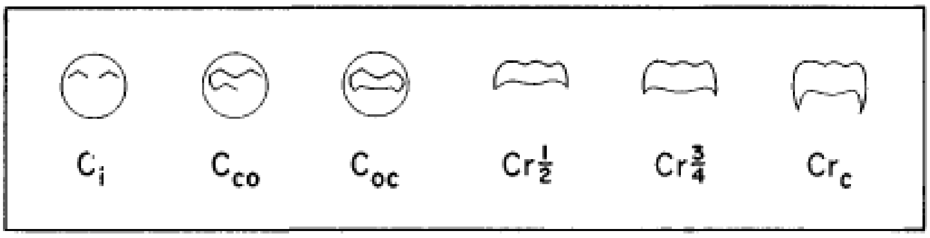


Figure 6: The stages of crown development for a mandibular molar (after Hillson 1996, 128).

Hillson (1996) along with Reid and Dean (2006) have conducted substantial research into the topic of variation in enamel formation times and LEH timing. Hillson's research is more dated and less focused on enamel formation specifically, but still is a valuable addition towards the timing of dental growth, especially since the research done by Reid and Dean only contains the incisors, canines and the molars (Reid and Dean 2006, 329). For this research, the estimation of the age at which the LEH episodes of incisors, canines and molars occurred is based on the research by Reid and Dean. However, for premolars, the age estimations of Hillson are still used. In the paper by Reid and Dean, estimates are provided that differ regionally. Different enamel formation periods are shown for northern American, southern African and northern European (Reid and Dean 2006, 343).These enamel growth age estimations are still rather broad and can span from two to five years.

An even more precise estimate of the age at the episode of LEH could be made if the dataset provided a more clear position of the LEH on the tooth. This is because the estimates of enamel layer formation can even give insight into which part of the enamel layer grew during a specific chronological age (see fig. 7). The height of the line indicating LEH can show at what specific moment during the enamel formation the stress episode occurred. The problem with this however is that it is a very time consuming task to measure the exact height of every stress episode and in addition to that, almost no previous research has records on the exact position of LEH. This method is more time consuming and is more suited for larger research projects.

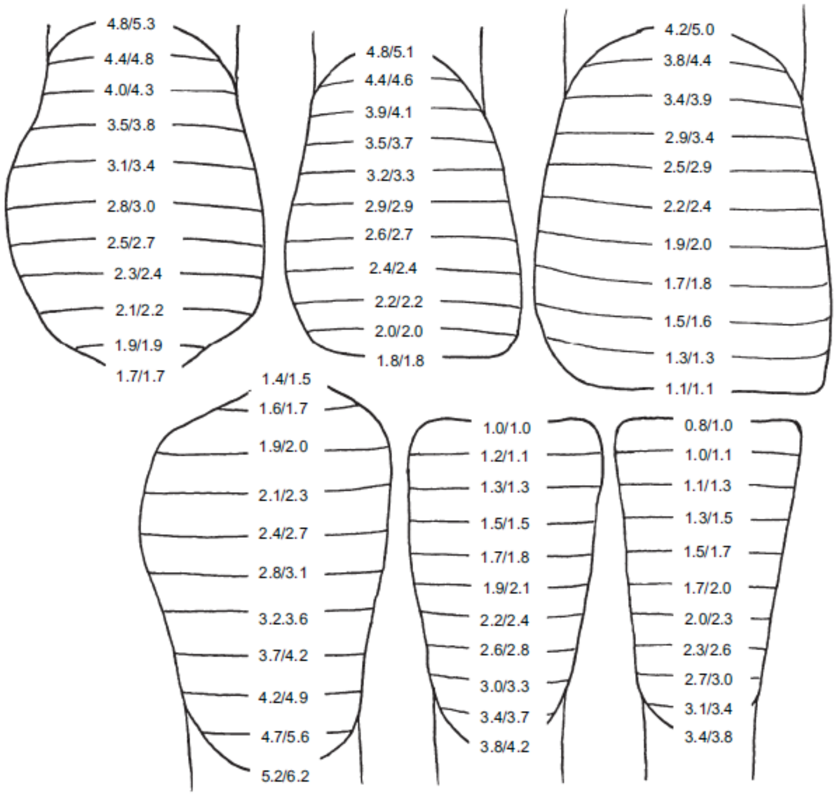


Fig 7: The mean estimates of the Chronological age for the anterior teeth, African sample vs. northern European sample (after Reid and Dean 2006, 343)

2.5 Archaeological Examples

LEH is a very common stress marker and thus a high degree of archaeological datasets, which include dental records, find LEH. This however does not mean that it is used in every analysis of these datasets; there is variation in the use of this data if at all and there is still speculation on what can be achieved with it archaeologically. Goodman and Rose (1991) wrote about the use of EH as a way to determine nutritional stress, but were aware of the many defects this method had, as there are many other possible causes (Goodman and Rose 1991, 291).

Read and Dean looked further into the possibility of using enamel growth to determine possible malnutrition, this research helped increase the accuracy and potency of EH analysis as an archaeological tool. In 2000, they released a paper in which they show that LEH can be used to time the episode during which the ameloblasts enamel production was disrupted (Read and Dean 2000, 135). They followed this research up in 2005 with a research containing over 700 teeth from both Africa and Europe in order to create an accurate timing of the period during which enamel growth is active (Reid and Dean 2005, 330). Their work can not only be used to determine the age at which a stress episode can occur but also to determine chronological age of an individual if the enamel is still being formed pre-death.

