# STANDING TALL:

## *Enhancing Stature Methodology through the Study of Health and Stature in Early Medieval Southern Britain*

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# Abstract

The stature reached in adulthood is a product of the net-nutritional intake during an individual's formative years, subtracted by external demands, e.g., excessive physical labour, diseases, and environmental factors. This means that a population's mean stature index serves as an invaluable source that can be utilized as a proxy for the health status of said population, past or present. Previous stature studies focusing on the early medieval period have relied on stature formulae developed on unrelated modern populations, with the most commonly used being developed on 20th-century North American populations. Yet stature is not only a product of nutritional intake, minus demands but is also an artefact of genetic predisposition and secular stature trends. Hence when using a formulae developed on modern populations, and applying it to past populations, only tentative results can be achieved, for no conclusion can easily be drawn if these two temporally and geographically unrelated populations share genetic predispositions towards the stature achieved in adulthood, or for that matter, have experienced similar secular stature trends.

This study aims to address this issue, by calculating stature formulae directly on British early medieval populations utilizing two methods, the anatomical and the regression method. These new stature formulae will allow more valid stature results and will allow for a more confidant discussion of the health status of populations of the early medieval period in greater detail than past studies that utilized borrowed formulae.

Another challenge faced in the study of stature estimation is the didactic debates regarding the methodology. Through the process of producing new stature formulae for the British early medieval period, a further discussion of stature estimation methodology can be put forward. This discussion will codify, and establish which approach produces better and more reliable results, but will furthermore allow for a problematization of the limitation of the methodology.

**Keywords:** *Stature Estimation, Regression Method, Anatomical Method, Early Medieval Britain, Biostatistics, Genetic Predisposition, Secular Stature Trends*

# Abstrakt (Swedish)

Kroppslängden som uppnås i vuxen ålder är en produkt av nettonäringsintaget under en individs barndom, subtraherad av externa faktorer, t.ex. krävande fysiskt arbete, sjukdomar och deras närmiljö. Detta innebär att en befolknings kroppslängdsmedelvärdesindex är en ovärderlig informations källa som kan användas i analysen av en befolknings medel hälsotillstånd, i dåtid och nutid. Tidigare kroppslängds studier med fokus på den brittiska tidigmedeltiden har förlitat sig på matematiska kroppslängds formler som kalkylerades på orelaterade moderna populationer, formler baserade på 1900-talets nordamerikanska befolkningar tenderer att vara de mest använda. Dock är inte kroppslängden som uppnås i vuxen ålder endast en produkt av näringsintag, minus de externa faktorerna, utan är också en artefakt av genetisk predisposition och sekulära kroppslängdstrender. I användandet av en matematisk kroppslängds formel som har utvecklats på moderna populationer och som sedan tillämpas på dåtida populationer, så kan endast preliminära resultat uppnås. Detta är fallet, för ingen slutsats kan dras om dessa två tidsmässigt och geografiskt orelaterade populationer faktiskt delar genetiskt anlag för den kroppslängd som uppnås i vuxen ålder, eller för den delen, om liknande sekulära växttrender kan bli etablerade mellan dessa populationer.

Denna studie syftar till att adressera dessa tidigare svagheter i metodologin som har används i studier av kroppslängd för den brittiska tidigmedeltiden, genom att beräkna matematiska kroppslängds formler direkt på dess befolkningars skelett kvarlevor, genom att använda den anatomiska och regressionsmetoden. Dessa nya formler kommer att möjliggöra mindre prelimära resultat, och kommer dessutom att tillåta en mer detaljrik diskussion om hälsotillståndet hos populationer under denna tidsperiod, än vad tidigare studier som använt lånade formler har lyckats uppnå.

En annan vanlig utmaning inom studier av kroppslängds beräkning, är den didaktiska debatterna om metodiken. Genom denna studies process att etablera nya matematiska kroppslängds ekvationer för den brittiska tidigmedeltiden, kan ytterligare möjliggöra en diskussion om vad som kan anses vara den mest effektiva tillhandahållanden metodiken inom dessa studier. Denna diskussion kommer att kodifiera och fastställa vilket tillvägagångssätt som ger de mest effektiva och tillförlitliga resultaten, men även problematisera de begräsningar som existerar inom tillämpandet av dessa matematiska metoder.

**Nyckelord:** *Kroppslängds Beräkning, Regressionsmetoden, Den Anatomiskametoden, Tidigmedeltida Britannien, Biostatistik, Genetisk Predisposition, Sekulära Kroppslängdstrender*

## Contents

## *List of Figures*

## *List of Tables*

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# 1. Introduction

Stature achieved in adulthood is a cumulative product of long-term developmental processes that begin already *in utero*, and is further influenced by the environment, physiological stressors, disease, and the nutritional intake during the formative years of an individual's life (Steckel 1995: 1903; Jantz & Jantz 1999: 57-66; Coly et al. 2006: 2417; Perkins et al. 2016: 150; Ruff 2018: XV; Naaz & Muneshwar 2023: 6). Due to the aforementioned factors, stature estimation from human skeletal remains play an important role in archaeological studies of past populations since this source of information is invaluable for studies on health. Furthermore, when studying stature on a population level, the stature variation and mean value of a population may be used as a nutrition and health index of past and present societies (Mays 2016: 646; Koukli et al. 2023: 1-2), allowing for a discussion of health in greater detail.

Yet within British studies of the early medieval period, little interest has been shown in the further development of this invaluable source of information for exploring health status. The British early medieval period (c. 450 to 1066 A.D.) was a time of great many changes. Throughout its six centuries, Britain transformed religiously, legally, ethnically, culturally, and socially, laying the foundation of the future English kingdom and state to come (Williams-Ward 2017: 1). Hence further investigating the stature of the population of such a key transformative period in British history, should not be neglected and will hence be given its due in this study.

Stature estimation methods have been used in archaeology since the 19th century, with their origins harking back even further to the mid-18th century. There are four main types of stature estimation methods, each with varying degrees of potential, precision, accuracy, and challenges:

1. Estimating the living stature based on **the skeletal length in the grave** requires the individual to have been buried in a supine (extended) position, with at least the crania and one talus in their original anatomical position. If the crania and the talus are determined to remain in their anatomical position, then the skeleton can be measured following the sagittal line; from the most distant point of the talus to the bregma point of the crania. In doing so, a fairly accurate cadaver stature should be possible to achieve. The issue that arises with this method, are the sole reliance on undisturbed funeral contexts, which when available, is rarely investigated with an *archaeothanatological* (i.e., the analysis of the context of human burials, with a focus on taphonomy) mindset (Duday et al. 2014: 235; Radu & Kelemen 2015: 332).

2. **The ratio method** relies on performing the estimates of the stature by utilizing

predefined body ratio comparative lists. The bone measurements found in these lists can be correlated with the length of each long bone of an individual, to estimate this individual's living stature (Zeman et al. 2014: 171-173), i.e., a femur of a certain length will find a corresponding predefined stature value, which then serves as the estimated living stature. These methods are easy to use, but the results are not as reliable as the other three methods, nor is it possible to calculate the error range of the estimate, beyond the predefined estimate ranges.

3. **The regression method** utilizes the height measurements of long bones (see Fig 1.), which in turn is regressed towards the full living stature (i.e., establishing the percentile contribution towards stature of each skeletal element), allowing for the calculation of stature regression formulae. Unlike the anatomical method (see below), the regression method can be applied for adult individuals whose skeletal remains are incomplete, but at least have one long bone preserved (formula: [3] (numbers within clamps, unless within a quotation, refers to specific formulae included in the study with corresponding numerical values)). The limited amount of remains necessary for the formulae is the main reason for its frequent use in archaeology. However, regression formulae trace the stature trends specifically of the base sample on which it is calculated, hence may not be applicable for other populations that are geographically, temporally, or ethnically unrelated. Applying a formula on a sample that is inconsistent with the population it was calibrated on, i.e., the base sample, may result in inaccurate estimates, with the true stature not being accounted for by the error range (Konigsberg et al. 1998; Vercellotti 2009: 135-136; Mays 2016: 648). This is an important factor to consider, as each population, present or past, is affected by natural variation and secular trends.
4. **The anatomical method** is not reliant on predefined bodily proportion ratios. The supero-inferior dimensions of each of the long bones that contribute directly to the stature are measured (see Fig 2.); from the bregma point of the crania (scalp) to the heel of the calcaneus (Raxter et al. 2006: 375-376; Mays 2016: 647). The measurements are tallied up, producing a SKH (Skeletal Height) value, i.e., the stature of the individual with all of the soft tissues missing. The missing soft tissue can then be estimated through the revised formulae [4 & 5] developed by Raxter et al. (2006), producing the estimated living stature. The soft tissue height factor does not exhibit any marked variation between the sexes or different populations, hence one and the same formula can be

applied for any single population (Raxter et al. 2006: 378).

The regression method (3.), and the anatomical method (4.), are the most commonly used methods in archaeological and anthropological studies of the past six decades, due to their ease of use and accuracy. The regression stature formulae developed by Trotter and Gleser (1952, 1958), on 20th century North American populations, have seen the widest use in archaeology, irrespective of geography and temporality (further discussed below).

The anatomical method, when applicable, is preferable, as more skeletal elements are used (from head to heel), producing more precise and accurate results. However, the anatomical method requires a level of skeletal completeness that is relatively rare in archaeology. This caveat limits the method's application in archaeology, many regions of Wales and southern England are marred by high levels of acidity in the soils (i.e., pH values of ≤6.5) (Williams-Wards 2017: 21), hence poor bone preservation is commonly encountered in Britain.

By contrast, the regression method is simple to apply, utilizing one or more complete long bones (e.g., relying on the correlation between femur height and full stature). However, these correlations are highly population-specific. The previous stature formulae developed by Trotter and Gleser (1952, 1958) on 20th-century North American sample populations, have typically been treated as the sole axiomatic approach for stature estimation within British archaeological studies of the past half century (Mays 2016: 647). There is rarely empirical evidence to support the notion that the body ratios of these North American populations correlate with that of archaeological populations which it is applied on, nor for that matter, the early medieval period's population. Yet these formulae are frequently used in archaeology, resulting in highly tentative stature estimates, rather than arrived at through rigorous statistical calculations. These less empirical results are consistently treated as conclusive evidence not only for the stature but also as a proxy for health in these populations, hence the errors produced by the stature results have a wider erroneous implication for the osteological studies of past populations.

These erroneous conclusions can be ratified by combining the two methods in tandem (e.g., Sciulli et al. 1990; Formicola & Franceschi 1996; Sciulli & Hetland 2007; Raxter et al. 2008; Maijanen and Niskanen 2009; Vercellotti et al. 2009; Ruff et al. 2012; Sladek et al. 2015; Ruff 2018), as this would allow for the calculation of formulae directly on the material which is being studied, i.e., when the material is complete and well preserved. This approach is referred to as the hybrid method. The anatomical method can be applied to individuals with more complete skeletons, which then can be used as a basis to establish the population's body ratios (e.g., the correlation between the femur height and the full stature), by regressing the height of each long against the anatomically determined living stature of the population, which would allow for the calculation of regression formulae (Raxter et al. 2008: 149). When the regression formulae have been established, these can be used to calculate stature for individuals with less complete skeletons. This would negate the issue of utilizing formulae developed on non-geographically or temporal related populations, e.g., the formulae developed by Trotter and Gleser (1952, 1958). This approach provides far more valid results than being reliant on modern populations, whose body ratios are difficult to ascertain if it matches that of the past archaeological populations. Hence this would allow for the calculation of stature estimates which can be used with greater confidence.

## *1.1 Significance of the Study*

This research project investigates the stature and health of 512 individuals, 181 females, and 327 males, each dated to the early medieval period, whose remains were recovered from 28 sites in southern Britain. This will be achieved by developing new mathematical formulae to calculate the stature of British early medieval skeletal collections. These formulae will be directly developed on the different British early medieval populations, in doing so, avoiding the weakness of past research in applying formulae developed on unrelated modern populations. The stature results from these sites can be further supplemented by other osteological health analyses, e.g., the prevalence of linear enamel hypoplasia (LEH), calculus and cribira oribitalia, each serving as a proxy for the health status of the individual in their formative years (Steckel 1995: 1903-1920; O'Brien 2015: 565-566; Perkins et al. 2016: 153; Hannah et al. 2018: 26; Brødholt et al. 2022: 11). The aim is to transform our understanding of health and its bearing on the development of stature in early medieval Britain, through the development of these new stature estimation formulae. These formulae will further have the potential to be applied across a wide temporal and geographical range, hence will not only benefit the material used in this study, but may assist future studies on the period, allowing for greater detail in the health discussions.

## *1.2 Codifying the Methodology*

One of the key aims of this study is to emphasize the necessity of each parameter that influences stature achieved in adulthood, ranging from secular stature trends to genetic predisposition. Furthermore, each stage of the calculation of the stature regression formulae will be addressed in detail, as to allow for a completely empirical result. This empiricism in regards to the calculation of the formulae has typically been missing in past stature studies, hence misgivings in regards to how the methodology actually functions in practice, persist to this day, as the erroneous application of past formulae (e.g., Trotter & Gleser 1952, 1958), or for that matter, the calculation of new ones.

There is variation to be found within stature regression equations, with a long-standing contentious debate regarding the use of either Ordinary Least Squares (OLS), or Reduced Major Axis (RMA) equations, and which of the two is more appropriate for the estimation of stature, and which provides greater precision (Maijanen & Niskanen 2009: 473). The choice in favour of either OLS or RMA is predicated on the factor of long bones' growth rate in relation to the full stature achieved in adulthood, if this growth is either isometric (equal) or allometric (greater or less); this factor has commonly been left unaddressed in stature studies. If the former is true, then RMA is more appropriate, and if the latter, then OLS is the better choice (Shingleton 2010: 1; Kilmer & Rodriguez 2017: 8-11). This crucial issue will be addressed and resolved in this study through the process of calculating the stature regression formulae of the British early medieval populations, and in doing so, identifying which of OLS or RMA provides a more reliable result.

This study aims to rectify past contentious factors of stature estimation based on the metrics of skeletal remains, by codifying proper stature methodology, on a step-by-step basis, ranging from its equations, calculation, and limitation to the interpretation of the results concerning wider evidence (e.g., health status). This will allow the results of this study not only to benefit the scholarship of the early medieval period, but furthermore, the methodological discussion that will follow will allow for easier calculation of stature regression formulae further afield.

## *1.3 Outlining the Temporal Study Area*

The discipline of early medieval studies had its inception more than three centuries ago. Traditionally, what is referred to as the early medieval period (or Anglo-Saxon period in England), begins in the early to mid-fifth century A.D., with the termination of Roman rule, and the arrival of the first Germanic settlers (e.g., Angles, Saxons, and Jutes) in the British Isles, and ends in 1066 A.D., with the Battle of Stamford bridge (last Viking invasion), and more importantly, the same year, the battle of Hastings (Norman Conquest) (Davies 1982: 2; Magennis 2011: 16-17).

To avoid the same mistakes of past studies (e.g., Sjøvold 1990; Ruff et al. 2016), not only was the temporal dating of the early medieval materials used in this study as a key factor to consider when selecting it, but furthermore, so was geography. The greater the geographical distance between two sample populations is, the greater the risk of the populations exhibiting different secular stature trends (i.e., external factors affecting the development of stature, e.g., nutritional access). Furthermore, the events referred to as *Adventus Saxonum,* i.e., the arrival of the Germanic tribes in Britain (Hughes et al. 2018: 513), had the effect increasing the heterogeneity in the ethnical composition of early medieval populations, as isotope and aDNA studies would suggest (e.g., Gretzinger et al. 2022; Hughes et al. 2018). Hence utilizing studies tracing the kinship composition of the period, and its changes, the stature trends can be matched with these migratory trends. Southern Britain saw the greatest demographical changes throughout the period, with the largest concentration of Germanic foreigners (Gretzinger et al. 2022: 115-117). Hence when developing stature estimation formulae, as is the aim of this study, the area of southern Britain is the ideal choice. In this study, 28 early medieval sites in southern Britain were chosen in this goal to address the changes in the affinity of the population, and the accompanying factor of stature.

### *1.4 Objectives*

This project will further explore the general health of different British early medieval populations by estimating their stature on a larger scale and with greater accuracy and precision than has previously been undertaken. The human remains from 28 different British early medieval sites have been collected, and used for the analysis in this study. The author analysed and measured the remains from 14 of the sites, the population of the remaining 14 sites, were analysed by different observers, who provided osteological metric records. These new results can be used to compare the health and general body trends at different sites across time. In addition, results can be paired with other health proxies (e.g., linear enamel hypoplasia) to transform our understanding of early medieval health.