These techniques are still used today in papers and research, an example of this is the work done by Łukasik and Krenz-Niedbała (2013). They determined the ages of LEH formation by using the standard set by Reid and Dean by analysing the position of the LEH (Łukasik and Krenz-Niedbała 2013, 296). In doing so they were able to determine for 77 individuals during what age they suffered from LEH and thus possible nutrition and other possible causes.

Many other archaeological researches employ enamel analysis when reconstructing the biological profile, this thesis also focuses on a dataset that was analysed by Schats in 2016 using this particular method. In the dissertation this was one of the comparative criteria between three datasets (Schats 2016, 133). The prevalence of LEH was used to determine which of the three datasets were under more non-specific stress. In addition the research indicated that there might be a statistical significant correlation between a younger age-at-death and the presence of LEH.

3 Materials and Methods

3.1 The Alkmaar Skeletal Collection

The skeletal collection that will be examined throughout this research is native to the late medieval town that was Alkmaar in that day in age, these skeletons range from 1448 to 1572 AD (Schats 2016, 20). This collection can be seen as an urban depiction of the Netherlands in that time and will subsequently be interpreted as such in this thesis. This allows for further comparison between different data sets later on in the research.

The test pits were excavated in 2010 in the center of Alkmaar in what is known as the Paardenmarkt by Hollandia Archeologen. The cemetery where the skeletal remains were excavated was part of the Franciscan monastery that was founded in 1448 (Schats 2016, 28). Both the church grounds and the area around it were used as burial locations; these graves most likely housed both poor and wealthy citizens, however the graves reviewed in this thesis are of only the outside burial type. There is still documentation on these burials; this was prepared by the monastery and church clerks back in the 16th century and onwards. The documentation by the church states that people buried in the cemetery were most likely commoners (Schats 2016, 29). This means that the skeletal collection contains a variety of people and this makes for a better more realistic reflection of the 15th century society. During the excavation a total of 189 individuals were excavated.

3.2 Selection Criteria

Not all 189 individuals can be used within this research however, since there are a number of selection criteria that need to be fulfilled. These selection criteria are chosen in order to improve the overall accuracy of the results and are in place to prevent unnecessary work.

The first criterion the individuals need to fulfill is maturity, the collection comprises not just of adults but also includes children; these children however will not be taken into account when doing the research. This is because of two reasons, the first being that the distinction between men and women can often not be made in juveniles, thus part of the research questions cannot include these individuals. Secondly, their premature death does not reflect an individual's final dentition;

their possible malnutrition and other defects might have shown at a later age, and these individuals do not add to the question of longevity.

The second criterion has more to do with available dentition: if an individual is excavated with high amount of either post- and/or ante-mortem tooth loss they are not selected for this research. These individuals add no additional information to the research and could even skew the research as they affect the question of prevalence. For this research, we counted any individual with more than three teeth available; the teeth are only counted if they include both the root and crown of the teeth, as the enamel needs to be present.

The last group of individuals that was not suitable for the research has been excluded due to archeological reasons. These individuals were recovered from one or more mass graves, this made this particular group of individuals a less accurate source of information even though these individuals were recovered and reassembled to some degree. Apart from their burial condition, many of these individuals lacked the first two criteria, but the choice was still made to exclude them from the results.

These selection criteria are slightly different from those used in the previous research on this dataset by Dr. R. Schats. In the previous research, three anterior teeth needed to be present in order to gauge the presence of LEH (Schats 2016, 137). This means that the research will use the same minimum amount of teeth required as the dissertation by Dr. R. Schats (2016), but does not limit these teeth to being anterior. This difference in selection criteria causes a slight difference for individuals included in the results. Over half of the initial individuals fulfill the criteria and 101 are included in the end, this is three more than previously but there are 15 more adults (Schats 2016, 137). For most of the individuals age and sex has been determined which are both needed to answer parts of the research questions asked, making this collection particularly suitable for this specific research (Schats 2016, 138).

3.3 The Database

During the research the skeletal collection will not directly be examined, instead the data presented by Dr. Schats will be used. This however does not mean that the data will directly be copied and used. For this research, the raw data collected by Dr. Schats has been revisited and entered into a new database. This database is implemented so that it fits the research and it includes every aspect that is deemed important with regards to the research questions and past research. The database will be a crucial resource when working with and interpreting the skeletal collection, and it will be structured so that it allows the use of statistical analysis and comparison of the data in an organized and quick manner.

The information available on the biological profile of the skeletons has been entered individually. The data include feature number, find number, preservation, sex, age, the specific teeth that are found with them, the occurrence of LEH, the number of LEH, on which teeth the LEH is found, the total number of LEH episodes the individual went through and lastly the years these individuals are thought to have undergone the stress episodes. Age specifically was a difficult parameter as there is no exact age. This is why we parted the age into groups that mirrored those used by Dr. Schats (2016) in her research: young adult (18-25), young middle adult (26-35), old middle adult (36-45) and mature adult (45+). All of this information has been entered into an access database by using a data entry form and has been exported into an Excel sheet so that it can be manipulated and used in SPSS analysis.

3.4 Data Analysis and Statistics

In order to be able to analyze the data with a higher accuracy some of the data points were grouped. The first example of this was age; the main reason for this was that the data source had already grouped the ages in four groups. In two instances, the age groups had to be reduced to two for statistical accuracy. The age groups are 18 – 25 (young adult), 26 – 35 (middle young adult) 36 – 45 (late young adult) and 45+ (mature adult), and in the case where two age groups are used they are 18 – 35 and 35+. The lower amount of age groups can be needed since there can be a lack of individuals in the older age bracket, and the resulting small sample size can make some statistical tests inaccurate or even impossible to run. Another grouping that was made regarded the number of teeth with LEH, in order to run a specific test this was turned into a high and a low amount of LEH. The distinction between high and low in this case was based on the average amount of teeth with LEH.

In order to be able to analyze the data and its implications on longevity, the method developed by Hillson, Reid and Dean mentioned in chapter 2 was used.

By recording on which teeth LEH was found their methods allowed the research to record during which ages the stress occurred. However, in this research the European sample from Reid and Dean was used as it fits the excavation area better. In table 1 the exact enamel growth age ranges are shown, these are taken from both Hillson's research and the research by Reid and Dean.

Table 1: The chronological age during which maxillary and mandibular teeth grown as estimated by Reid and Dean (Read and Dean 2006, 329) (*the premolar estimated are taken from Hillson (Hillson 1996, 123). (UI = upper Incisor, UC = canine, UPM = upper premolar, UM = upper molar).

UI1	**UI2**	**UC**	**UPM1***	**UPM2***	**UM1**	**UM2**	**UM3**
1.1 – 5.0	1.8 – 5.1	1.7 – 5.3	1.5 – 6.0	2.0 – 7.0	1.3 – 3.0	4.3 – 6.3	9.3 – 11.4
LI1	**LI2**	**LC**	**LPM1***	**LPM1***	**LM1**	**LM2**	**LM3**
1.0 – 3.8	1.0 – 4.2	1.5 – 6.2	1.5 – 6.0	2.0 – 7.0	1.3 – 3.3	4.2 – 6.2	9.3 – 11.2

The data and the grouped data can be entered into the database and can be divided into a number of statistical categories; the two main categories are of the categorical and the numerical type. The presence or absence of LEH is an example of nominal data and the age groups are a good example of ordinal data. In addition to this there were groups of numerical data mainly measurement data, the amount of teeth of an individual would be a good example (Fletcher and Lock 2005, 1-5).

In this research the focus mainly lies on the analysis of the nominal data and often the measurement data is turned into nominal data for analytical purposes, the amount of teeth with LEH (measurement) is divided into two groups: high and low. This turns this measurement data into nominal data, which allows it to be used in the statistical Chi-squared test (Fletcher and Lock 2005, 129). Most of the data is already of the type that allows the Chi-squared test to be run.

The reason this test is chosen is because the data collected is not normally distributed, this means any of the tests which require normally distributed data are no longer available to test the hypotheses of the current research. Only non-parametric testing was appropriate for this dataset and the handbook of biological statistics was used to decide the type of non-parametric test used in every null hypothesis. The main goal of working with these statistics is to discover if there are any patterns observable that significantly differ from the norm. In order to do this a null hypothesis is made, this hypothesis decides what you want to test.

This hypothesis usually states there is no difference between x and y and along with this null hypotheses another hypothesis is made that states that x and y are different. To decide which hypothesis is right a test is ran that provides a p-value, if this value is low enough the null hypotheses is assumed wrong and the alternative is accepted (McDonald 2014, 22). In this research, the p-value needs to be lower than .5 to prove a significant result. All of these tests are run in IBM SPSS 21.

4 Results

This chapter will analyze and present the data that was found after compiling all the eligible individuals from the skeletal collection. Due to the good preservation of the site, a sizable portion of the 189 retrieved individuals could be used for the analysis. However as previously mentioned, only adults were taken into account for the research since for these individuals the dental records are available and sex and age estimation is possible. Of the 189 individuals, 165 were adults and 101 of those were eligible for the research. The datasheets provided by the previous research contained data on the sex and estimated that 55 of these 101 individuals were female, 41 were estimated male and the last five were too ambiguous to estimate.

4.1 Prevalence of Linear Enamel Hypoplasia

The first thing investigated was whether the number of teeth was in line with the expected number of teeth. Since the dental formula is 2.1.2.3, the expected count follows the percentages as visible in table 2. The teeth appear to be represented in a correct and expected fashion although the molars are slightly under represented. This however could also be because not every person has third molars as these are commonly congenitally absent (Hillson 2005).

Table 2: Number of teeth available for study categorized in tooth type.

Tooth type:	Excavated	Percentage	Expected
Incisors	490	25.7%	25%
Canines	272	14.3%	12.5%
Premolars	541	28.3%	25%
Molars	605	31.7%	37.5%
Total	1908	100%	100%

Of these 101 individuals suitable for the research, there was a 68.3% prevalence of LEH and a 31.7% absence; this means that 69 of the 101 individuals had visible LEH. It is to be expected this percentage would be even higher if more teeth were excavated, as the total teeth recovered is around 60%. Some of the 32 individuals with complete absence of LEH could have had the stress-marker on these missing teeth.

4.2 Linear Enamel Hypoplasia and Sex

Of the 69 individuals with the LEH stress-marker, sex could be estimated for 68 individuals. Of those 68 with LEH, the larger part consisted out of females. In total 39 of these individuals were estimated to be female and the other 29 male. When these numbers are compared to the total number of males and female in the sample their presence is almost identical, 70.9% of females and 70.7% of males had LEH (see table 3). The total amount of LEH was slightly lower since most of the undetermined individuals had no LEH (possible due to relatively poor preservation). As expected when looking at these percentages there was no statistically significant difference between the two ($\chi 2=0.000$, $df=1$, $p=0.985$, $n=96$), if anything the degree to which they were similar strongly indicated the absence of any kind of correlation between sex and LEH. To further cement this hypothesis, a Chi-squared test was also ran for just middle young adults and young adults leading to a similarly insignificant result ($\chi 2=2.834$, $df=1$, $p=0.092$, $n=96$). Although in this case the numbers are closer to a correlation, indicating that there could be trends within age groups and sex, there still is no significant difference within this dataset. This increase in correlation will be further examined when looking at age-at-death and LEH as it more fits that sub-question.