Furthermore, the resulting methodology and discussion sections will serve as an evaluation and critique of stature estimation methodology and its application in archaeology. Therefore, the output of this project will not only further the discussion on British early medieval health and stature but also contribute to the development of a more refined bioarchaeological toolkit for this period, which in turn can aid future research and provide a blueprint for temporally and geographically-specific stature studies on a larger scale.

The objectives of this study are threefold:

1. To develop reliable regression formulae for British early medieval populations, which will allow for the calculation of reliable stature data.

2. To further analyse and discuss the achieved stature data in the frame of the early medieval period in Britain, e.g., in relation to migration, secular trends, nutritional intake, and certain pathologies.
3. To clarify and problematize the dichotomy of previous methodological approaches to stature estimation. Through this discussion, combined with the empirical stature evidence produced in this study, the aim is to assemble and codify a proper methodological framework, which will benefit future stature studies further afield, beyond the early medieval period in Britain.

## *1.5 Thesis Structure*

The chapters of this thesis have been structured to guide the reader through the different key points of the methodology, and the material which form the basis of the research. **Chapters Two** outline the previous developments and history of stature estimation research. Examining the earlier research highlights past issues within the methodology and the issues that persist to this day, which will in part be addressed in later chapters of this study.

**Chapter Three** breaks down the different parameters affecting the development of stature, ranging from aspects investigated in modern paediatric studies to demographical investigations of modern populations, which ties together in a discussion of secular stature trends along with previous archaeological examples. This is further discussed in the following two chapters, chapters **Four** and **Five**, which address the early medieval period's migratory factors and health trends that can affect the development of stature.

**Chapter Six** outlines the mortuary practices of the period and its three phases. **Chapter Seven** begins with a discussion of the methodological criteria utilized when sampling the skeletal material by the author. This section is followed by a brief description of the sites that contributed a larger section of the material used in this study.

**Chapter Eight** examines the methodology on a step-by-step basis, which was applied and utilized in the development of new stature regression formulae. **Chapter Nine** puts into practice the methods presented in the previous chapter, and presents the results and newly calculated regression stature formulae, for either of the sexes. **Chapter Ten** further discusses the results, concerning the previously discussed stature parameters. This chapter further discusses the different methodological approaches, and which produces the most effective and accurate results. This chapter is followed by the conclusion in **Chapter 11**, addressing both the application of stature estimation in the early medieval period, and its health-related connotations, but further summarizes how stature studies moving forward can be made more efficient and empirical.

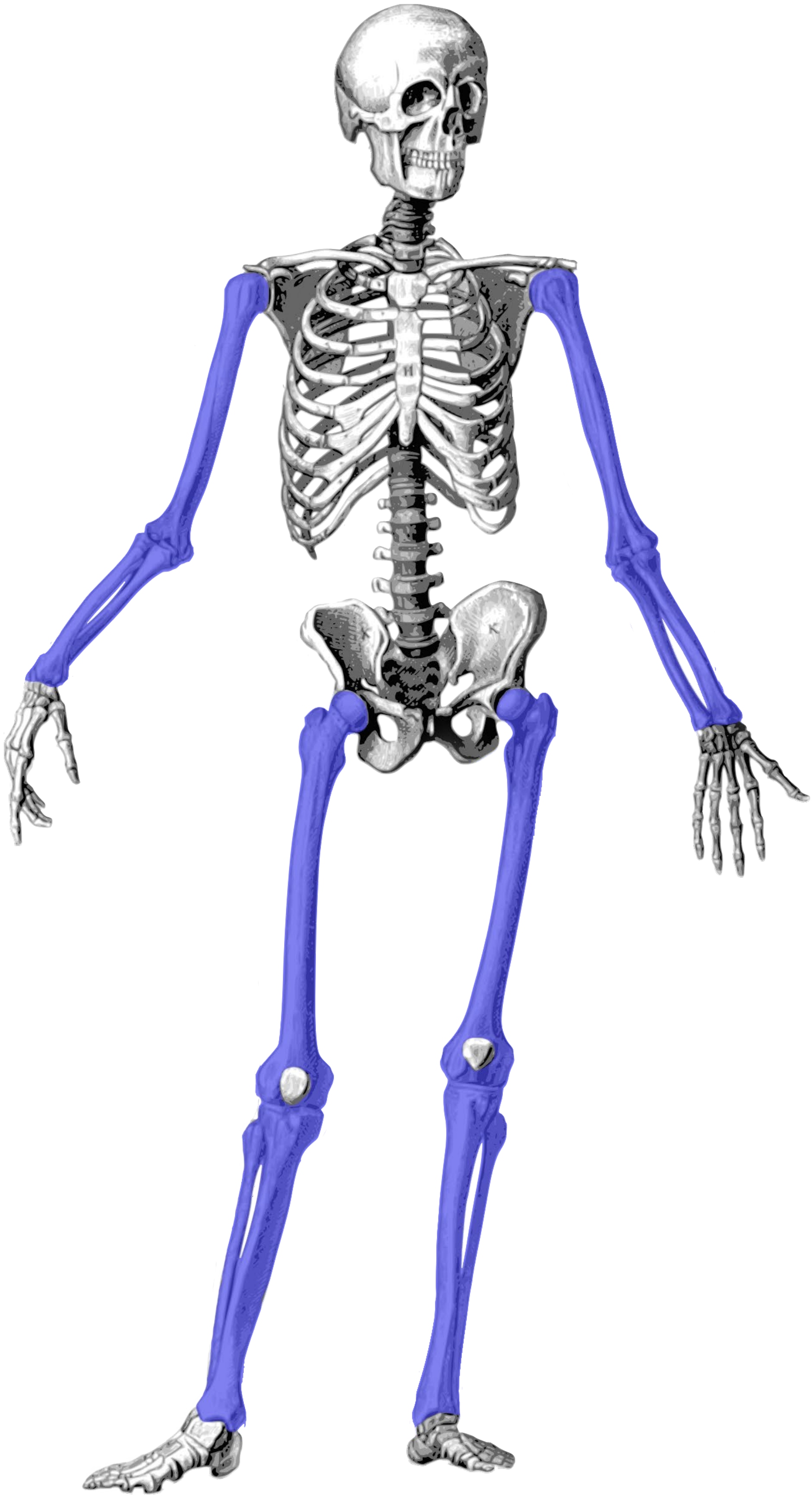

**Fig 1.** The human skeleton in an upright extended position, with each of the long bones utilized with the regression method highlighted in blue. Redrawn and edited by the author, original engraving in: The Household Physician by McGregor-Robertson Blackie (1890).

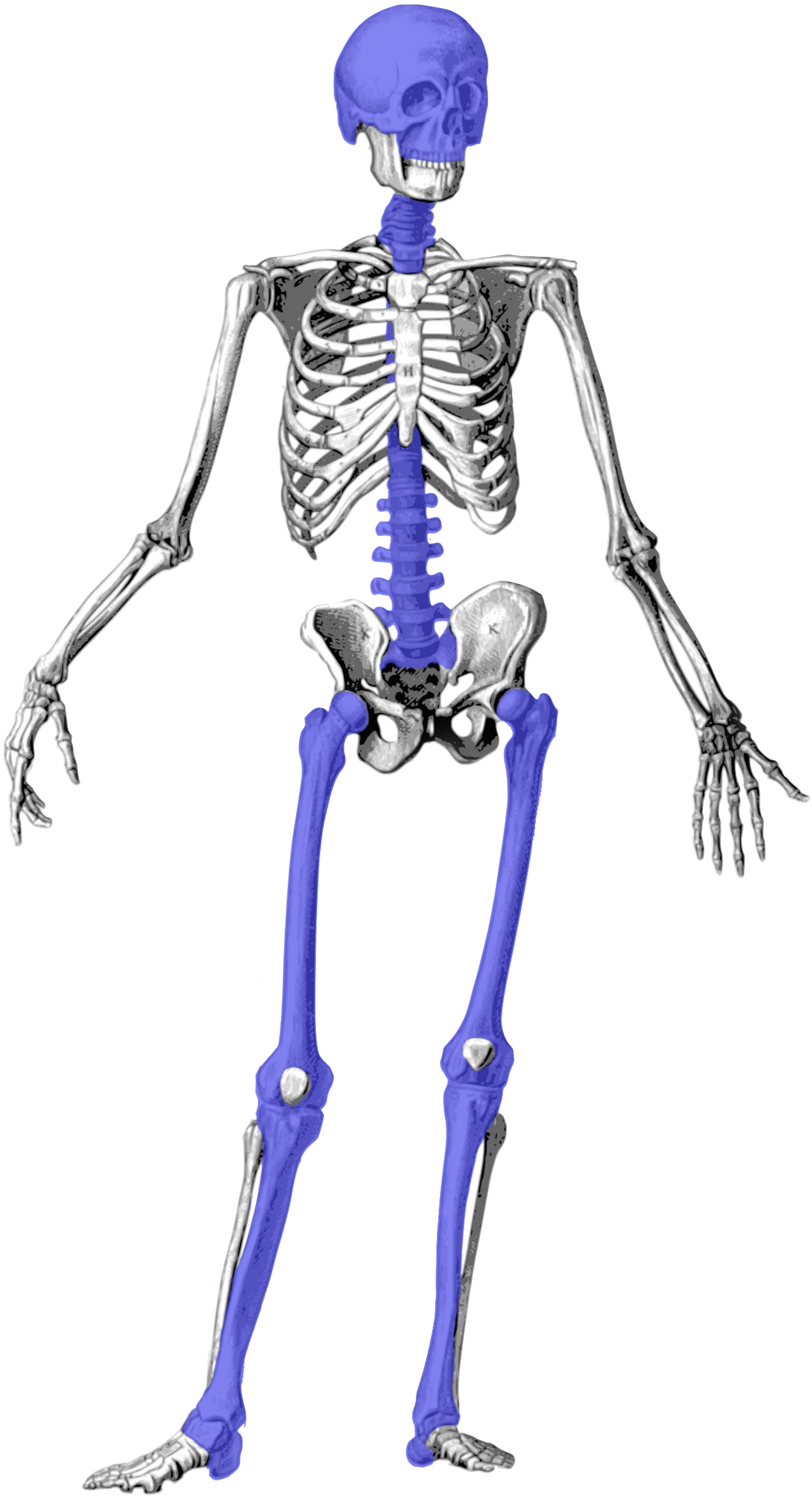

**Fig 2.** The human skeleton in an upright extended position, with each of the skeletal elements utilized with the anatomical method highlighted in blue, which is used to achieved the SKH value through tallying up each of the measurements. Redrawn and edited by the author, original engraving in: The Household Physician by McGregor-Robertson Blackie (1890).

# 2. Research Background and the History of Stature Estimation

The mathematical theorem underpinning the calculation of stature regression and anatomical formulae is equally important as the quality of the base sample used to regress the bone length towards the full stature (Zeman et al. 2014: 171; see Chapter 7 for an outline of the sampling practices). Hence outlining past issues and limitations of the methodology is of interest before proceeding to discuss the current methodological paradigms, as many past issues remain unaddressed till this day.

This following chapter will discuss the methodological development of stature estimation since its inception in the mid-18th century, leading up to the currently used methodology, i.e., the anatomical and regression method (see Chapter 8 for a discussion of the statistical underpinnings of the methodology), and how these two methods are combined to form new regression formulae in the hybrid approach, followed by how it has been applied in the past on British early medieval samples.

## *2.1 The Early Methodology*

Before the regression and the anatomical method, there was the ratio method. The ratio method was first introduced by the French anatomist, Jean-Joseph Sue, in 1755. The ratio method refers to the usage of predefined metric body ratio charts (e.g., the height correlation between the torso and the limbs) based on a sample population, which can be used in the estimation of the stature of other individuals and populations. Yet one issue which arose when applying this methodology to the estimation of stature using skeletal remains, was that Sue (1755) had performed all of his measurements on human cadavers, with their soft tissue still present. This fact did not stop Sue's charts from mainly being applied to human skeletal remains, when in fact, Sue had only correlated the length of different body segments, rather than the correlation of each long bone to the full living stature (Zeman *et al.* 2014: 171-173).

This issue was first rectified in 1831 in a joint effort by Mathieu Orfila and Octave Lesueur, who published the results of 51 autopsied bodies, that had been measured with the soft tissue still present, but furthermore, each bone has been measured in a desiccated state, with the measurements taken directly on the bones after the bodies' soft tissue had been completely removed (Orfila & Lesueur 1831). As such, Orfila and Lesueur (1831) developed the notion of being able to estimate the stature of an individual by the measurements taken directly from their long bones. The tentative nature of the method was acknowledged and emphasized in the discussion, as the results were only: *"[...] assez près de la verité* [close enough to the truth] *(Orfila & Lesueur 1831: 381)"*. But similar to previous attempts, this new method still utilized simplistic charts with predefined body ratios, and neither did it describe how these measurements had been taken on the bones, hence the method was difficult to replicate for other scholars (Zeman *et al.* 2014: 172). This lack of explicit description for the application of the method would come to be a common reoccuring theme throughout the early, and later development of stature methodology, limiting the empirical transparency and replicability.

At this point, French institutions had been the main focal centres for the development of the theory, and methods concerning stature estimations. Nonetheless, attempts were being made outside of France, and in the mid-19th century the British surgeon, George Murray Humphry tried to establish the mean proportions of contemporary European populations: *"... the ideal proportions of the well-developed European, deduced from the measurements of numerous skeletons (Humphry 1858: 87-88)"*, and how the mean values of the living stature would correlate with the mean height of each of the bone segments. Humphry's (1858) work continued the previous research trend developed by Sue, Orfila, and Lesueur, but with a focus on a wider material and populations (Humphry 1858: 106-112).

The limitation and recurring errors present in the methodology developed by Sue (1750), Orfila and Lesueur (1831), and Humphry (1858), was a well-known fact in the second half of the 19th century, that was later reiterated by John Beddoe (1888), during his anthropological work with General Pitt-Rivers, on a Romano-British sample (further discussed in the methodology chapter):

> […] common observation teaches us that short men have, as a rule, shorter legs in proportion than tall men; and it would seem that this applies to both femur and tibia […] in a series sufficiently large enough to swamp the exceptions, bring out an unduly low stature for short men, and an unduly high one for tall men, thus exaggerating the actual differences (Beddoe 1888: 202).

It was now apparent that the current methodology was imbued with issues which had a bearing on the accuracy, and in its current state would not suffice moving forward. A solution to the issue would not come immediately, but the same year as Beddoe's (1888) criticism was published, the French surgeon, Etienne Rollet, publicized his doctoral thesis (Rollet 1888), which at the time was the most detailed study of stature. In Rollet's (1888) thesis, 100 individuals were included (50 males, and 50 females), with a fairly wide age range: 24-99 years old at the time of death. Measurements of the human cadavers were taken within the first week after death, hence the bodies' soft tissues had not greatly deteriorated by the time the measurements were taken. After the cadavers had been measured, their soft tissue were completely removed, as to lay the bones bare, allowing for the bones to be measured in a non-dry state. In some instances, the bones were remeasured again after a few months when they had reached a dry desiccated state, on average, the bones had lost 2mm in length during this process. Another factor that had been ignored in the past, but which Rollet made sure to present in his research, was how the measurements of each of the different bones were to be taken when estimating the stature of an individual (Trotter & Gleser 1952: 463).

Rollet's (1888) thesis did not address all of the past issues with stature estimation, but his thesis, and its produced data set, came to be used as the foundation for several other important stature studies which would follow within the next decade. The French anthropologist, Léonce Manouvrier, was one of the scholars inspired by Rollet, and who would go on to address many of the different issues with the methodology. Manouvrier (1892, 1893) used the same data set as Rollet but limited the number of individuals from 100 to 49. This reduction was due to Manouvrier's discovery that stature estimation is commonly unreliable with individuals who are older than 60 at the time of death (further discussed below) (Trotter & Gleser 1952: 464; Raxter *et al* 2006: 376). Manouvrier further went on to organize the individuals into three groups: *micro-skeletons*: those individuals with below-average stature, individuals with average stature, and *macro-skeletons*: those above average stature (note the similarity to the early iterations of the method). Each category had its stature organized separately, in doing so, the previous criticisms by Beddoe (1888), concerning the reoccurring errors were addressed. As Manouvrier concluded, based on Galton's (1886) and Beddoe's (1888) previously expressed criticism, that stature estimation methods that utilize charts (i.e., the stature ratio method) cannot estimate all statures in the same way without encountering fairly large error margins for those individuals who are either above or below the mean value of the population being studied (Trotter & Gleser 1952: 464; Zeeman 2014: 173).

## *2.2 The Development of the Regression Method*

Galton (1890: 419) was critical of the lack of a good statistical basis in stature research. Throughout the work in his book: *Natural Inheritance* (1889), Galton discovered the statistical concept of correlation (co-relation), which came to be referred to as the *law of correlation* (Galton 1889: 421). The *law of correlation,* more commonly today referred to as interclass correlation; is when two or more variables are correlated through shared sets of influences

(Stigler 1989: 76). This was later further developed by Karl Pearson (1892; 1896; 1897), and Udny Yule (1895, 1896, 1897a, 1897b), leading up to Pearson developing the statistical concept of regression, which towards the end of the 19th century was applied for stature estimation (Pearson 1899). Regression is a type of correlation which consists of two or more variables; with one dependent variable (typically referred to a $y$), whose value is dictated by the independent variable's value (typically referred to as $y$) (Zar 2010: 328). For example, the estimated stature (dependent variable) is calculated through the height of a specific skeletal element (independent variable). This means that the regression method (as the previous ratio method) still utilizes ratios in its stature estimates (Ruff *et al.* 2012: 602); but rather than predefined ratio lists, regression formulae are developed through rigorous statistical testing, using estimated coefficients, enhancing the precision of the method.

Pearson (1899: 187) in part used the same set of French data as Rollet (1888), and Manouvrier (1892, 1893), when developing his new regression method [1] (Trotter & Gleser 1952: 464):

> Let $m_a$, $m_b$ be the mean size of $A$ [height of selected skeletal element] and $B$ [estimated stature]; $\sigma_a$, $\sigma_b$ their standard deviations; $r_{ab}$ their coefficient of correlation; then the most probable value of $B$ for a given value of $A$ is[:]
>
> $$[1]\ B = \left(m_b - \tfrac{\sigma_b}{\sigma_a} r_{ab} m_a\right) + \tfrac{\sigma_b}{\sigma_a} r_{ab} A$$
>
> $$= c_1 + c_2 A$$
>
> Where $c_1$ and $c_2$ are constants for the pair of organs [skeletal elements] under consideration (Pearson 1899: 171).

As Orfila and Lesueur (1831: 381) had stated nearly seven decades earlier, stature estimates are susceptible to errors within a margin, which was reaffirmed by Thomas Dwight (1878):

> Hence, and owing to the difficulty of the investigation, no one should dare to say the skeleton is that of a person of precisely such a height, but that height was so and so, and certainly between such and such limits [...] (Dwight 1878: 40)

As a mathematician and statistician, the factors of errors within each estimate was a well-known concept for Pearson, hence he included a formula to calculate the error ranges when using his regression formula. This formula [2] allowed for the first time the possibility of quantifying the accuracy of the estimated stature within a range (Pearson 1899: 171):

$$[2]\ .67449\sigma_b * \sqrt{(1 - r_{ab}^2)}$$

Throughout Pearson's (1899) research, using both remains from archaeological, and contemporary populations (late 19th century), he determined that genetic predisposition towards stature development tend to vary temporally and geographically, *"Stature is quite as marked a racial character as cephalic index* [the maximum breadth to the maximum length of the crania index…] *(Pearson 1899: 241)"*. He cautioned against applying the formulae developed on one population, onto another unrelated population, without caution, especially if there is a significant difference in region and time frame (Pearson 1899: 175; further discussed in the methodology and discussion section). As such, it was suggested to either develop separate formulae for populations when possible, using his regression concept, or to investigate if there are shared body ratios between a population on which the formula is being applied and the original population on which the formula was developed on.

Pearson's study was followed by a wide range of stature studies that used his regression method, with the first large-scale study being conducted by the German physical anthropologist, Emil Breitinger (1937). Breitinger's (1937) study included 2400 German living adults, all males, with a mean age of 26. The measurements were taken between bony prominences of the limbs resulting in the measurements taken by Breitinger not being as accurate as measurements taken directly on the bones, nonetheless, this was the largest stature estimation study at the time, which utilized regression formulae (Trotter & Gleser 1952: 466).

Following Breitinger's study, several influential stature estimation studies followed suit (e.g. Stewart 1948; Telkkä 1950; Dupertius & Hadden 1951; Trotter & Gleser 1951a & b). But it was not until the American forensic anthropologist Mildred Trotter, together with the biological anthropologist Goldine Gleser, published their third joint effort on stature estimation (Trotter & Gleser 1952), that the method would see significant changes.

Trotter and Gleser's (1952) contribution did not completely overhaul the regression method but introduced the use of simple linear regression formulae for stature estimation; which is a simplified version of the regression method, that investigates the linear relationship between the independent ($\hat{y}_i$) and dependent ($x_i$) variables (further discussed in the Chapter 8):

$$[3]\ \hat{y}_i = \beta_1 x_i + \beta_0$$

To be able to statistically test the validity of this new application of the regression method, a fairly large sample was necessary. In the years following the end of the Second World War in the Pacific in late 1945, the human remains from thousands of US servicemen who had been casualties in the conflict were being repatriated to the USA. This repatriation process offered the opportunity to examine the human remains, which in most cases had been completely skeletonized, and offered the possibility to take measurements directly on the bones. In most instances, the identity of the servicemen had never been lost, therefore, it was possible to use the stature measurements that had been taken at their induction into the Marine Corps and compare it to the estimated stature based on their bones. One issue which arose, as the servicemen sample of 1200 individuals used by Trotter and Gleser (1952) was fairly homogenous: 1115 Caucasian males, and 85 Afro-American males, with a mean age of 24 years old at the time of death. To be able to investigate the sexual dimorphism factor of stature in contemporary North American populations, a more diverse sample that also included females would be necessary. The *Terry Collection* of human remains from the Smithsonian Institute was added as a supplement. The collection consisted of 855 individuals: Caucasians: 255 males, and 63 females; Afro-Americans: 360 males, and 177 females (further samples of US minority populations were also included), with an age range of 19-99 years old at the time of death (Trotter & Gleser 1952). The living stature of the individuals from the *Terry Collection* was not always known, but their cadaver stature had been measured before the bones had been completely desiccated, and by adding a correction factor of 2.5cm to the cadaver stature, a reliable living stature is believed to have been achieved (Trotter & Gleser 1952: 492).

Trotter and Gleser (1952: 495) were able to calculate linear regression formulae on these 2055 individuals and were able to estimate their stature within fairly (suspiciously) low error ranges (e.g. maximum femoral error range of Caucasians: males: ±3.27cm, females: ±3.72cm; Afro-Americans: males: ±3.94cm, females: ±3.41cm). However, these significantly low error ranges have later come under scrutiny, as no t-test variables were used, and the SE (Standard Error) value (i.e., SE = $\frac{\sigma_{\hat{y}}}{\sqrt{N}}$) were merely multiplied by two (Jeong & Jantz 2016: 82). This produces a significantly lower yet erroneous error ranges than when approached utilizing appropriate formulae, e.g., 95%CI (95% Confidence interval) formulae multiplied with $t_{0.05(N\text{-}2)}$ (t-test value/student test, with two degrees of freedom (i.e., the sample number subtracted by two)) value (further discussed in the methodology section). Hence the actual accuracy of the previously developed formulae by Trotter and Gleser (1952), is difficult to gauge based on the data provided in their study (further addressed in Chapter 10).

Further issues are to be found within the measurement methodology of Trotter and Gleser's (1952) study. Trotter performed all measurements of the bones in the study from 1952, with the bone posing the biggest issue for consistency proving to be the tibiae (Trotter & Gleser 1958:

88; Lynch *et al.* 2019: 171), this remains an issues with the tibiae tending to show the largest inter-observer errors among all of the bones used for stature estimation. Trotter cites several different sources as their measurement standards: maximum length of the humerus, radius, ulna, fibula, and for the bicondylar length of the femur, Hrdlicka's (1947) measurements standards are cited, while for the maximum length of the femur, Martin (1928) is cited. The measuring method used for the maximum length of the tibia is cited as originating from personal communication from Krogman (1948), these tibia measurement standards are similar to the definitions presented by Martin (1928), and Hrdlicka (1947) (Jantz *et al.* 1995: 759):

> End of malleolus against the vertical wall of the osteometric board, bone resting on its dorsal surface with its long axis parallel with the long axis of the board, block applied to the most prominent part of the lateral half of the lateral condyle (Trotter & Gleser 1952: 473).

The issue does not lie with the definition given for the tibia measuring procedure, but rather there is evidence to suggest that Trotter did not follow these procedures in the study from 1952. When the material was re-assessed by Jantz et al. (1995: 758), Trotter's tibia measurements were systematically on average 13 mm too short. As it seems, Trotter had omitted the malleolus from the measurements, yet the definition states that it should be included (Trotter & Gleser 1952: 473). These systematic errors of measuring the tibia without the malleolus result in the underestimation of the percentile contribution of the tibia's length to the full stature of the individual. As such, when Trotter's tibia formulae have been applied to other populations (i.e., populations that have had their tibiae measured correctly with the malleolus), the estimated stature will always result in overestimated stature.

In 1958, Trotter and Gleser reprised their stature study, utilizing the skeletonized human remains of 5517 servicemen casualties in the Korean War (Trotter & Gleser 1958: 81). The issues regarding the tibiae measurement standards and the resulting overestimated stature reached with its formulae now became apparent, when the same approach and formulae were applied to a wider material:

> … the tibia is longer on average than the fibula, whereas in the previous study, the reverse relationship was found. Possibly this difference between the two studies may be accounted for by different technicians measuring the maximum length of the tibia… (Trotter & Gleser 1958: 88).

These erroneous factors were attributed to interobserver errors, as unlike the previous study, the material from 1958, all of the measurements were taken by various military lab technicians

(Trotter & Gleser 1952: 472, 1958: 80).

Even with later studies (e.g., Jantz et al. 1995; Jeong & Jantz 2016), highlighting the shortcoming of Trotter and Gleser's (1952, 1958) research, the resulting regression stature formulae remains in frequent use through physical anthropological and bioarchaeological studies. In large this is due to the simplicity of the predefined formulae based on the large reference sample that were calculated by Trotter and Gleser (1952, 1958), which have made it an attractive method for other scholars to use in their studies, usually untested, and unmodified, ignoring Pearson's (1899: 241) century old caution (later further discussed in: Eveleth & Tanner 1976; Ruff 1994; Holliday 1997; Holliday & Ruff, 1997).

## *2.3 The Development of the Anatomical Method (The Fully Technique)*

The idea of reconstructing the stature of an individual by measuring all of the bones that contribute to the full living stature (from the bregma point of the crania (i.e., the scalp) to the heel of the calcaneus), and then tallying up the measurements of the bones to a so-called skeletal height (SKH), was already introduced in 1878, by the American physician and anatomist, Thomas Dwight (1878: 40-49). This was further developed in 1885, by the French physician Paul Topinard. Similar to Dwight, Topinard (1885) was sceptical about the accuracy of current (at the time) ratio method presented by Orfila and Lesueur (1831), hence Topinard attempted to develop a reconstruction method that would utilize more bones, with higher accuracy for its estimates. In theory, Topinard was correct in his assertion that greater accuracy can be achieved through the use of a greater number of bones contributing to the full stature in the reconstruction, yet when applied in practice, similar to most ratio methods, the results suffered from underestimating those of shorter stature, and overestimate those of taller stature (Galton 1886: 247; Zeman *et al.* 2014: 172).

In 1954, the French medical doctor: Georges Fully, had completed his medical studies, when he was called upon by *Fédèration des Anciens Combattants* (The French Department of Veterans Affairs), to aid in the identification of the human remains of French POWs (i.e., Prisoners of War) uncovered in the concentration camps of Vaihingen, Germany, and Mauthausen, Austria. The possibility of identification through DNA analysis was still three decades away, so it was necessary to devise other types of methods in the identification process of the French POWs' human remains. Instead, Fully decided to estimate the stature of the human remains as a way of identification, as the concentration camp records (especially those of Mauthausen) included stature for each of the POWs (Stewart 1979: 916). In theory, these records could be correlated with the estimated stature results, which could aid in the identification process of the individuals, together with other characteristics.

The report of the identification work conducted at Vaihingen has never been made available to the public, but was likely similar to the methodology described in Fully's publication about the identification work at Mauthausen (Fully 1956). At Mauthausen, Fully managed to determine the identity of 102 French POWs' human remains, through the aid of stature estimation using his new method (Raxter *et al.* 2006: 375; Zeeman *et al.* 2014: 173). Fully's new method was based on the previous work conducted by Clavelin and Dérobert (1946), which was an early investigation into forensic anthropological methods. Other aspects as the long bones measuring standards previously developed by Rollet (1888) were also implemented. Unfortunately, similar to many of his predecessors, Fully never specified how each of the remaining non long bone measurements were to be taken (crania, vertebral column, and articulated foot height). Fully's bone measurements are assumed to have been as follows: the crania measured from basion to bregma; the vertebral column: from the second cervical to the first sacral vertebral; the articulated foot height: superior point of the talus to the most inferior point of the calcaneus. When each of the bones had been measured, the measurements were tallied up, giving the skeletal height, the stature of the skeleton without any soft tissue present (Raxter *et al.* 2006: 375). To be able to transform the skeletal height into an estimate of the actual living stature of the individual, a solution for the missing tissue needed to be developed. Similar to Manouvrier's solution to the previous erroneous phenomenon, Fully developed three different correction factors depending on the skeletal height:

> Skeletal height equal to or below 153.5 cm, add 10 cm.
>
> Skeletal height between 153.6–165.4 cm, add 10.5 cm.
>
> Skeletal height equal to or above 165.5 cm, add 11.5 cm. (Raxter et al. 2006: 375)

With these three correction values, Fully was confident of being able to estimate the living stature of 102 French POWs with a surprisingly low average error range of c. ±0.6cm (or: ±0.4-0.9cm) (Stewart 1979: 919-920; Raxter *et al.* 2006: 375).

Following the publication of Fully's (1956) method, it became fairly popular within archaeological and anthropological research. But during the following decades, several issues with Fully's method began to emerge, especially when applied to non-European populations, as it tended to underestimate the stature of the individuals by a mean value of 2.4cm (King 2004; Bidmos 2005; Raxter *et al.* 2006: 374). Fully's proposed three correction values might have been too conservative, hence the systematic underestimation when the unmodified method is applied to other populations. As previously mentioned, Fully's lack of clarity for the bone measurements added to the possible errors. Fully's incredibly low error ranges are also questionable, as compared to later studies that used modified versions of Fully's anatomical method, such as Raxter et al. (2006) revised method, which had a pooled mean error range of ±4.37cm (Raxter *et al.* 2006: 374-378). Fully was assassinated in 1973, likely due to his position as the head medical examiner of the French correctional system (Stewart 1979: 916), following his death, the method saw no significant development for the next three decades.

In 2006, Raxter et al. would go on to revisit Fully's technique, with the aim of testing the accuracy of the method on a more diverse sample, than the French sample originally used by Fully. Raxter et al. (2006) used the human remains of 119 individuals from the same sample of the Terry collection used by Trotter and Gleser (1952). The 119 individuals consisted of Caucasians: 32 males, and 25 females; Afro-Americans: 33 males, and 29 females; with an age range of 21-85 at the time of death, with the mean age being 54 years old (Raxter *et al.* 2006: 378). Several of the individuals do exceed the recommended age limit of 60 years old at the time of death, however, the cadaveric stature for all of the individuals from the Terry collection is recorded, hence the age factor only had a negligible effect on the results.