Table 3: A cross-tabulation between sex and LEH observed within the dataset.

Sex and Linear Enamel Hypoplasia					
			LEH		
			Absent	**Present**	**Total**
Sex	**Female**	**Total**	16	39	55
		% Total	29.1%	70.9%	100.0%
	Male	**Total**	12	29	41
		% of Total	29.3%	70.7%	100.0%
Total		**Total**	28	68	96
		% of Total	29.2%	70.8%	100.0%

4.3 Timing Linear Enamel Hypoplasia

Within the population, the majority of LEH was observed within the early formative years, as visible in table 4, table 5 and table 6. Part of the reason for this could be because there is overlap in the determination of LEH timing, since many of the teeth share age rages. However, even with that in mind there is a clear difference visible in the later years as the amount of LEH decreases from year two and is almost halved when the age reaches six. The total percentage of individuals having episodes of LEH goes from 65% to 36% during year 6, which is a 45% decrease in the observed amount of LEH. The timing of LEH is especially high from year two to year four; 94–97% of the individuals with observable LEH showed the stress-marker. This difference is even larger when comparing men to women, as 90 – 95 % of the women with LEH showed signs of the stress-marker during year 2 and year 4, while the prevalence of LEH during these years in men was 100% and 71% of the male dataset respectively. The specific trends between women and men become even more visible when looking at table 5, which shows the same information as presented in table four but visualizes it. In women, the episodes of LEH occur more frequently at an early age but there is hardly any increase after year 1, the prevalence is also more consistent during the first five years and even persists between the ages of nine to eleven. When looking at men on the other hand there is a more explosive increase from year one to year two, which lasts to year five, after this the episodes of LEH decrease rapidly.

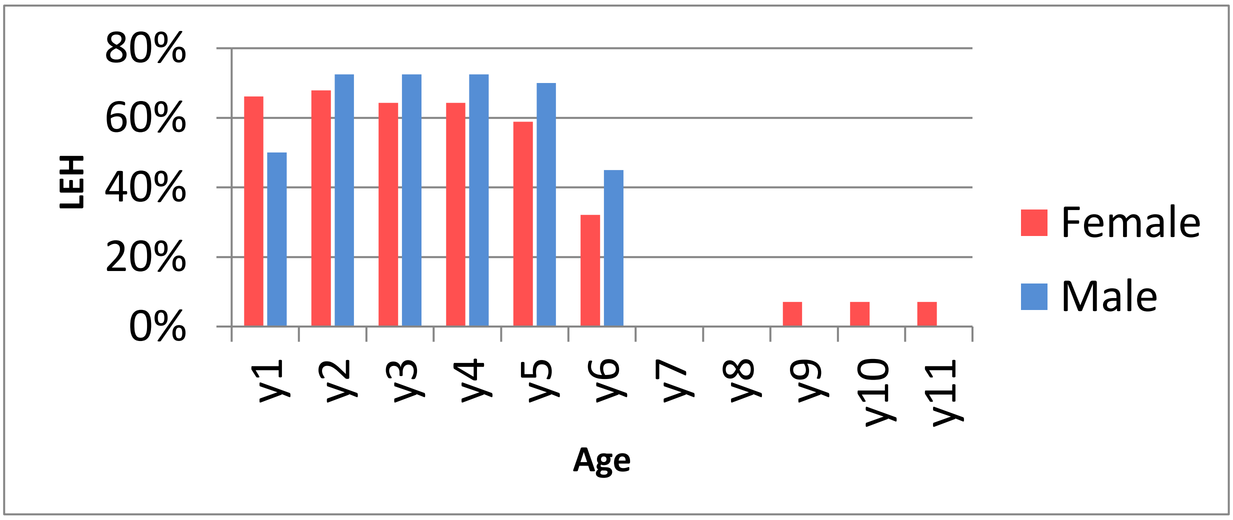
Table 4: A table showing the number and percentage of individuals that suffered from LEH and the chronological age at which these episodes occurred (Y=year).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
Female	36	37	35	35	32	18	-	-	4	4	4
% of Females	66%	67%	64%	64%	58%	32%	0%	0%	7%	7%	7%
Male	20	29	29	29	28	18	-	-	0	0	0
% of Males	49%	71%	71%	71%	68%	44%	0%	0%	0%	0%	0%
Total	56	66	64	64	60	36	-	-	4	4	4
% of total	55%	65%	63%	63%	59%	36%	0%	0%	4%	4%	4%

Table 5: Estimation of the timing of the LEH episodes both displayed as grand total and as the percentage compared to the total amount of cases of LEH for male, female and both.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
Female	36	37	35	35	32	18	-	-	4	4	4
% of Females	92%	95%	90%	90%	82%	46%	0%	0%	10%	10%	10%
Male	20	29	29	29	28	18	-	-	0	0	0
% of Males	69%	100%	100%	100%	97%	62%	0%	0%	0%	0%	0%
Total	56	66	64	64	60	36	-	-	4	4	4
% of total	82%	97%	94%	94%	88%	52%	0%	0%	6%	6%	6%

Table 6: A bar chart showing the chronological age at which individuals suffered LEH.



4.4 Age-at-Death and Linear Enamel Hypoplasia

The age-at-death could be estimated for 96 individuals of whom 67 were affected by LEH, the age groups were consistent in size as seen in table 7, but the 36 – 45 age group is larger than the rest while the 45+ age group is a lot smaller than the other three, possibly due to a lower life expectancy. When looking at the relation between estimated age-at-death and the presence of LEH a trend becomes visible, in which a higher prevalence of LEH is visible in individuals that died at a younger age. In young adults, this prevalence is 85.7% and goes down to 71.4% in middle young adults, while being the lowest at 52.8% in late young adults. This difference in percentage of LEH is statistically significant and can be interpreted as a positive correlation between a younger age at death and the presence of LEH ($\chi 2=9.831$, df=4, $p=0.02$, n=96).