Rather than following the previous concept, of stature correction values, as originally introduced by Manouvrier (1892, 1893), and further used by Fully, Raxter *et al.* (2006: 377) chose to recalculate the correction values based on the SKH values. This new approach had two formulae calculated, in favour of the previous three correction values, one with an included age factor [4], and one without the age factor [5] (Living Stature (LS); SKH ($x_i$)):

$$[4]\ \mathrm{LS}=1.009x_i-(0.0426*age) \pm 12.1$$

$$[5]\ \mathrm{LS}=0.996x_i \pm 11.7$$

The new formulae were tested on the diverse sample of 119 individuals from the Terry Collection, and neither ancestry nor the sex of the individuals had any significant bearing on the results (Raxter *et al.* 2006: 378). As such, these two formulae can be applied across the board for any population, no matter what the time frame might be, unlike the regression formulae which are heavily reliant on specific populations' body ratios. The age factor included in formula [4], is only necessary to calculate for individuals who are determined to have been ≥30 years old at the time of death, e.g., an individual with an estimated age of 30 years old at the time of death should be calculated as: $1.009x_i-(0.0426*1)+12.1$. For individuals who were younger than 30 years old at the time of death, then the age factor should be added as zero, or emitted completely. This is caused by the fact that the vertebral column starts to deteriorate over time after reaching the age of 30, due to shrinkage in the soft tissue in the vertebral column (Mays 2016: 648). The age factor after 30, is estimated to negatively affect the stature by c. 0.0426cm (c. 0.06cm according to Trotter & Gleser 1951a: 318; Trotter & Gleser 1952: 464) per year, i.e., a stature loss of c. 1.3cm by the age of 60 (Raxter *et al* 2006: 376-377).

## *2.4 Combining the Two Methods in the Hybrid Approach*

A common practice in the past has been to use regression formulae developed on human remains from contemporary modern populations (e.g., Pearson 1899; Stewart 1948; Telkkä 1950; Dupertius & Hadden 1951; Trotter & Gleser 1951a & b, 1952, 1958; Allbrook 1961; Genoves 1967; Lundy 1983; Radoinova *et al.* 2002), and apply it on archaeological populations. Pearson cautioned against the use of regression formulae that has been derived from one population, onto another population, without having empirical evidence that would suggest similar body ratios (Pearson 1899: 241; Stevenson 1929: 303; Raxter *et al.* 2008: 148). Only a direct measurement of stature for individuals who still have all their soft tissue preserved, or stature estimated through the anatomical method, can reveal the true body ratio of a population (crural and cormic index) (Auerbach 2011: 68; Ruff *et al.* 2012: 602). This came to be unintentionally illustrated by, Paul Huston Stevenson (1929), when he applied Pearson's regression formulae which originally had been developed on a late 19th-century French population, to an early 20th-century Chinese population. As Stevenson states concerning Pearson's caution:

> […] such extension was deemed theoretically permissible on the assumption […] regression formulae, in general, might be expected to change from one race to another yet certain of these, viz. regression formulae of indirectly on directly selected characters, should not change (Stevenson 1929: 303).

An assumption, as the one stated above by Stevenson, can only be made when there is a known affinity, or body ratio similarity between two, or more ethnic groups, past or present. The only bodily height factor which appears uniformly across temporal, sex and geographical boundaries, is the factor concerning the height contribution of missing soft tissues (Raxter et al. 2006: 378). Stevenson's study came under immediate scrutiny, as Pearson was one of the editors of the journal that published Stevenson's paper:

> Before applying our French reconstruction formulae to a second race, it would certainly be wise, where it is possible, to test whether the above index [mean body ratio values] is

> approximately the same for the two races [One of Pearson's editorial notes] (Stevenson 1929: 311).

Pearson's (1899) original sentiment has since been re-emphasized throughout several later works (e.g., Dupertuis & Hadden 1951; Trotter & Gleser 1952; Eveleth & Tanner 1976; Feldesman et al. 1990; Ruff 1994; Holliday 1997, 1999; Holliday & Ruff 1997; Ruff 2010). Yet, Trotter and Gleser's (1952, 1958) regression formulae (as discussed above) remain till this day the most commonly applied formulae in stature estimation of British early medieval populations. Ruff et al. (2012: 609-610) highlighted this, as e.g., the populations from southern Europe, had on average longer tibiae, compared to those from the North. This longitudinal variation is caused by the lengthening of distal limbs in warmer climates, and shortening in colder climates (Trinkaus 1981; Ruff 1994; Ruff *et al.* 2012).

Mays (2016) tested Trotter and Gleser's (1952 & 1958) formulae on a British Medieval sample from Wharram Percy, to see if these formulae applied to the populations of the sites. Mays (2016) was able to establish the body ratios for the Wharram Percy population with the revised anatomical method, allowing for the comparison with the body ratios between the 20th-century North American Caucasian military, and civilian skeletal collections used by Trotter and Gleser (1952, 1958). Mays (2016: 8) concluded: that the femoral regression formulae by Trotter and Gleser (1952, 1958) gave satisfactory results, however, the earlier tibiae formulae had a tendency to underestimate the stature of the individuals (as discussed above). Mays (2016: 653) encouraged future studies on the subject, as a wider material needs to be investigated to be able to draw any conclusions for the variability of stature methods applied for British: early, mid, and later medieval populations (certain issues of Mays approach are further discussed in Chapter 10).

A solution to the issue discussed above, regarding the uncertainty of regression formulae developed on modern populations in its application for archaeological populations, is to utilize the anatomical method in tandem with the regression method. This was first put into practice by Sciulli et al. (1990) utilizing the previously developed approach by Fully (1956) on prehistoric populations from Ohio, the stature results achieved with the anatomical method was subsequently used as a baseline to calculate the regression formulae on. This approach was later further explored by Formicola and Franceschi (1996) in their studies of stature of early Holocene Europeans. Raxter et al. (2008) utilizing their newly developed anatomical formulae (Raxter et al. 2006, 2007) formulated stature regression formulae for ancient Egyptian populations with greater precision than previous approaches. The height of each long bone can be regressed against the anatomically determined living statures, which in turn can generate new stature regression formulae, based on the skeletal remains of the base sample (Raxter et al. 2008: 149). This approach has seen success in several osteological studies in the last two decades (e.g., Sciulli & Hetland 2007; Raxter et al. 2008; Maijanen and Niskanen 2009; Vercellotti et al. 2009; Ruff et al. 2012; Sladek et al. 2015; Ruff 2018), as it provides far less tentative results reliant on modern populations, whose body ratios are difficult to ascertain if it matches that of the past archaeological populations.

## *2.1 Early Medieval Stature Studies in Britain*

The modern scholarly studies of Early Medieval Britain (in past English scholarship, this period within the bound of modern England is commonly referred to as the Anglo-Saxon period) stretching as far back as 1754, with the Scottish philosopher and historian, David Hume's: *The History of England, Volume. 1: From the Invasion of Julius Caesar to the Revolution in 1688.* But Hume only briefly discussed the early medieval period (a few chapters in volume one, out of six), in favour of those periods which he deemed more important in the history of England (Hume 1754). Hume describes the period as uncivilized, consisting of brutish, but noble German invaders:

> ...to have carried to the highest pitch the virtues of valour and love of liberty; the only virtues which can have a place among an uncivilized people, where justice and humanity are commonly neglected (Hume 1754: 16).

It was first towards the end of the century, that the period was given its due, by Captain James Douglas (1793), and the English historian, Sharon Turner (1799). Douglas (1793), emphasized the marked difference between the early medieval populations, and their material culture from the previous Romanized Britons. And Turner (1799), stressed the importance of the period in English history, as he argued that the Anglo-Saxon period laid the foundations for those which succeeded it (Burch 2015: 16). The English historian, John Mitchell Kemble (1849), identified the genesis of the early medieval period as the arrival of continental Germanic settlers. This was followed by greater emphasis on fieldwork, e.g., by the English antiquarian, Bryan Faussett (1856), who excavated early medieval Kentish cemeteries. The work of Faussett (1856) garnered the attention of several physical anthropologists, who now took an interest in the period, and its human remains. In 1862, Joseph Barnard Davis and John Thurnam (1862), described the human remains of several adult male Saxon individuals, to have been of great stature. Only a few individuals are given more precise estimates, e.g., an adult male (no precise individual is stated) from the cemetery of Ozingeli, this individual had an estimated stature of six feet four inches (c.

195cm), to six feet six inches (c. 201cm) (Davis & Thurnam 1862: unnumbered page in the appendix). What these estimates were based on, or how it were achieved, is never elaborated on (in situ grave stature?), hence should not be considered (though not impossible) as empirical results.

In 1888, John Beddoe (1888; as previously discussed) collaborated with the renowned General Pitt Rivers and conducted a stature estimation study on a British-Romano population from White Horse Hill. Beddoe expanded the project to include both earlier, and later populations, this expansion included 75 early medieval individuals (50 males, and 25 females). These early medieval individuals originated from Long Wittenham, Brighthampton, Harnham, and Ozingell (Beddoe 1888: 206, 209). The mean stature estimated for these individuals were: males, 174.7 cm; females, 160.2 cm (Beddoe 1888: 209). Beddoe based his method on previous studies, e.g., by Orfila and Lesueur (1831), Humphry (1858), and Topinard (1885), hence Beddoe's efforts, though erroneous in their basis using the ratio method, should be considered the first actual attempt at an empirical stature estimation study of early medieval populations in Britain.

In 1899, with the publication of Pearson's (1899) regression method, the new methodology was tested on a few of the individuals from Beddoe's (1888) previous Anglo-Saxon sample. The method gave the mean estimates of males, 170.9 cm; females, 156.0 cm (Pearson 1899: 216). Note that no error margins were calculated using Pearson's (1899: 171) own error range formula for these early medieval stature results. Yet, these results presented by Pearson (1899: 216), do highlight the strength of the regression method in its ease of application and empiricism, over the ratio method, even in its early stages of development. Following Pearson's (1899) study, stature estimation methods were applied in limited studies in Britain, mainly on specific sites (e.g., Humphreys et al. 1925), but no wider site comparisons were undertaken.

It would take until 1936 before a larger scale early medieval stature estimation study was attempted again. Henrich Münter (1936) conducted a general study on the lengths of the long bones of British populations, from different eras. This study included early medieval samples from several different museum collections: 233 adult males, and 93 adult females were used in Münter's (1936: 258) study (used in the previously discussed study by Wells 1960), and the mean stature results achieved with Pearson's (1899: 171) formulae were: males, c. 168.1 cm; females, c. 156.6 cm (Münter 1936: 269). Münter (1936: 259) went further in his discussion of the stature results and discussed the issues that arose when modern sample populations (early 20th century, e.g., Trotter & Gleser 1952 & 1958) were used as a comparative population, for early medieval samples, to extrapolate the ratios and formulae from (further discussed in the Chapter 8).

Even with both Münter's (1936: 259) and Pearson's (1899: 241) caution against extrapolating stature based on formulae developed on non-related populations, with no known affinity ties, Trotter and Gleser's (1952 & 1958) regression formulae remain the standard in the study of early medieval populations in Britain due to a lack of better alternatives. Mays (2016: 647) suggested that the popularity of Trotter and Gleser's (1952, 1958) formulae within British archaeology may be traced back to its inclusion in Brothwell's (1963, 1981) osteological laboratory manuals "*Digging up Bones*", hence these formulae have been considered the norm in British stature studies, in lieu of better options. This is evident with many of the early medieval populations used in this study which had previous stature estimates performed, e.g., Llandough (Loe 2003a), Appledown (Harman 1990), Weyhill (Clough 2020) and Updown (Duhig & Rega 2008), with each study utilizing the Trotter and Gleser (1952, 1958) formulae. However, it is further a common practice not to specify the stature methodology utilized to estimate a population's stature, e.g., the stature estimates of Collingbourne Ducis (Dinwiddy 2016), Barrow Clump (Dinwiddy & Watts-Plumpkin 2019), Melbourne (Duncan et al. 2003) and Leadenhall (Conheeney 2005); yet it may be inferred that the same Trotter and Gleser (1952, 1958) formulae were likely utilized in these latter studies, similar to the former.

The study of Walther (2017), attempted to trace the changes in health trends in Britain during the transition from Roman rule to the early medieval period, using the health data and estimated stature of populations from 20 different British cemeterial sites, ranging in date from either of the two periods. Yet for the latter period, only 23 individuals, 15 males, and eight females, were utilized in calculating the regression stature formulae. It is statistically not possible to trace stature trends of a period through the use of only eight individuals (as was the case with the female sample of said study) and is unlikely possible to be able to produce reliable formulae using a sample of only 15 individuals (as in the case of the male sample), hence the results can only be considered as tentative. Nor for that matter is the methodological approach of Walther's (2017: 105, 192-193) study correct, nor empirical, as the SEE (Standard Estimated Error is lacking consideration for the *x* variable, i.e., the bone elements) and 95%CI (95% Confidence Interval, i.e., final error range of the estimated stature) value is erroneously calculated, with no t-test performed for the final error range.

## *2.2 Calculating Regression Formulae on Pooled Sex Samples*

Sjøvold (1990: 442) argued that the differing body proportions, i.e., the relation between the full stature and the height of each long bone, between males and females, is merely caused by the differences in stature, suggesting that males and females of similar stature should exhibit similar correlations between long bone height and the full adult stature. Sjøvold based this assertion on the previous research conducted by Saller (1931), in which the male (N: 1230) and female (N: 1160) populations of the island of Fehmarn, Germany, were anthropologically and morphologically investigated. Saller concluded that males and females of the same stature bracket exhibited similar body proportions. Yet great caution should be exhibited in regards to the above study and its accompanying results, as Saller's (1931) study was conducted with an emphasis on racial anthropological research, with a clear bias towards eugenics and Germanic "*racial traits*" (Teschler-Nicola 2007: 59-60).

If true, similar shared stature trends would be possible to trace between the sexes, hence a larger base sample could be assembled, with pooled anatomical measurements of both males and females used to calculate the regression formulae. This would in theory solve one of the key issues faced when attempting to formulate regression formulae in archaeology, as the frequency of recovered human remains in a complete enough state to have their stature estimated with the anatomical method is rare (Mays 2016: 647). Hence gathering a large enough sample of both males and females to formulate separate regression formulae is a difficult task, which could be alleviated if the two sexes could be pooled together. This has been attempted in several studies (e.g., Sjøvold 1990; Vercelotti et al. 2009; Maijanen & Niskanen 2009; Ruff et al. 2012). Yet calculating regression formulae on pooled samples of the two sexes is predicated on the assumption that stature trends are shared fairly equally between the sexes, and would then suggest that sexual dimorphism and secular stature trends (discussed in the next chapter) only have negligible effects on stature development. A further discussion is necessary in regard to the actual applicability and accuracy of Sjøvold's (1990) suggested approach (further addressed in Chapter 10).

## *2.3 Chapter Summary: Past and Current Stature Estimation Methodologies*

This chapter has focused on the past landmark developments within stature estimation methodology, from Sue (1755), to the currently most commonly employed methods developed by Trotter and Gleser (1952, 1958) and Raxter et al.(2006); and furthermore, how these two methods can be used in tandem, using the hybrid approach, which is one and the same approach utilized in this study (see Chapter 8 through 10).

Further issues of past use of stature estimation within British archaeology have been highlighted, along with the possible issues posed by utilizing base samples assembled by different unrelated populations, or samples in which males and female populations data sets are combined. Several of these issues will be further addressed in the next chapter, and further discussed in the methodological chapter (Chapter 8), the result chapter (Chapter 9) the discussion chapter (Chapter 10) and finally in the conclusion chapter (Chapter 11).

# 3. Growth Related Studies

Variation in skeletal growth is a complex interaction between genetics and environment (Hoppa 1992: 275). Stature has long been recognized as a proxy for health within paediatric studies (MacConaill 1938), as studies on the development of stature in modern children do show similar results (e.g., Naaz & Muneshwar 2023). Steckel's (1995) bioarchaeological studies reached similar conclusions, that external stressors during the formative years can have negative effects on stature development:

> […] stature is a measure of consumption that incorporates or adjusts for individual nutritional needs; it is a net measure that captures not only the supply of inputs to health but demands on those inputs (Steckel 1995: 1903).

Further summarized by Jantz and Jantz (1999: 66): *"Stature is an outcome of nutritional intake minus demands. Demands are principally in the form of disease and work."*

## *3.1 Developmental Studies*

Juveniles of any group, culture, or community (modern or past), are commonly considered as a good metric for the general fitness of a population. Hence studies of growth-related changes in archaeological populations have mainly focused on examining stature development indexes and using these as proxies for the health and adaption to the environment of a population's surroundings (Mensforth *et al.* 1978; Johnston & Zimmerman 1989; Hoppa 1992). Yet many comparisons can be extrapolated from modern studies on stature development.