When looking at the total amount of episodes of LEH this hypothesis becomes even stronger, this is visualized in table 8. This table shows the percentage of individuals that had no or a lower than average number of LEH versus the individuals with higher number of LEH then average. This is then compared against two age groups, A young and an older age group, these range from 18 – 35 and 36+, the percentage show that the amount of individuals with higher than average LEH decreases by almost 50% in the older age bracket. The difference between these two age groups is statistically significant ($\chi 2=6.417$, df=1, $p=0.011$, n=96). This correlation is stronger than when previously looking at just the presence and age. This method restricts the number of age groups and gives a more general picture, but makes up for this by taking the number of stress episodes of the cases into account.

Important to note is that this difference can also have been caused by a lower amount of teeth in older individuals as the dentition has preserved in varying amounts. The difference in retrieved teeth is significant ($\chi 2=19.814$, DF=6, $p=0.006$, n=96). This significance is also observed in the previous analysis of the dataset (Schats 2016, 138). This means that the difference in the retrieved amount of teeth can skew the research, as the older age groups tend to have a lower amount of dentition available to analyze. However, table 9 shows there still is a large difference in the percentage of LEH prevalence even when taking into account that older individuals had less teeth when recovered. This is shown by the decrease from 53% to 38% in percentage of LEH of the recovered teeth, the percentage of teeth with LEH was unexpectedly high in the age group of 36 – 45; an explanation for this might be the presence of individual outliers that raise the amount of LEH significantly.

Table 7: A cross-tabulation showing the prevalence of LEH within specific age-ranges, while also displaying the expected count to show how much the presence deviates.

Age and LEH					
			LEH		
			Present	Total	%
Age	18 – 25	Count	18	21	85.7%
	26 – 35	Count	20	28	71.4%
	36 - 45	Count	19	36	52.8%
	45+	Count	10	11	90.9%
Total		Count	67	96	96

Table 8: A cross-tabulation between two age groups and the frequency of LEH episodes including an expected count to visualize possible deviations.

Age and high amounts of LEH					
			Teeth with LEH		
			0 – 6	6+	Total
Age	18 – 35	Count	23	26	49
		% of Total	46.9%	53.1%	51,0%
	36+	Count	34	13	47
		% of Total	72.3%	27.7%	49.0%
Total		Count	60	36	96
		% of Total	59.4%	40.6%	100.0%

Table 9: statistics regarding the amounts of teeth recovered and the amounts of LEH observed.

	Average number of teeth recovered	Average number of teeth with LEH	Average number of episodes of LEH	Average number of episodes per tooth with LEH	Percentage of recovered Teeth with LEH
18 – 25	22.0	11.8	20,1	1.71	53,4%
26 - 35	21.1	9.4	14,7	1.57	44,3%
36 – 45	17.8	9.2	16.1	1.76	51,4%
45+	14.1	5.4	9.6	1.78	38,3%

When trying to compare the correlation between estimated age-at-death and the presence of LEH in men and women a change needs to be made to the age group, this is because when the Chi-squared test is run with the four original age groups the sample size becomes unreliably small. To achieve a reliable sample size the age groups were combined into 18 – 35 and 36+, as was done in table 8. The results of this are seen in table 10 and table 11: 85.7% of females in the 18 - 35 age category had LEH present in their dental record, for males this was 65%. Males on the other hand had a larger portion of LEH present in the 36+ category, but overall the prevalence of both groups is around 70%. The difference in LEH presence between younger and older males is only 15% and there is no correlation to be found in the prevalence of LEH for these age groups ($\chi2=1.129$, DF=1, $p=0.288$, $n=40$). However, this difference becomes larger when you look at the female sample: for this group the difference is slightly above 30% and after employing the statistical test there is an indication that there is a strong correlation between the presence of LEH and the age of women ($\chi2=6.266$, DF=1, $p=0.012$, $n=52$).

Table 10: a cross-tabulation of age and the presence of LEH in female individuals.

Female			Teeth with LEH		
			Present	**Total**	**%**
Age	**18 – 35**	**Count**	24	28	85.7%
	36+	**Count**	13	24	54.2%
Total		**Count**	37	52	71.2%

Table 11: a cross-tabulation of age and the presence of LEH in male individuals.

Male			Teeth with LEH		
			Present	**Total**	**%**
Age	**18 – 35**	**Count**	13	20	65.0%
	36+	**Count**	16	20	80.0%
Total		**Count**	29	40	72.5%

5 Discussion

The primary goal of this thesis has been to observe and uncover the different patterns that can be found within the LEH distribution of the medieval Alkmaar dataset. This chapter will function as the interpretation and discussion of the resulting data and aims to explain the patterns and correlations found in order to answer the research questions posed in this research.

5.1 Observed differences between men and women in LEH prevalence

After analyzing the data regarding the sexes, the degree of LEH between men and women seems very balanced, both having a ~71% prevalence of LEH in their dental records. This seems to be in agreement with the previous research done by Dr. Schats (2016) where 56% prevalence was seen for men and a 73% for women within the same dataset (Schats 2016, 138). The difference between the researches in male LEH prevalence is 15%, this might seem large but both of these are not significant. The difference in statistics is due to a deviation in the research criteria, as Dr. Schats (2016) research is somewhat more restrictive in grouping the individuals into male and female. Initially both of the statistical analysis however does not point towards a correlation between sex and LEH prevalence.

In previous research by S. Łukasik, M. Krenz-Niedbała (2014) a similar result was found, in their research the prevalence was 46.4% for men and 55.1% for women. Both of these results were also found to be insignificant (S. Łukasik, M. Krenz-Niedbała 2014, 301). This 8.7 % difference is smaller than the 15% difference observed in the research done by Schats (2016), but larger than the difference observed in this research. This type of distribution is further reinforced by a research conducted by Tomczyk *et al.* (2012), where a 15% male and 10% prevalence was found, comparatively this is the largest difference but this still is not significant (Tomczyk *et al.* 2012, 65). The prevalence itself is something that heavily varies between sites, ranging from 71% to 12% in these studies alone, but the comparative distribution between sexes however does not. The other LEH distributions all fall within the range of being insignificant and the results found in this data analysis fall in line with those previous researches.

5.2 Patterns in the timing of LEH and the observable differences between men and women

The dataset provided the exact number and type of teeth that were affected by linear enamel hypoplasia, when combined with the timing techniques developed by Reid and Dean and the older timing provided by Hillson an image could be developed reflecting the ages during which LEH occurs most frequently for the Alkmaar dataset.

This data could help identify during which ages the research subjects were most prone to LEH. The data analyzed on timing of LEH shows that the majority of the LEH cases for both male and female occur during the ages two to three with a prevalence of 97%, this majority continues into the ages three to four and from four to five were there still is 94% prevalence of the LEH. For males, the high number of LEH cases continues into five to six years old, with 97% prevalence. In contrast, females have 92% of the LEH cases also occurring during the ages of one and two. This could be interpreted as female individuals having higher chance of suffering from malnutrition from their first year on, as reflected in their dental records but being less prone to the stress marker during year two to year six, while a few individuals remain to suffer from LEH even into their teens. Males start of being less impacted by LEH and suffer most cases during the period from year two to year four, after which it stops being seen in the dental records. Meaning that malnutrition is most common around ages two to four, after this it becomes less frequent or at least is no longer as observable in the dental record.

This result is in line with previous research done by Miszkiewicz (2015); in her research the mean hypoplasia formation age was 2.5 years old in the first area and 3.2 in the second (Miszkiewicz 2015, 83). The dataset used to compare came from a medieval priory cemetery from Canterbury (UK), which is a similar dataset to the medieval cemetery of Alkmaar. These age ranges fit very closely with those presented in this research, although they are more precise then the result produced by the analysis in this paper. The reason for this spike might be the switch from weaning to post weaning as this can often lead to nutritional fluctuations (Miszkiewicz 2015, 83).

A different result however was found in a research done by Berbesque *et al.* (2018), in this study an early archaic hunter and gatherer group was analyzed. The mean LEH formation time that was found in this research was 4.18 years old, which is later than the other researches (Berbesque *et al* 2018. 5).This however could be because the weaning ages vary within these hunter-gatherer societies and for the late old world the mean age for weaning is 3.2 years old (Berbesque *et al* 2018. 6). This means that the same hypothesis for high amounts of LEH during this nutritional transition period could still be a cause.

The third research I compared this data to, was compiled by Nause (2010), the dataset was from a roman site dating back to the first to the fourth century AD. The data in this set had the same peak distribution, the peak occurs from the 2.75 year to the 4.75 year (Nause 2010, 94). For the most part the research its results coincide with those found in this paper, the peak lasts a little longer but most of the data overlaps. The same increase and decrease is observed where up until the third year the amount of LEH increases and afterwards it gradually decreases (Nause 2010, 116). This research once again argues that this distribution might be due to the nutritional stress that is experienced to a child when introducing it to new foods after weaning. During weaning this stress might occur when the infant loses the benefits from breast milk (i.e., passive immunity or the nutritional value) (Nause 2010, 116). This notion that weaning causes a disruption in the nutrition reoccurs in all of the papers used a comparative material and is indicated as one of the main causes for the spike of early LEH.

5.3 The correlation between age-at-death and presence of LEH observable in the osteological record

When analyzing the data on presence of LEH in specific age groups a positive correlation was observed; the individual with a lower estimated age-at-death had a higher prevalence of LEH in their dentition and having. This indicates that the stress that caused the LEH influences longevity as the life expectancy of people with LEH is lower. The correlation found between age-at-death and LEH is significant, but the significance was not as strong as observed in the previous research on the dataset, now being p=0.02 compared to p=0.007 respectively. This deviation is caused by the 15 extra individuals included in this statistical analysis (Schats 2016, 138). Because many of these 15 individuals were in older ages groups they had a higher number of ante-mortem tooth loss, the difference in significance thus might have been caused due to the lower amount of teeth found in these older individuals. The difference in tooth frequency might skew the research making it seem like a lower amount of LEH is present in more mature age groups simply due to an absence of osteological records rather than an actual significant decrease. The difference in recovered tooth as is also shown as being highly significant, indicating that this is a concern that needs to be taken into account when making an interpretation. However, when comparing the percentage of the LEH in recovered teeth a large difference is observed, as 53% of the teeth found in individuals with an estimated age-at-death of 18-25 suffered from LEH and in the age-range 45+ this number goes down to 38%. In addition to this, there are fewer individuals in this age category so this age group might have been skewed by one or two extreme outliers in the dataset. These two statistics are at odds and make it difficult to determine to what degree the correlation between age-at-death and the presence of LEH are impacted by the difference of varying age groups their dental preservation.