A modern paediatric example, Jerry Wales et al.'s (1992) study, included 91 British children who had suffered from abuse at a very young age at home. The study discussed how the abuse had affected the children's physical development, and especially how the stature development had been stunted. One-third of the abused children had a shorter stature than the national average for the age groups, with the main contributing factor being that these abused children of shorter stature predominately came from lower-income homes (Wales *et al.* 1992: 633-635). Similar results regarding slowed stature and physical development have been reached in other paediatric studies regarding stress, abuse, and lack of stimulus at a young age (e.g., Skuse 1989; Money 1992; Rogol *et al.* 2000; Johnson & Gunnar 2011), both in developed and developing countries, with a link to education and annual income of the household (Sussane 1980; Perkins et al. 2016; Soliman et al. 2021).

The stature of the mother is one of the greatest predictors for the future genetic growth of a child, as a smaller mother constrains the intra-uterine growth independently of the genetic predisposition (Coly et al. 2006: 2417; Perkins et al. 2016: 156), i.e., a mother suffering from poor health and stunted growth will typically produce a smaller child. The general health of the mother during pregnancy can affect the prenatal environment significantly, hence poor nutritional intake, excessive stress, and physical activity may cause developmental issues for the infant already in the womb (Jantz & Jantz 1999: 66; Naaz & Muneshwar 2023: 6). Nutritional stunting is commonly caused by insufficient maternal nutrition, undernutrition, or insufficient breastfeeding up until six months of age, and infectious diseases. The effects of stunted growth may have long-term or permanent effects, ranging from e.g., increased morbidity through a weakened immune system, hypertension (i.e., high blood pressure), limited cognition, and lower reproductive abilities, to reduced stature achieved in adulthood (Soliman et al. 2021: 1-2).

During the first year of life, stature growth is the most rapid, and the growth patterns are fairly uniform cross-culturally and temporally, due to the nutritional requirements of infants being (generally) met through breastfeeding. However, variation may even be encountered at this stage, if the mother who is breastfeeding the child herself is suffering from poor nutritional intake or health issues which may cause developmental stunting in the child (Hoppa 1992: 283; Perkins et al. 2016: 150). Hence even in infancy, the health of the mother plays an important contributing factor towards the developing health and growth of the individual.

Following the weaning process, a steep decline in the pace of growth is exhibited, and diet, socioeconomic status, genetic predisposition, and environment, start to become a factor in the growth trajectory of the individual. The first two to three years of life are crucial, as a stunted growth rate before the age of two or three, has been linked to reduced stature in adulthood (Hoppa 1992: 283; Jantz & Jantz 1999: 66; Walker et al. 2009: 120; Soliman et al. 2021: 1-4). Nutrition is the most important external factor affecting stature development, with stunted growth typically being attributed to a limited supply of nutrition. Whereby the maintenance of the basic metabolical functions of the body takes precedence, causing resources otherwise earmarked for growth to be rediverted. Several types of disease (e.g., diarrheal, hookworms, intestinal parasites), infections (e.g., infection of the respiratory tract), or inflammation, can hinder food intake, or absorb the nutrients, causing a nutritional deficit, hence increasing metabolical requirements which in turn diverts further energy from the growth patterns (Perkins et al. 2016: 153-154). Coly et al. (2006: 2412-2415) study of growth patterns of the modern Senegal population (2874 individuals of varying ages), showed that individuals whose growth development had been stunted in childhood could exhibit a significantly shorter stature even in

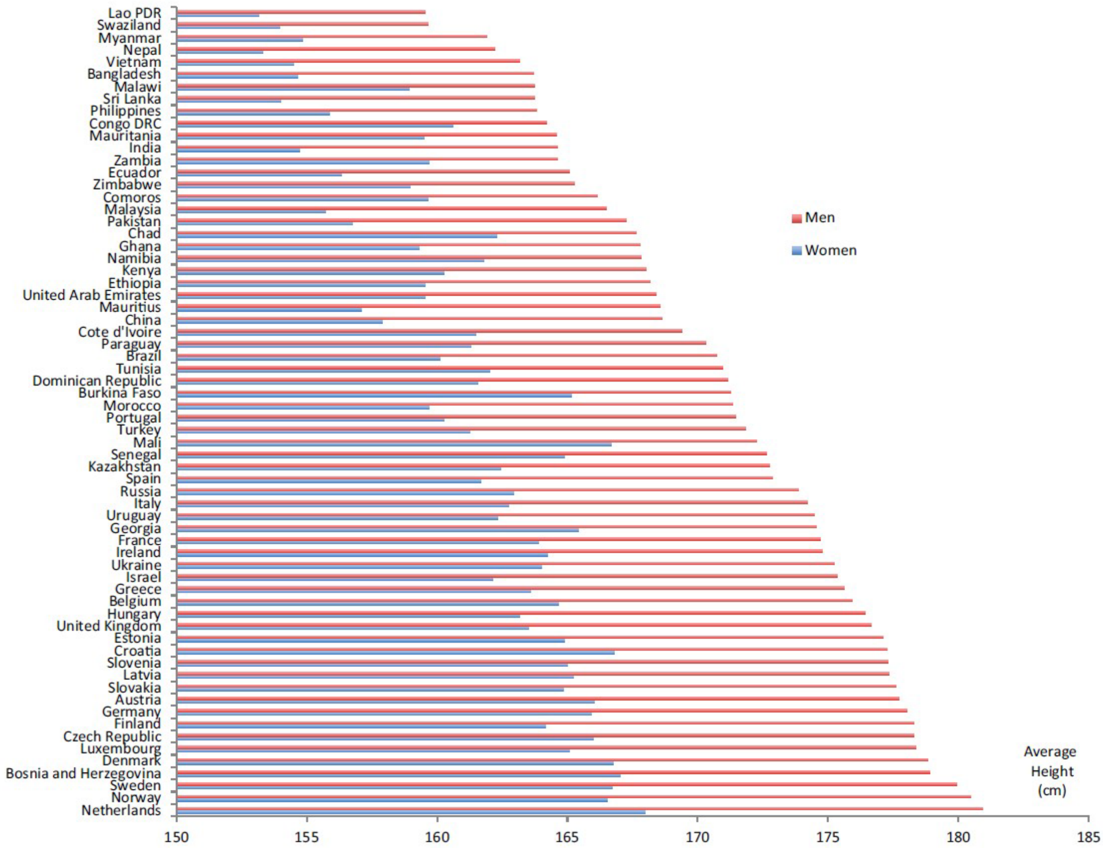

**Fig 3.** Mean height (in cm) of modern adult men (red) and women (blue) across different countries, according to the 2003 World Health Surveys measure of self-reported statures (Perkins et al. 2016: 153).

adulthood compared to those whom never suffered from developmental stunting. Of the Senegalese adults affected by previous developmental stunting, the stature deficit for males could be up to 9 cm below the country's average, and 6.6cm for females. If the health or nutritional intake improves for the individual during their formative years, a so-called developmental catch-up period may be initiated. A developmental catch-up period is usually initiated when the protein intake surpasses the normal required amount, e.g., an increased intake of milk or meat, which promotes an increase in growth hormone production. Many times these developmental catch-up periods are related to a delayed puberty due to the previous developmental stunting, hence the growth period is extended. However, for those adult Senegalese who previously suffered periods of growth stunting, and who later experienced a catch-up period, the effect was limited to a stature increase of c. 1.5cm for males and c. 3cm for females (Coly et al. 2006: 2415-2419; Soliman et al. 2021: 6).

A more extreme example of growth stunting caused by limited access to resources and nutrition can be found in the modern Korean peninsula, where the average stature of North Koreans is 13cm shorter, of either of the sexes, compared to their southern counterpart (Perkins et al. 2016: 152).

### *3.1.1 Health Factors Affecting the Mean Stature of a Population*

The stature of an adult individual can be used as a proxy for their health during childhood and adolescence (Steckel 1995: 1918; Larsen 2002: 126; Gooderham *et al.* 2009: 736), with adult stature usually attained no later than the age of 18 in females (with possible incremental increase up until the age of 21) and 20 for males (Coly et al. 2006: 2415), with Trotter and Gleser (1958: 101) suggesting stature growth could continue till the age of 23 (further bioarchaeological growth related studies: Johnston 1962; Mahler 1968; Walker 1969; Armelagos *et al.* 1972; Sundick 1972, 1978; Lallo 1973; y'Edynak 1976; Merchant & Uberlaker 1977; Hummert 1983a, 1983b; Goodman et al. 1984; Cook 1984; Jantz & Owsley 1984a, 1984b, 1985; Mensforth 1985; Saunders & Melbye 1990; Lovejoy et al. 1990; Hoppa 1992; Farwell & Molleson 1993; Molleson et al. 1993; Miles & Bulman 1994; Ribot & Roberts 1996; Hutchins 1998; Humphrey 2003).

Genetic predisposition is an important factor for the final achieved stature of an individual, as is evident in modern Western societies, e.g., the tallest mean stature in the world is held by the Dutch (Perkins et al. 2016: 153), but is less pronounced in past populations. Genetic differences concerning stature are cancelled out by the individuals' childhood health (Steckel 1995: 1903-1920; Perkins et al. 2016: 153; Brødholt et al. 2022: 11). Yet Brothwell (1981: 100) argued that stature reached in adulthood is only 10% a factor of the individual's environment, while 90%, would be affected by the genetic predisposition of the individual. Brothwell based this assertion on the study of the stature of twins, yet no specific studies are cited. Whilst modern studies of growth patterns in twins attribute the genetic stature predisposition as a factor of c. 80% for the stature achieved in adulthood (e.g., Silventoinen et al. 2003, 2004; McEvoy & Visscher 2009). These numbers are tentative, as these are difficult to quantify, even with large enough anthropometric samples. In modern developed Western countries, the average stature has significantly increased over the past two centuries, since the Industrial Revolution, hence these changes cannot solely be attributed to genetic predisposition, or changes in the gene pool, but rather caused by secular changes (see below). The greatest increase in average stature was recorded in Europe, throughout the period from 1930 to 1980. Different stature trends are recorded in developing countries, as stature increase appears to have stagnated, or as in some African countries, even decreased (Perkins et al. 2016: 149-151). Even within homogenous populations, exterior factors can cause substantial interpopulation variation (Gowland & Walther

2018: 174). As such, stature is used as a tool and a proxy for an individual's health, but not as sole the evidence make health inferences from. The stature results should always, when possible, be supplemented with further evidence to allow for a more precise analysis of the individual, their respective health (e.g., pathologies and diet), and genetic predisposition.

#### *3.1.1.1 Archaeological Examples*

Poor natural, and sociocultural conditions, during the formative years of an individual, can result in their adult stature lagging behind their genetic potential (Rosenstock *et al.* 2019: 5657). This was illustrated by Steckel's (2004) study on the decreasing Scandinavian mean stature from the Viking age, onto the Industrial era, with the latter eras having significant negative effects on the stature. This was caused by a wide range of multifaceted factors, but the net nutritional conditions (i.e. the nutritional value of the diet minus the claims made on it by disease, physical exertion, and the maintenance of essential body functions) were negatively affected due to more urbanization, trade (both contribute to the spread of diseases), climate deterioration (e.g. the little ice age), more societal stratification, conflicts (e.g. the Thirty Year War and the Great Nordic War), and new diseases brought back to Europe from the colonization of the New World (i.e., North and South America). All of these negative health factors contributed to the decreasing stature of the Scandinavians, which only began to recover in the early 20th century (Steckel 1995: 1919; Steckel 2004: 214-216).

Steckel's (2004) results do bring to light many important factors for stature development and decline over time for the Scandinavians, but the tentative nature of the results should not be ignored. Steckel (2004: 213) utilized the femoral formulae developed by Trotter and Gleser (1952), without establishing if there were any ratio correlations between Trotter and Gleser's (1952) sample population, and the Scandinavians being studied (as Mays 2016). These formulae were in turn applied to the skeletal measurements which had been recorded by a wide range of observers (Steckel 2004: 215-216), hence similar to Trotter and Gleser's (1958) second study of military casualties from the Korean War, inter-observer errors are likely. Another example of stature trends regressing within an archaeological population, are to be found within Lallo (1973) and Goodman et al. (1984) studies of the 13th century A.D. population in the central Illinois River valley, which showed a temporal decrease in the diaphyseal long bone length, compared to previous periods. This change is believed to have been caused by a change from hunting and gathering to a more sedentary lifestyle, with maize as the main sustenance in the succeeding periods. Negative trends in stature development are usually associated with environmental and lesser-quality nutritional intakes (Saunders 2008: 134-137).

However, regressing trends in stature is not always detectable, when comparing beneficial periods, with negative ones. Gooderham *et al.* (2019) investigated the health, and bone growth changes that took place in the transition between the Moorish and Christian rule of Medieval Portugal; 42 juvenile skeletons were used in the study: originating from three early Medieval Islamic, and three later Medieval Christian sites (Gooderham *et al.* 2009: 736). The hypothesis was that health, and bone growth, should have regressed during the transition to the Christian periods, as these latter periods were marked by civil strife, urbanization (severely lacking in sanitation), famine, and epidemics. The regression of medical practices is also cited as a major factor, as the mortality rate among Christians being treated, far exceeded those treated by Muslim medical professionals (Gooderham *et al.* 2009: 738). The earlier Moorish period, which by all means, should have produced better bone growth, and healthier individuals, had no significant statistically different results, than the later Christian periods (Gooderham *et al.* 2009: 744). This study highlights the importance of statistical testing, rather than only relying on historical records, to infer the health status of a population based on secular trends.

Another historical example of the extreme can be found in North America, during the first half of the 19th century, as slave children were significantly smaller than their Caucasian counterparts, most likely indicating a very poor nutritional intake (Steckel 1995). Children and adolescents whose diet is rich in carbohydrates yet lacking in protein have a tendency to exhibit stunted stature development, compared to those who have more varied and nutritious diet (Brødholt et al. 2022: 11). But when the individuals reached the age of 8-12, their net nutritional condition improved, due to having reached the working age for slaves, and therefore given a better, and more protein-rich diet, "[… *an*] *undernourished child slows down and wait for better times (Tanner 1978: 128).*" With this improved diet, the young slave individuals had a vigorous catch-up period (as discussed above), reaching a stature in adult age only a few centimetres shorter than the North American Caucasians (Steckel 1995: 1923). Malnutrition can delay puberty, hence a catch-up period is suggestive of a sharp improvement of the health status of the individual, and likely an increase in the amount of protein intake, e.g., milk or meat (as previously discussed), hence initiating the onset of a late puberty growth spurt (Perkins et al. 2016: 150; Soliman et al. 2021: 6). However, as previously discussed by Coly et al. (2006: 2415-2419), even with a growth catch up period initiated by a greater nutritional intake, the full genetic stature predisposition cannot be fully achieved. This is a fairly unique example, as there are no anthropological examples of systematically poor treatment of younger individuals, with such inadequate sustenance until they reach working age.

### *3.1.2 Secular Stature Trends*

No discernible difference in growth trajectories or skeletal size has been detected through studies of the remains of archaeological populations. This would suggest that no major changes in human growth patterns have taken place over time. Rather than genetic differences compared to modern counterparts (if such comparisons actually can be made in relation to affinity), the negative stature development in the past can likely be attributed to the harsher contemporary environments and lesser nutrition intake, among other causes and external stressors, i.e., secular stature trends, which stunted the growth patterns during the formative years of individuals of archaeological populations (Johnston & Zimmerman 1989; Saunders 2008: 134-136).

In human biological scholarship, the term "*secular trends*", refers to the biological changes or trends in human beings over long periods of time. These changes can either be *positive*, i.e., an increase in growth acceleration, or *vice versa*, *negative*, i.e., a decrease (Roche 1979: 3). Secular isometric trends, or scaling, refers to near equal growth acceleration of certain parts of the body in relation to the growth of the stature and body mass, this is apparent with, e.g., the heart, lungs and intestine (Lindstedt 1987: 66; Shingleton 2010: 2-3). Whilst secular allometric trends refers to the disproportionate seize related changes of morphological traits (Klingenberg 2016: 113), i.e., the increasing or decreasing correlation of body size (stature) in relation to shape and other bodily characteristics (e.g., the height of each bone element) in a being (Lindstedt 1987: 66; Shingleton 2010: 1). Allometry is a well-known and widely researched phenomena within evolutionary biology over the last century (e.g., Snell 1892; Huxley 1924, 1932; Cock 1966; Gould 1966; Calder 1984; Schmidt-Nielsen 1984), Zoology and Morphometrics (i.e., quantitative analysis of form, e.g., size and shape) (e.g., Jolicoeur & Mosimann 1960; Jolicoeur 1963; Sneath & Sokal 1973; Oxnard 1974; Pimentel 1979; Bookstein 1986; Rohlf 1990; Marcus et al. 1993; Klingenberg 2010, 2016; Mitteroecker et al. 2013), and in physical anthropological research (Trotter & Gleser 1951a, b; Fogel 1986a, b, 1995; Steckel 1987, 1995; Steegmann, 1985, 1986, 1991; Komlos 1990, 1994; Floud, et al. 1990; Floud 1994; Jantz & Meadows 1995; Jantz & Jantz 1999; Wilson et al. 2010). Humans, similar to any other biologically long-term evolved creature, are not exempt from allometric consideration (Wilson et al. 2010: 684-685), yet its consideration within archaeologically related stature studies has commonly been missing. If long bones are affected by allometric, or isometric secular trends (each long bone is), then it should be treated as a key factor of consideration when formulating stature regression formulae, as this determines how the formulae are calculated (either using Ordinary Least Squares (OLS), or Reduced Major Axis (RMA) formulae), and how the error ranges are calculated (further addressed in the methodological and result chapters, Chapter 8 and 9).

Biological changes, such as allometric secular stature trends, may be caused by either genetic or environmental causes, and typically it is difficult to determine which of the two is the main contributing factor. However, such trends within archaeological populations in which the nutrient intake is limited, as is the case with the material of this study (further discussed below), then these secular trends can in large be attributed as an artefact of environmental causes. The environment in which these individuals spend their formative years tends not to be suited for reaching their genetic stature predisposition. These environmental causes can range from external stressors (e.g., excessive physical exertion), and disease, to diet (e.g., when dominated by carbohydrates yet lacking in protein). A lot of this stems from the health of the mother (as discussed above), as the fetus *in utero* is fully reliant on its mother's health and nutritional intake (Steckel 1995: 1903; Jantz & Jantz 1999: 57-66; Naaz & Muneshwar 2023: 6). Hence the poor living conditions and low nutritious intake of a current generation in a population, will cause the succeeding generation to suffer equally, or worse, especially in their developmental growth, with stature being one of the key factors affected.

The lower limbs exhibited well-defined positive secular allometric trends in relation to the full stature, i.e., these bones increase in proportionality as stature increases, whilst the upper limbs remain fairly isometric, i.e., the proportionality remains fairly the same even as stature increase "[…] *lower limb bone secular change is more pronounced than upper limb bone change* […] *(Jantz & Jantz 1999: 65).*" Secular trends do exhibit genetic biases among different populations, but furthermore, exhibits well defined sexual biases, e.g., Caucasian males were the only group which exhibited allometric trends (negative) of the humeri in the 19th to 20th-century North American sample groups used by Jantz and Jantz (1999: 58-60). Males and females, either purposely, or inadvertently, respond to environmental changes differently, with greater changes seen in secular trends predominantly affecting the males of a population (e.g., Stini 1969; Greulich 1976; Wolanski & Kasprzak 1976; Stinson 1985). This is believed to be the result because the female body is more resistant to environmental changes and hence will exhibit less changes as a result of secular allometric trends over time (Wolanski & Kasprzak 1976: 548; Jantz & Jantz 1999: 65). Wolanski and Kasprzak's (1976: 549) study of late-19th to mid-20th century Polish populations, reached the conclusion that both advantageous and disadvantageous environmental stimuli produced changes in the male sample first, whilst comparatively, far stronger environmental changes were necessary before a shift was seen in the female sample's secular trends. This means that, on average, female stature samples will be far more homogenous than their male counterparts within the same population.

Hence secular trends in regards to long bone length, either caused by genetics or the environment, isometric or allometric, is one of the reasons why it may be inappropriate to apply a stature formulae that have been developed on one population onto another (Hoppa 1992: 285). Wilson et al. (2010: 688) argued that the stature formulae developed by Trotter and Gleser (1952, 1958) on the late-19th to mid-20th century North American populations, is not a good fit in forensic anthropological research studying modern North American populations. This conclusion was reached, as the stature results using the previous formulae were not considered conservative enough in their estimates, hence not representative of current living generations. This is likely an artefact due to the effects of secular trends affecting North American populations since Trotter and Gleser initially developed the formulae (Wilson et al. 2010: 688).

A British example closer temporally to the samples used in this study, Wells (1960: 139-140) study of limb proportion to the full stature of the early medieval male sample previously measured by Münter (1936; discussed above), these results were compared to the 20th century North American sample population used by Trotter and Gleser. According to Wells, the upper limbs, especially the humeri, were longer in the British early medieval sample, hence Trotter and Gleser's (1952) upper limb formulae underestimated the stature, with the opposite result regarding the shorter limbs of the early medieval sample. Wells attributed this greater upper limb length as caused by habitual physical use (Wells 1960: 139-140). However, studies of modern elite athletes, e.g., cricket and tennis players, comparing the length of the dominant arm, with that of the non-dominant, the results proved that physical loading have little to none bearing on the development of the bone length (c.+1% in bone length of the dominant arm) (e.g., Haapasolo et al. 1996; Shaw & Stock 2009). Hence rather than being caused by a secular habitual trend, genetic predisposition within the early medieval populations of Britain towards longer upper extremities is a more likely explanation.

## *3.2 Chapter Summary: Growth-Related Studies and Secular Stature Trends*

This chapter focused on the complexity of skeletal growth through several contributing factors, typically referred to as secular stature trends, i.e., non-genetic stature causations shaping the final stature achieved in adulthood, e.g., the environment, diet, and health of the mother whilst the fetus develops in utero, or through breastfeeding, and the health of the individual through adolescences. These different stature factors were problematized in a discussion of past pediatric, anthropological, and archaeological studies of stature, both on an individual and population level (Steckel 1995: 1903, Jantz & Jantz 1999: 66, Perkins et al. 2016: 153-154).

One key factor in the study of long-term population stature development which has rarely been addressed in past bioarchaeological studies, is the marked difference in bodily responses towards secular stature trends between the sexes. For example, the female samples tend to exhibit a greater homogeneity in their stature trends, than their male counterparts (e.g., Stini 1969; Greulich 1976; Wolanski & Kasprzak 1976; Stinson 1985). These differences between the sexes suggest a disparity in the expected achievable accuracy of any regression formulae calculated on a population that includes male and female samples, as the female stature trends should theoretically be far easier to trace. This important secular factor returns to the discussion of the previous chapter, regarding Sjøvold's (1990) pooled sex approach, problematizes the variability, and hints at the discussions that will be returned to in later chapters of this study.

Another important factor discussed here, for consideration in the study of stature, and in the calculation of stature regression formulae, is the matter of bone lengths' correlation to the full stature achieved in adulthood across a population sample, either being isometric (i.e., even) or allometric (i.e., uneven). This is a foundational factor when calculating a stature regression formulae, due to its bearing on the choice between Ordinary Least Squares (OLS) or Reduced Major Axis (RMA) approaches, which has a bearing on the final accuracy of the formulae (further illustrated and discussed in Chapter 8 through 10).

Outlining and understanding how stature develops, negatively (reduction) or positively (increase), both on an individual and population level, through external factors, is paramount when studying the correlation of stature with the health of an individual or population, past or present (further addressed in Chapter 10).

# 4. Adventus Saxonum and the Population Range

Following the collapse of Roman-controlled Britain in the late-fourth to early-fifth century, and the withdrawal of the legions, the following centuries saw many changes; ranging from the structure of society to cultural expression, and the appearance of Germanic foreigners who settled in eastern and southern England (i.e., *"Adventus Saxonum"*, further discussed below), and the introduction Germanic and Frankish continental artefacts in the archaeological assemblages. These foreigners saw success in their incursions into the previously imperial territory of Britain through a myriad of factors, as later chroniclers speak of a civil society that had dissolved, large-scale depopulation through famine, disease, and conflict. However, the transition from Romano-Britain to the succeeding period of the early medieval, would have been gradual, which is evident in the continued occupation of previous regional centres, e.g., Canterbury and Lincoln, with some regions showing the absence of continental Germanic artefacts in the archaeological assemblages, as far as the seventh century, e.g., St Albans and Chilterns. The cultural exchange did not only happen one way, as Romano-British artefacts, e.g., Roman glassware and coinage, have been uncovered in furnished graves prescribed to Germanic foreigners; the practice of furnished graves became far more prevalent in the burial practices of the period, as it appears to have been reintroduced by newly arrived foreigners (Loveluck & Laing 2012: 537-538; Charles-Edwards 2013: 189; Morris 2021: 23-30).

Key events of this period (see Table 1.), and the spread of foreign people and influences to the isles, are important to highlight here for this study, as it form the basis for the discussion of the formulation of the period's population range and demography.

**Table 1.** Some significant dates in British early medieval history (Campbell 1991: 20; Magennis 2011: 16-29).

| | |
|---:|---|
| **449 A.D.** | Estimated beginning of the Angles, Jutes, and Saxon settlement period in Britain |
| **c. 550 A.D.** | Gildas's: *On the Fall of Britain* |
| **597 A.D.** | St Augustine brings Roman Christianity to Kent |
| **673-735 A.D.** | Life of Bede (Ecclesiastical History) |
| **793 A.D.** | First arrival of the Vikings, raid at Lindisfarne |
| **851 A.D.** | Danes' first winter in England |
| **878 A.D.** | Introduction of "Danelaw" |
| **871-899 A.D.** | Reign of king Alfred of Wessex |
| **937 A.D.** | Reign of king Edgar, West Saxon king of all England |
| **1013-1040 A.D.** | Dane kings of England |
| **1066 A.D.** | The battle of Hastings, and the battle of Stamford Bridge. |

As discussed in the previous chapters, the affinity of a population or group is of great importance, and consideration, when calculating stature formulae. To address this issue in regards to the material used in this study, this chapter will approach the topic of migration of Germanic foreigners into Britain during the early medieval period, and how this affects the population range at the different sites used in this study.

## *4.1 Adventus Saxonum*

It should not come as a surprise, that foreign individuals (place of birth beyond the region of the sites where their remains were uncovered) are uncovered within the populations of human remains recovered from British early medieval sites (Walker et al. 2020: 181); *"... there will always have been* [and will be] *some elements of society who travelled much and/or afar (Needham 2014: 221)."* These foreign "*elements*" or individuals could have been, e.g., raiders, religious specialists, traders or leaders *etcetera*. A good British example which can illustrate this, is the site of Cliffs End Farm (McKinley et al. 2014), on the island of Thanet, along the coastline of Kent; the human remains were dated through radiocarbon dating, giving three distinct periods for the inhabitation of the site: Late Bronze Age, Early Iron Age, and Middle Iron Age. Through strontium isotope analysis the origin of the individuals buried at the site, it was possible to trace: seven out of thirteen individuals from the Late Bronze Age as being of foreign origin; two out of five from Early Iron Age were foreign, and five out of seven from the Middle Iron Age were foreign. These foreigners' origin were traced to both southern and Northern Europe, i.e., Scandinavia (McKinley et al. 2014: 144). This highlights that immigration in the British Isles from northern and continental Europe was a continuous process which started already during the Late Bronze Age.

> For the fire of vengeance, justly kindled by former crimes, spread from sea to sea, fed by the hands of the impious easterners, and did not cease, until, destroying the neighbouring towns and lands, it reached the other side of the island and dipped its red and savage tongue in the western ocean (Gil. DEB. 24).

Roman rule lasted for nearly four hundred years in Britain, only to be replaced by foreign Germanic influences from a myriad of different sources of origin, at least such was the dominant erstwhile consensus. This transition period, from the abandonment of the Roman administration to the arrival of the Germanic foreigners en masse, has remained clad in mystery since the study of the early medieval period began three centuries ago. The chroniclers *Bede* and *Gildas* have remained the authoritative voices of this period, who speak of a period where civil society dissolved, a large-scale depopulation through famine, immigration of Germanic foreigners, disease and both inter and extra-violence (Morris 2021: 23). This transitionary period is commonly called, *Adventus Saxonum* ("The coming of the Saxons"), and refers to the migratory period of increasing Germanic influences (Saxons, Angles, and Jutes), spanning the fifth to the sixth century. The archaeological record from the late fourth to early fifth shows an initial sharp decline in population, following the withdrawal of Roman rule in Britain (Hughes et al. 2018: 513).

> In the early fifth century [...] Britain reverted to a level of economic simplicity similar to that of the Bronze Age, with no coinage, and only hand-shaped pots and wooden buildings. (Perkins 2006: 124).

This transitionary period's poverty is exchanged for a period of ever-increasing Germanic influences, which is especially prevalent in the material recovered from the furnished graves. However, cultural continuity from the Roman-Christian era remained present in the archaeological records from the more rural sites (Hughes et al. 2018: 513), or in some instances, both Germanic and Roman-Christian groups appear to have existed side by side, e.g., Berinsfield and Queens Farm (Hughes et al. 2014; see below).

As is typical in historical narratives, the notion of a complete replacement of the previous Briton population with a Germanic population (i.e., "The Replacement Hypothesis") proved attractive for early scholars of the subject, as the introduction of new artefactual typologies, and the disappearance of others, then only required minor hypothetical discussions in such cases (Hughes et al. 2014: 82; Hughes et al. 2018: 513). A famous example within historical and archaeological studies that illustrates this issue is the notion within Archaic and Classical Greek studies of: "The arrival of the Greeks"; which has been a contentious topic since its introduction in the 19th century. This notion suggests that Greek-speaking Indo-Europeans migrated and settled in Hellas during the Late Bronze Age, replacing those who lived there before (Hall 2002: 38-46). The Oxfordian classical scholar, Sir John Linton Myres, phrased the development of "Greekness" as: *"[…] the Greeks never wholly were* 'one people'*, but were in the process of becoming one (Myres 1930: 538)."* Jonathan M. Hall (2002: 48), argues hence for caution in regards to the Late Bronze Age Greek materials, as the homogeneity of Mycenaean archaeological assemblages cannot be used to extrapolate information of homogeneity within the affinity of its population, but rather suggests merely homogeneity in its cultural and material expression. Could a similar phenomenon have been in motion in early medieval Britain? To a certain degree, yes. This were brought to bear through the cultural exchange with a contingency of foreigners who settled in the British Isles in the fifth century A.D., and who coexisted with the local Britons (to a certain degree), rather than a complete ethnic replacement through warfare, conquest and ethnic cleansing (Gretzinger et al. 2022: 112; Morris 2021: 34). This notion of a complete population replacement in early medieval England have in large been discredited, through the revaluation of the archaeological assemblages and the use of modern methodologies (Halsall 2013: 103-113). However, it is clear that large sways of people migrated to Britain during this period, bringing their language and cultural expression to the British Isles, hence the question should be phrased as: to what extent did foreign populations conquer or integrate into the early medieval Britain?

The range of human remains and archaeological material in its raw form can only attempt to address so many scholarly quandaries before reaching its limits. Here, the last three decades of biochemical research can aid in expanding the limits of possible hypotheses that may be addressed to the biological parts of the archaeological assemblages, e.g., human and animal remains. With regards to the early medieval period, a long-standing question regarding migration has been attempted to be answered mainly through artefactual typologies (e.g., the studies by Åberg 1926), this may be further explored through molecular methodologies (e.g., strontium and oxygen isotope analysis), which can be used to investigate the demography and provenance of the human remains uncovered in cemeteries dated to the period (Shiner 2012: 79-80; Brettell et al. 2012: 118).