In research done by Boldsen on a Danish medieval village from the 11th to 14th century similar trends were observed, a correlation was found on younger age-at-death and the presence of LEH in their dentition (Boldsen 2007 62). The same trends are also found in the research by Nause (2010) who concluded that based on the LEH episodes, sub-adults who undergo chronic and repeated stress die at a younger age (Nause 2010, 112). The research by Nause (2010) however also indicates that individuals who survive severe episodes of stress might be able to do so as they are better equipped to deal with these episodes. The individuals that only have a few or single severe episodes in her research have a higher age-at-death. The individuals who cannot deal with these severe stress episodes would perish and thus not show the severe episode in their dentition (Nause 2010, 113). LEH as a stress indicator affects longevity if it is chronic and repeated, in Nause's research this is also reflected as these individuals have a considerably lower estimated age-at-death (Nause 2010, 113). This does not mean that LEH does not affect the 'strong people' their longevity, it simply means that these people were healthier or genetically stronger to begin with and would have probably been even healthier if they had not suffered these stress episodes. It is important to note however, that it is systemic LEH that is thought to affect longevity the most, and not just single cases of LEH.

After observing the correlation between age-at-death and LEH, it was interesting to see whether the same correlation could be found between age-at-death and the number of cases with a higher than average frequency of LEH in their dentition. This hypothesis was tested and the significance was even stronger then when looking just at age and LEH, these numbers being p=0.02 and p=0.012 respectively. 51% of the individuals within the 18 – 35 suffered from a higher than average amount of LEH while for the 36+ group this number was 27.7%. The 18 – 35 age range almost has double the number of High frequency LEH cases compared to the 36+ bracket. This is coincides with the idea that systemic LEH affects longevity more than single episodes mentioned by Nause

Further into the statistical analysis however a pattern is recognized when comparing the prevalence of LEH between the sexes, this is observed when looking at the differences in prevalence of 18 – 35 year old males and females compared to individuals older than 35. This pattern indicates there is a statistically significant amount of LEH present in women between the age of 18 and 35. Similar patterns can be observed in a research by Šlaus (2000), in which a Croatian late medieval dataset shows higher frequency of LEH can be recognized in young female adults (Šlaus 2000, 201). Possible reasons for this could be that younger women are more prone to suffer the after effects of the LEH from their youth; this could be due to the impacts of childbirth and weaning as it is strenuous process. The meaning of this correlation is difficult to understand however as there are many cultural and biological factors that can affect this. Men and women deal differently with environmental stress; they can be exposed to varying amount of physical stress due to cultural preferences, etc. (King *et al.* 2005, 556). Because of this, significant differences have been found where both men and women have more LEH (King *et al.* 2005, 556). The reason young women in the Alkmaar skeletal collection are more affected by systemic stress indicated by LEH is a topic for another research.

5.4 Considerations for Further Research

Ideally, when researching datasets a hands-on approach would possibly prevent certain problems from arising, in addition it would allow for some more in depth analysis on the material used within the research. In the case of this research topic, it would have been possible to employ the newer LEH timing techniques developed by Reid and Dean possibly greatly increasing the ability to retrieve information on the most common ages at which these stress episodes occur (Reid and Dean 205, 331). However, this type of analysis would have gone beyond the scope of a bachelor thesis, for a research of that scope this work could function well as the basis as this thesis holds a lot of the basic information as well as a database. More time and the hands-on approach would have made it possible to make some additional photo-documentation and record some more precise measurements that would be specifically be useful to the timing of LEH episodes in this research.

This is because there are a few issues with the timing; these are mostly to do with the methods used to determine the timing. One of these problems is that the age-ranges of each tooth imply are relatively broad, as illustrated in chapter 3.3. This becomes apparent when looking at the slightly older methods used to determine the timing of LEH developed by Simon Hillson, the age-ranges indicated by the maxillary and the mandibular premolars range from one year old to seven years old. This can cause an age determination to be less clear, so in future research maybe not taking this tooth into consideration at all when timing the LEH would be wise.

To improve the accuracy of the data the first course of action would be to exclude the premolars from the dataset, as the age-ranges they indicate are too broad, by removing these from the data less overlap would be present in the data making for a less general conclusion. In addition to this, the canine can still be used as an indicator of LEH for year six so data can still be collected for this age, so there is no large loss in source of LEH timing. Without the premolars, the research could also start using the more specific timing that was developed by Reid and Dean can be used as shown in chapter 3.3. By looking at the specific location of each episode of LEH, a more precise age determination at the time of the LEH episode would be possible; however, this process would be more intensive as it would require more research into the dataset as the Alkmaar dataset is still lacking the exact location of the LEH episodes.

Additionally, the only tooth that can actually be used to determine LEH after year six is the third molar as the enamel develops between the ages nine and twelve, but this is also problematic as this tooth is often missing from the osteological record. A way to solve the underrepresentation of the third molar might be to count its frequency individually and determine what the expected frequency would be in order to weight it against other teeth with LEH. At this moment only the total of all three molars combined is present in the dataset making it impossible to weight, but in following cases, counting the third molar apart is recommended. This would allow an estimate to be made on the amount possible malnutrition between the ages nine and twelve by weighing the third molar.

6 Conclusions

The aim of this thesis was to identify recognizable patterns of LEH within the skeletal collection in Alkmaar in order to add to the previous research on both this region and the general topic of LEH. In order to answer this question the research was confined to three sub-questions. First, what differences in LEH prevalence can be observed between men and women? Secondly, what patterns can be observed regarding the age of the individual when LEH episodes occur and what differences can be observed between men and women? Thirdly, what is the correlation between LEH and longevity of life? After digitizing the data recorded in the past, the research was able to run statistical test that were similar to other statistical analysis done on the subject in order to compare these and give context to the results. In doing so, the research questions were answered successfully to a high degree.