### *4.1.1 Oxygen and Strontium Isotope Analysis*

Beyond written sources, and the archaeological assemblages, the demography of past populations can be investigated further in greater detail through stable isotope analysis (elements which do not undergo radioactive decay, hence remain part of the structure of the element, e.g., bone collagen). Isotope investigations of human remains is possible to achieve by analysing the ratio and signature of both strontium ($^{86}Sr/^{87}Sr$) and oxygen ($\delta^{18}O$) isotopes which are present in the skeletal structure of the recovered human remains. These isotopes store data that can give geographical signatures of the origin of the individual, or where their formative years were spent (Shiner 2012: 82). Teeth enamel is a common source for this analysis, as the enamel is less susceptible to contamination contained in the surrounding matrix of, e.g., the grave fill, than the regular bone cortex. The ratios or signatures of oxygen ($\delta^{18}O$) or strontium ($^{86}Sr/^{87}Sr$) which are detectable in the enamel are formed during the period of formation of the teeth, e.g., the first molar (i.e. the first permanent teeth to be formed), which begin its development through

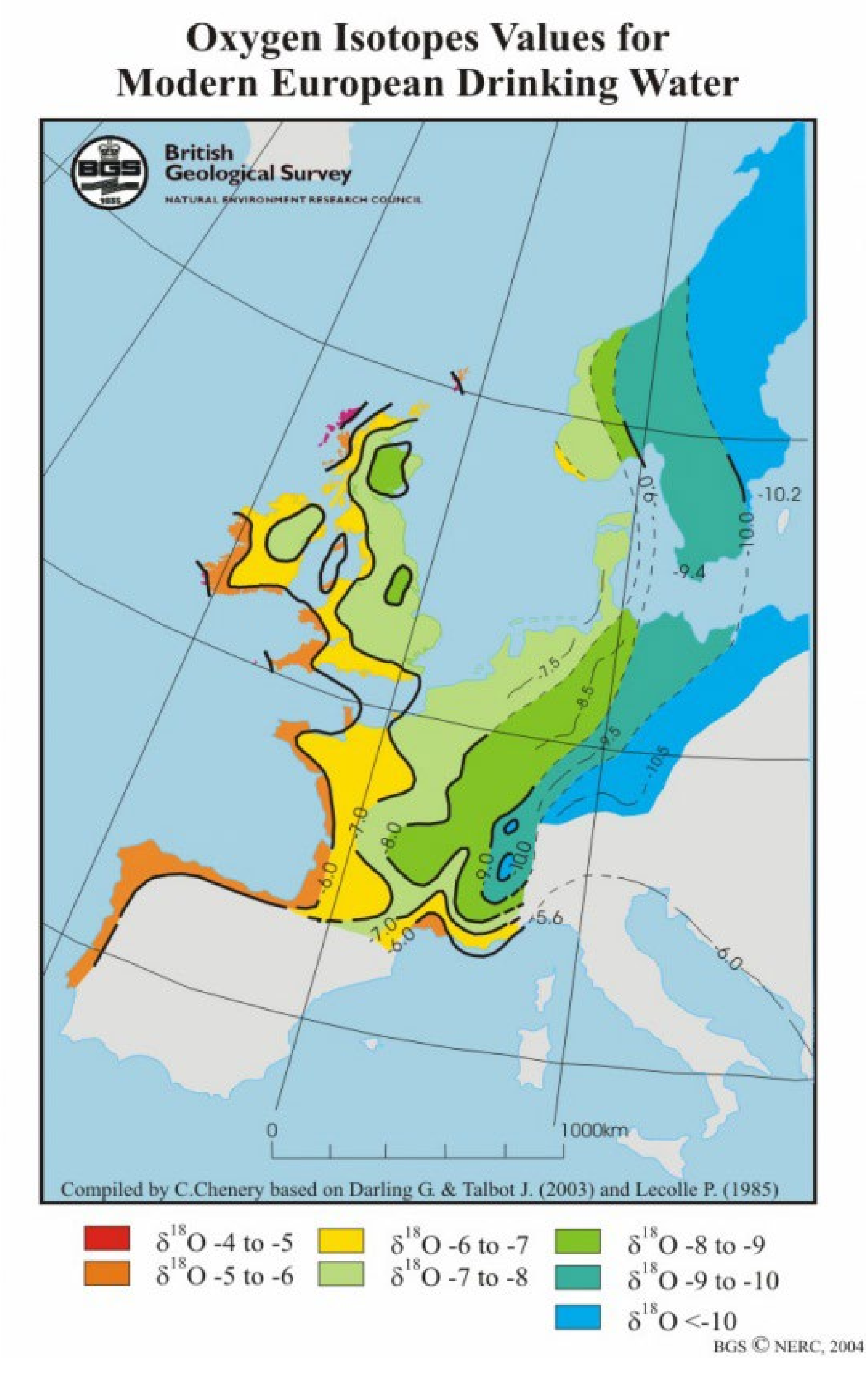

**Fig 4.** The British Geological Society map of the oxygen isotope values of modern European drinking water (2004), BGS © UKRI.

mineralization at birth and is fully formed at the age of 11 to 12 years old, whilst the second molar forms between age two and eight, and the third molar (if present) form later in childhood, around age seven to sixteen, hence each molar reflects the isotope signature of the individual during their formative years, i.e., which region the individual was reared in (Sealy et al. 1995: 290; Hughes et al. 2014: 81-85; Hughes et al. 2018: 519).

Enamel, unlike bone matrixes, do not remodel itself over time, hence the signature does not change. While bone tissue frequently remodel itself, with old bone tissue (in a healthy individual) continuously being replaced at the rate of c. 2-5% of the cortical bone being remodelled yearly, hence the isotope signature may change over time if an individual migrates and settles in a region in adulthood which is different than where they were born. Cancellous and woven bones react differently, constantly fed by blood vessels, hence tend to reflect a shorter time period than compact bone, as these areas have a quicker turnover and remodelling phase (Sealy et al. 1995: 291; Hadjidakis. & Androulakis 2006: 386-390). These factors allow the signatures of enamel to be used and compared with the signature of the bone matrix, to determine if an individual has migrated throughout their lifetime since the formation of the enamel (Katzenberg 2008: 430; for case studies see e.g., Schwarcz & Schoeninger 1991; Sealy et al. 1995; White et al. 1998).

The ratio of oxygen isotopes in groundwater (i.e., drinking water) decreases the further it is from the ocean, with increasing altitude, as greater quantities of the heavy isotopes fall in precipitation, average yearly temperature, hence forming a specific regional signature. However, as Fig 4. illustrates, these regional signatures are transversely shared throughout western Europe (i.e., precipitation regions), due to similarities in the above outlined environmental criteria. Humans' intake of oxygen isotopes occurs mainly through groundwater, but on a smaller scale, is also absorbed through the moisture in the air and food. The structure of the skeletal matrix is formed in equilibrium with the composition of the water contained in the body, hence the oxygen signature is imbued in the skeletal structure, and dental enamel, which form during the formative years of an individual's life (Katzenberg 2008: 430; Brettell et al. 2012: 118; Hughes et al. 2014: 81-83).

While the strontium isotope signatures are derived from bedrock and are mainly dependent on three factors: the age of the formation, the initial strontium ratio, and rubidium abundance in the bedrock mineral (Lahtinen et al. 2021: 4). Bedrock can be broken down through a myriad of different weathering processes, e.g., *mechanical weathering*: pressure expansion, frost wedging, root wedging and salt expansion; *chemical weathering*: carbonic acid, hydrolysis, dissolution, and oxidization; furthermore, bedrock can also be broken down through *erosive*

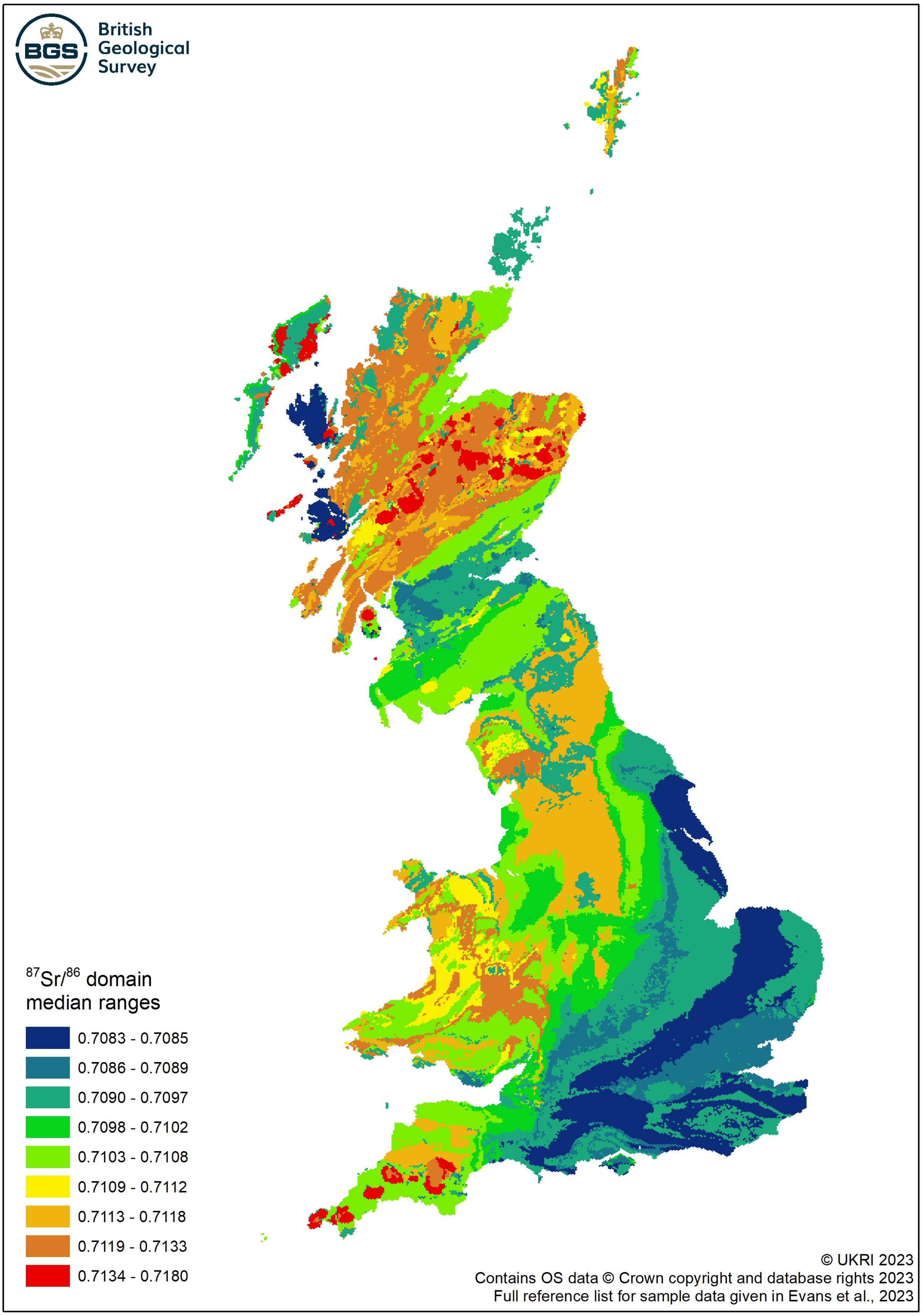

**Fig 5.** The British Geological Society's map of the Strontium isotope values of Great Britain, based on geological domains, (2023), BGS © UKRI.

*processes*, e.g., water, wind, mere gravity or ice. These plentiful processes turn the bedrock into smaller particles and soil, hence forming new sediments that carry the signature of the original regional bedrock which it is derived from. Aiding in the specific regional signature, generally speaking, the older the rock formation is, the higher $^{86}$Sr/$^{87}$Sr values will be; this signature is further regulated by the initial strontium to rubidium ratios, and the rock type, e.g., calcareous rock types are generally lower in strontium than silicate, due to the effect which seawater has on its formation. These signature migrates and travels, with everything which is grown in the soil which has been produced by the dismantled bedrock (Johnson et al. 2017: 159; Hughes et al. 2018: 517). These plants may hence be ingested by herbivores or humans, hence the strontium traces migrates into the biological structure of either animals or humans. The strontium signature can also migrate second-hand, e.g., through the devouring of the flesh of a herbivore who had ingested the local flora carrying the strontium signature, either by a carnivore or a human being (i.e., omnivore). Similar to oxygen isotopes, strontium signatures can also be derived from the drinking water, with some studies (e.g., Klusek 1984), suggesting this source to be more dominant in providing a strontium signature than the actual diet, whilst others (e.g., Tolstykh et al. 2011), suggest equal contribution between groundwater and diet to the signature. This full process leaves a distinct signature in the skeletal remains which, similar to the oxygen isotopes, can be used to trace the origin of an individual (Bentley 2006: 135-146; Hughes et al. 2018: 517).

To determine the strontium levels which is derived from food products and plantstuff from a specific region, then skeletal remains of local fauna (non-migratory) current flora and soil samples, can be analysed, as to compare their respective levels to that of archaeologically recovered human remains, to determine if the human remains possess strontium levels which is a good match with the local regional levels (Sealy et al. 1995: 292). If the individual level proves to be an ill-fitting match, then a wider interregional comparison of strontium levels may be necessary, as the individual may have originated from somewhere else.

Special considerations are necessary when analysing a population whose diet consists of a marine diet, or mixed marine and terrestrial diet, as mixed sources of strontium may obfuscate the regional signature, hence complicating the analysis. This can be investigated through the analysis of nitrogen levels ($\delta^{15}$N), as high values of nitrogen are observed in diets rich in marine food, due to the longer food chain; whilst significantly lower in diets consisting of terrestrial foodstuff (Lahtinen et al. 2021: 1-7). The Solution to this is to formulate two different strontium baselines, one for the local terrestrial strontium isotope range (as discussed above), and one corresponding marine range, which can be achieved by, e.g., analysing the strontium isotope range of local marine mollusc shells, etc. (Fornander et al. 2015: 3-6).

#### *4.1.1.2 Isotope Population Range Examples*

The upper Thames valley has been proven through archaeological research to have been densely populated during the late Roman era, as within an 8km radius of the modern village of Berinsfield, three late Roman towns, several villas, and hamlets have been uncovered. A late Roman cemetery, Queens Farm (188 graves), was uncovered 1.2km southeast of modern Berinsfield, with radiocarbon dates reaching into the early fifth century. This dating is temporal with the earliest phase of the early medieval cemetery of Walley Corner (114 graves), which lay nearby, 600m north, 1.4km east by southeast of modern Berinsfield. The health of the individuals and their dietary strategies (based on $\delta^{13}C$ and $\delta^{15}N$ analysis) appears to have been different between the two cemeterial populations, hence have been hypothesized as suggesting the prevalence of a type of apartheid or tribal separation between the two distinct groups (Hills & O'Connell 2009: 1097-1099; Hughes et al. 2014: 83).

Hughes et al. (2014), chose 19 adult individuals from the cemetery of Walley Corner for isotope analysis. These individuals were chosen from the earliest dateable graves of the cemetery, with estimated dating ranging from the early to the late fifth century, based on the artefactual typologies in concordance with the radiocarbon dating. The local bioavailable strontium was established through analysis of local soil samples and dentine sourced from local herbivores. The strontium signatures were compared to the signatures extracted from the enamel of the second molar of these 19 individuals; the oxygen isotope values were compared to the well-established oxygen isotope values of drinking water from around Europe (Hughes et al. 2014: 84-85).

The isotope result showed that 15 individuals were of local origin, whilst four individuals had isotope values that did not match that of the region. One of these, Burial 6, is an adult male, whose both oxygen and strontium values suggest a non-British origin, but rather likely originated from southern Germany. Burial 81, also an adult male, their isotope result proved more complicated, as their oxygen values matched with northeastern England and north-central Europe; their strontium values concurred in this ambiguous result, giving a northeastern England to central Germany as origin. However, Hughes et al. (2014: 88-90) suggest Burial 81's lack of grave furnishing suggests a foreign origin of the individual. The remaining two individuals are of British origin, but who spent their formative years outside the geological region of Berinsfield (Hughes et al. 2014: 88-90).

Hughes et al. (2018) performed a second study, sampling another 19 individuals (utilizing the same methodology outlined above) from the site of Eastbourne, Sussex, along the southern English coastline. These 19 individuals (similar to Berinsfield) were dated through artefactual typologies along with radiocarbon dating, which gave a period from the late fourth to the sixth century (Hughes et al. 2018: 513-518). Ten individuals (five males, two females, one adolescent, and two of unknown sex) proved to have isotope values which were consistent with the geological region of Eastbourne, hence can be considered as being of local origin, or at least to have spent their formative years in the region. The remaining nine individuals of the sample exhibited isotope values foreign to Eastbourne. Two females (Burial 64 and 264), had oxygen values that matched Eastbourne, but their strontium values suggested an origin from a geological region adjacent to the site. Three individuals (burial 51, 355, and 796), a young male (burial 796) and two adult individuals of unknown sex, had strontium values matching central England, however, these values can also be found in western Germany, northern France, and Denmark, suggesting a tentative foreign origin of these three. The last four individuals (burial 57, 270, 309, and 481) exhibited higher strontium values and lower oxygen values than the site average. Individual 57 and 309, both males, originated from northeastern England, possibly western continental Europe; individual 270, possibly female, had values matching central to northern Europe; individual 481, a young male, originated from southern England (Hughes et al. 2018: 522-523).