6.1 What differences in LEH prevalence can be observed between men and women?

After analyzing the differences between both sexes, it became apparent that the skeletal collection of Alkmaar followed the same trends as the other researches reviewed in this thesis. This means that there are no significant differences found between males and females in the prevalence of LEH in their dentition. There is a 71% prevalence of LEH for both the men and women in this dataset, this is the most evenly divided dataset compared to the other researches mentioned, however they all share that this is an insignificant correlation so these differences are negligible.

6.2 What patterns can be observed regarding the age of individuals when the LEH episodes occur and what differences can be observed between men and women?

Within the skeletal collection of Alkmaar, there are multiple trends visible regarding the mean age at which LEH occurs. The highest number of LEH episodes occurs during the individuals their second to fourth year. During these three years there is a 97%, 94% and another 94% prevalence during the second, third and fourth year respectively. Additionally there is a trend visible in which females have higher rates of LEH in the first year, but men have a higher amount of LEH from the second until the sixth year of age. The differences between men and women however are too small to be significant. The trends visible in the timing of LEH of this skeletal collection is similar to a few other researches, these researches have a consensus on what the possible cause is for this spike in early LEH prevalence. The cause for LEH during year 2 to four might be due to the nutritional imbalance that is caused by switching from weaning food to normal nutrition. This switch leaves the children prone to both disease and malnourishment, these can both lead to the formation of LEH.

6.3 What is the correlation between LEH and longevity of life?

The last question gave yielded a more complex answer than those before as there was a more multilayered analysis needed to come to a conclusion. The statistical tests showed that there was a clear correlation between a younger age-at-death and the presence of LEH, this idea was supported by the other researches done on the topic. The hypothesis was that the individuals who had systemic LEH, meaning a higher number of reoccurring LEH episodes, would be most affected. The test that was ran to look into these individual with higher amounts of LEH then average, in order to test if these individuals with systemic LEH were even more prone to perish at a young age. This test showed an even stronger correlation, these results mirrored those of other past researches. Lastly, a test was run to determine if there was a difference between age groups and sex, these tests showed that the women of the medieval Alkmaar were significantly more likely to die at a younger age when LEH was present then the men of Alkmaar. The cause for this is still to be determined and is likely due to a mix of both cultural and environmental factors.

6.4 What are the recognizable patterns of LEH within the skeletal collection of Alkmaar?

By answering these three questions, it has become apparent that there are multiple different patterns recognizable. These patterns show that the distribution of LEH has implications on the biological profile of the effected individual, for the skeletal collection of Alkmaar this means that mean and women will be expected to have the same prevalence of LEH. The episodes that are observed in the dataset mostly occurred between the individuals their second and fourth year, the cause of these episodes are thought to be due to the nutritional stress that is caused when the weaning process is stopped and the children switch to other food sources. The long lasting effects of these episodes of stress are determined to be significant, especially if they are frequently reoccurring. A significant correlation was shown between the both the presence and degree in which LEH is present and the life expectancy of an Alkmaar individual. This means that the Alkmaar population its longevity was affected and lowered when LEH occurred. These different patterns all help reconstruct the Alkmaar past and add to the research that has been finished on LEH, these however are only a few of the patterns that can be recognized and some of these patterns result in new questions.

6.5 Future Research

In answering the question on patterns regarding longevity a new question was raised, why is the presence of LEH so much higher than in the other age and sex groups. As was stated the reason for this might be multifaceted and to do so would be a completely new research also focusing on the cultural aspects of the medieval communities of Alkmaar. This would be too large a question to answer with certainty in this thesis and thus would be interesting for future research.

In future research it would also be interesting to see whether analysis based on the methods developed by Reid and Dean would change the distribution of LEH timing as a more specific age timing can be drawn from that. This might give a more detailed and precise distribution of LEH and at which ages it occurred, just as seen in the other researches, which were used to compare the thesis to. This would be a time consuming practice however and is more in line with a master thesis rather than a bachelor, but could be interesting to explore further.

Another topic worth investigating in the future is the correlation patterns found around individuals with a higher than average frequency of LEH episodes. Patterns already became apparent during the data analysis, and there are definitely more pattern to be found. In this thesis the only thing looked at was the amount of teeth with LEH, other criteria that could be interesting to compare and test are the number of LEH episodes, or even find ways to compare severity of episodes by measuring the length of the disruption of enamel production. This would allow identifying what the differences implications on longevity are between severe and less severe malnutrition on the estimated age

Abstract

The patterns of LEH thus far recognized within the skeletal collection of Alkmaar have produced significant results regarding multiple topics: the differences in distribution of LEH patterns between men and women, the timing of LEH episodes and between the age-at-death and the prevalence of LEH. Within this dataset, there is no significant difference recognized between males and females regarding the prevalence of LEH, this stress-marker occur in the same frequency for both sexes. This however does not mean that there are no differences observed between men and women in the age distribution of LEH and the timing of the LEH episodes. The female individuals found in Alkmaar tend to suffer from malnutrition from a younger age then the males and the prevalence of LEH lasts longer, for some individuals into their early teens. Males however have a higher prevalence of LEH then females after the age of one, but there are no signs of LEH in males after six years old. Lastly, the patterns recognized when analyzing the correlation between LEH and longevity of life seems to indicate a connection between the presence of and an increase in risk of dying at a younger age. This risk seems to increase in individuals that have severe LEH where multiple markers of malnutrition episodes are present, this correlation between childhood health events and its impact on health at adulthood can be used when constructing the biological profile of individuals if investigated properly. LEH has proven to be a rich source of information that can provide a useful insight into the Alkmaar dataset, but more research into the dental records will be needed in order to properly understand and explain the significant patterns presented in this thesis.

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Figures

Tables