Similar to early medieval stature studies in Britain, the population range of the period through isotope analysis, merits further future research, to reach less tentative results. Brettell et al. (2012: 117), suggest a further emphasis focused on the isotope signatures of European water sources, to expand the dataset, and enhance the resolution of oxygen isotope studies, allowing for less tentative results when tracing and discussing an individual or a population’s origin. As it stands now, oxygen isotopes can only give a general estimate of origin (see Fig 4.). A similar issue is faced in strontium isotope studies (see fig 5.), as the geological regions of northwestern continental Europe, where many of the Germanic immigrants are believed to have originated from, exhibit a fairly similar strontium signature (Brettell et al. 2012: 118), as is evident with, e.g., Burial 81 from Berinsfield (Hughes et al. 2014: 88-90). Brettell et al. (2018), sought to remedy this issue, by investigating the oxygen and isotope signatures of early medieval sample populations from Britain, and contemporary continental northwestern Europe. Twenty-one individuals from four sites were chosen in this endeavour: seven individuals from Ringlemere (England), five individuals from Hannover-Anderten (Germany), and 12 individuals from

Giberville and Sannerville (France). Each of these sites were chosen for their early medieval dating, but furthermore, none of these sites are located within the same oxygen isotope zone (Brettell et al. 2018: 118-120). The results of the study proved non-satisfactory, as the oxygen isotope levels were consistent with that of the local values, except in regards to the Ringlemere sample, whose oxygen levels were higher than that of modern drinking water in the Kent region, however, this is unlikely suggestive of foreign origin of these individuals, but rather falls within the error range of intrapopulation variation; perhaps a wider isotope study of early medieval Kent, with a larger sample, can explain this anomaly. As for the strontium isotope results, even with the diversity of its sample populations, it reiterated the shortcomings of the other isotope studies, as the geology of the different regions proved too similar, hence only giving, again, tentative results concerning the provenance of the Ringlemere population compared to their European continental counterparts (Brettell et al. 2018: 134-137).

Based on the results outlined above, even if tentative, the different early medieval populations appear to have been in some instances, fairly homogeneous in regards to their geological origin, or consisting of individuals whom originated from regions in continental Europe with similar oxygen and strontium values. However, a greater resolution, and the use of a larger number of individuals is crucial, when investigating the migratory patterns of the whole period, rather than on a site by site basis. Leggett et al. (2022) conducted such a large scale isotopic study, analysing both strontium and oxygen isotopic values extracted from the teeth enamel of 700 individuals, whose remains have uncovered in England, in contexts dating to the first millennium AD (i.e., spanning the periods of Romano-Britain, Early Medieval and Viking Invasion). This study revealed consistent migratory patterns, which fluctuated over time, and was not limited to specific periods or centuries, suggesting an ongoing process from the late Roman period through the Norman Conquest. Of important to note, migration from colder high altitude regions (e.g., lower Germany) was higher in the 5th-7th centuries, whilst during the Viking Age, as to be expected, an significant increase in migration from Scandinavia is to be found in the results (Leggett et al. 2022: 15-19).

Leggett et al.'s (2022: 20-22) study further analyzed the gender composition of those individuals of foreign origin. During the Roman period, a larger sample of the male population had distinct foreign patterns of oxygen and strontium isotopic values, suggesting migration from outside southern Britain, whilst the female population's values indicated a greater frequency of local origins. This later changed during the early medieval period, with both the male and female populations exhibiting a fairly even divide between local and non-local origins. However, these migratory trends and schemes were not even across the board, e.g., early medieval Finglesham, Kent, where the male population exhibited a greater frequency of foreign origin, than their female counter parts (Leggett 2021: 19). There were subtle differences, with more men from colder regions and more women with warmer climate signatures (Southern Europe). During the later period with the Viking incursions, a notable shift occurred again in the gender composition of those of foreign origin, with the males exhibited a stronger Scandinavian pattern, than their female counterparts. In contrast, the female sample exhibited isotopic enrichment (e.g., enrichment through specific diet) or similar to previous periods, migration patterns suggesting origins from southern Europe or from further west in the British Isles, e.g., Wales or Cornwall, or further west afield from Ireland (Leggett et al. 2022: 20-22), as similar oxygen isotopic values are to be found in these regions.

Caution should be observed before drawing conclusions from isotope data, as oxygen and strontium isotope results should not be conflated with proof of affinity. For example, an individual of Germanic affinity (or descent) who spent their formative years in Britain, may exhibit the same isotope signatures as an individual of local Briton affinity whom grew up in the same precipitation and geological region. However, the large scale studies by Legget et al. (2022), and the smaller region based studies discussed prior, do suggest a continuous migratory patterns into England throughout the early medieval period, from diverse origins, ranging from southern to northern Europe, likely suggesting a diverse ethnical composition of this period's regional populations, which is difficult to discern, if only utilizing the grave goods (Leggett 2021: 19).

### *4.1.2 Kinship through Ancient DNA*

Ancient DNA (aDNA, i.e., Ancient Deoxyribonucleic Acid; the molecular building block that is imbued with the information concerning the development of an organism) can many times fare better (Schultes et al. 2000: 38). Comparatively to isotopic analysis, aDNA can trace long term migratory patterns, whilst isotopic data, unless using a large resolution with material from several different periods, rather traces short term migratory patterns, due to the bone turnover patterns (i.e., remodelling). The replacement of old bone tissue with new, which is exhibited at different paces, e.g., cortical bone tissue at a five percent turnover per year, being far slower than endosteal surface which has a turnover of 15% per year, meaning that the full bone tissue is replaced each twenty years of an individual (Nanci 2017: 117), hence its isotopic signature represents a specific twenty year period of an individual's life. When analysing past populations

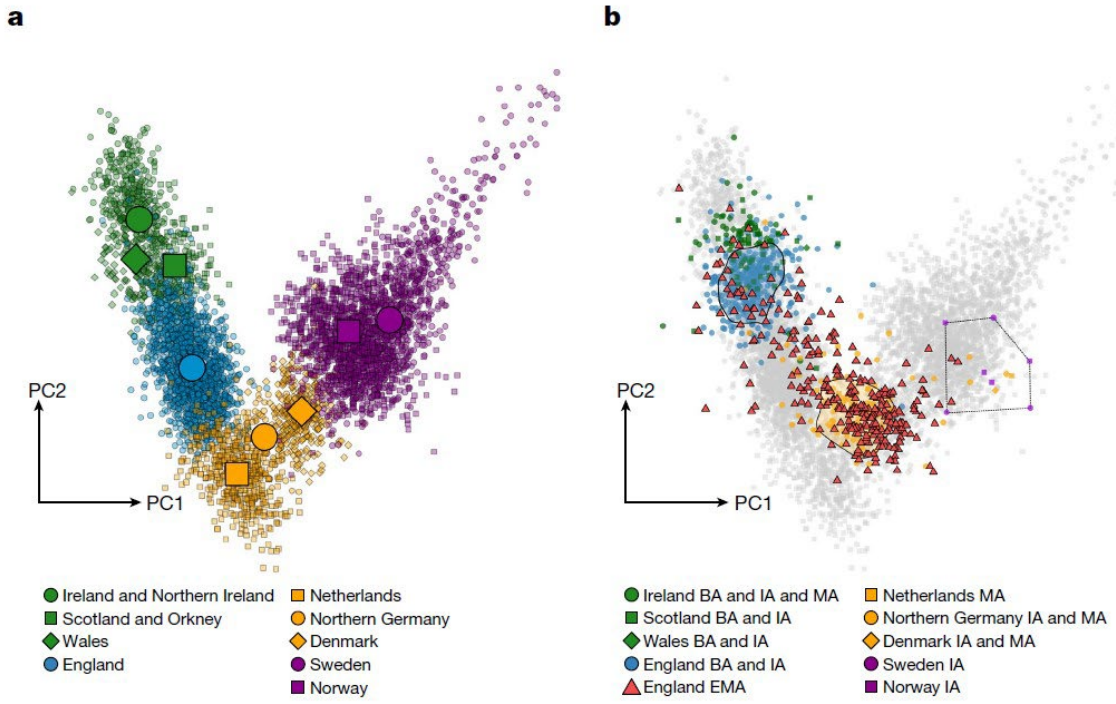

**Fig 6.** A. Present-day genomes from northwestern Europe. B. Ancient individuals utilized in the study by Gretzinger et al. (2022). Polygons indicate where two-thirds of the respective groups are located: **(England Bronze Age(BA) + Iron Age (IA) and North Sea IA + Early Middle Ages (EMA), respectively) (**Gretzinger et al. 2022: 115).

with the aim of tracing kinships between individuals, or groups, utilizing aDNA analysis as a method (similar to stature studies), then a large dataset is required. This is done to prevent erroneous conclusions, which might stem from sampling errors or from analysing too small of a sample group, which does not represent the larger population trends (Stone 2008: 467). Gretzinger et al. (2022) performed a large international and interdisciplinary study of early British DNA genomes (the largest to date, participated by 80 different scholars), homing in on the early medieval period, to attempt to address the controversy outlined above where isotope studies fell short, regarding the increasing Germanic influences following the Roman withdrawal from Britain. In this endeavour, the human remains of 460 northwestern European individuals, who in majority were dated to the early medieval period from 37 different sites were analysed and had their aDNA extracted. The sample consisted of: 278 individuals from Britain, which had been excavated at 11 different sites: Apple Down (included in this study), Dover Buckland, Eastry (included in this study), Ely, Hatherdene Close, Lakenheath, Oakington, Polhill (included in this study) and West Heslerton (Gretzinger et al. 2022: 112-113).

The result of the study showed that 76% of the sampled early medieval British population had recent ancestry from continental northern Europe (Fig 6.). These results are most prevalent in eastern and Central England, with the percentile falling off further south and west; the mean value across England is closer to c. 50%. Contemporary populations from Lower Saxony proved genetically indistinguishable from those Germanic foreigners uncovered at the 11 English sites, suggesting a common ancestry. However, the ancestry of some foreigners were traced further afield to France (explaining the Frankish influences in the material culture) northern Netherlands, Belgium, Denmark, and southern Sweden. Not surprisingly, the genetic influences from Scandinavia increased significantly in the later phases of the early medieval period, to c. 30.6%, with the larger invasion and settling of Scandinavian Vikings (Gretzinger et al. 2022: 115-117). X and Y-chromosomal data were examined, along with mtDNA (i.e., DNA located in the mitochondrial, only inherited matrilineally), suggesting that there was no larger sex bias among those foreigners who migrated to Britain in the late fourth to the fifth century, with both males and females migrating together (Gretzinger et al. 2022: 117). This would disprove previous suggestions of elite males migrations during the period (e.g., Thomas et al. 2006: 2653-2656; further discussed below).

The human remains excavated at these sites in Britain provided whole genome sequences of ancient British DNA which allowed for comparison with that of the modern British population. Hundreds of modern-day British and Western European sequences were analysed, giving the results that more than a third (c. 38%) of modern English DNA genomes (c. 30% of modern Welsh and Scottish DNA), are derived from Germanic early medieval immigrants. Furthermore, those Germanic immigrants (i.e., Anglo-Saxons) are genetically similar to modern German and Danish populations (Gretzinger et al. 2022: 117).

## *4.2 Chapter Summary: Discussing the Population Range and Kinship Evidence*

A population/migratory scheme that found a wider consensus in the scholarship in the 80s, 90s, and early 2000s, regards the changes prevalent in the archaeological record to testify of a migration of a small Germanic contingency of elites, who brought with them a cultural, social, religious and political continuity which followed the transformative trends taking place in contemporary continental Europe (Hodges 1989; Higham 1992; Härke 1998, 2002; Hills 2003). Such an assertion would find concurring evidence in the isotope evidence as discussed above. If a large-scale invasion or assimilation of Germanic people had taken place in the fifth century, then a large number of those individuals interred in early medieval cemeteries should in theory reflect this in their oxygen and geological regional origin (Hughes et al. 2018: 514). Neither Berinsfield's (Hughes et al. 2014), nor Eastbourne's (Hughes et al. 2018), nor Ringlemere's (Brettell et al. 2018) isotope results support the previously discussed notion of *Adventus*

*Saxonum*, i.e., mass migration, replacement and conquest by people of Germanic affinities. Rather, a diverse migratory scheme, both from the British Isles and continental western, central, and northern Europe, appears to have happened simultaneously (Hughes et al. 2018: 523). This theory finds support in the large scale studies by Leggett et al. (2020), and the Y-chromosome study conducted by Thomas et al. (2006: 2653-2656), which traced the Y-chromosome variations patterns of Germanic origin over several generations, which may originally have been derived from small immigration of Germanic foreign elites, who enjoyed elite status in their newly adopted environments, hence may have been dominant in reproductive rights. May this be the conclusion which the past three centuries of scholarship have sought?

The aDNA study by Gretzinger et al. (2016), certainly found evidence that would not concur with the conclusions reached by Thomas et al. (2006), yet reached similar conclusions as those by Leggett et al. (2020). The aDNA results would point towards large-scale Germanic immigration during the late fourth to the fifth century, followed by other phases of immigration. However, no complete population replacement appears to have taken place, rather cohabitation, assimilation, and acculturation are more likely, as individuals of Briton aDNA genomes have been buried along with Germanic counterparts (Gretzinger et al. 2022: 114), similar Leggett (2021: 19) discussed similar factors, in the case of the male immigrant population found at Finglesham, Kent, which appears to have assimilated to the local customs. Hence attributing the appearance of Germanic aDNA in Britain cannot be completely prescribed as evidence of wide-scale violence and conquest, but neither can it be completely ruled out in every instance. Yet the migration of a small Germanic contingency of elites (e.g., Thomas et al. 2006) has in large been disproven through recent aDNA and isotopic analysis.

A question that may arise based on the evidence outlined in this section: how come the results differ so significantly between Gretzinger et al. (2022), and Leggett et al. (2020), and previous and later isotope studies? The main explanation is likely found in the far greater scale of the former, as Stone (2008: 467) explained, that a large data set is required when tracing kinship to avoid erroneous conclusions due to lack of resolution in the sample. Isotope studies have their place in bioarchaeological studies of past population demographics, however, as the discussion above has proven, it should not be considered the sole conclusive evidence of migration for a whole period, but rather part of the answer, along with aDNA analysis.

The discussion of this chapter highlights the great variability of the early medieval population of Britain, and how diverse the origins many times could be of those whom migrated to Britain during this period. Returning to the discussion of Chapter 2, a sample population used to calculate regression stature formulae on, through the results of the anatomical method, which may consist of individuals of varying ethnic affinities, may reduce the accuracy of the calculate regression formulae. Hence it is key, when establishing new stature formulae, to acknowledge possible issues and limitations of a sample, ahead of producing the final stature formulae, and this chapter has outlined such challenges that will be addressed in later chapters.

# 5. Dissecting the Period: Life and Health in Early Medieval Britain

As previously discussed regarding secular stature trends, 10-20% of stature achieved in adulthood, cannot be attributed to genetic predisposition (e.g., Brothwell 1981, Silventoinen et al. 2003, 2004; McEvoy & Visscher 2009), but rather is the product of an individual's environment, dietary intake and health throughout their formative years. Hence when discussing the average stature values of a population, and its development, the general health of said population needs to first be addressed, as to trace the stature trends and its causation. This chapter will approach the general health status and diet of the early medieval populations of Britain, as to preface the underlying factors affecting the estimated stature presented and discussed in later chapters.

Of the 28 sites used in this study, full osteological, pathological, and general health data have only been published for six sites, and vary in the degrees of presented detail: Barrow Clump (Dinwiddy and Watts 2019), Collingbourne Ducis (Dinwiddy 2016), Leadenhall (Conheeney 2005), Llandough (Loe 2003), Weyhill (Walker et al. 2020), and unpublished pathological examinations of the materials from: St Peter's Tip (1996), Updown (Duhig & Rega 2001), Melbourn (Duhig 2003b), provided by Corinne Duhig. Further challenges were encountered with e.g., two of the larger assemblages used in this study, Godalming (Surrey) and Tiddington Road (Stratford-upon-Avon), which at the time of writing, are still under investigation, and have yet to be fully analysed beyond the metrics recordings by the author. Hence the pathological data of the period is incomplete, and it is not possible to discuss the intricate health factors of the early medieval period on a site-by-site basis, nor a population-by-population basis.

> […] there is no coherent recording of osteology [in Britain] (some reports note every piece of bone growth, others just note the outstanding pathology), and there so far no coherent system of presenting disease and impairment in reports (Lee 2012: 717).

With this limitation in mind, using the currently available material and data, a discussion addressing the temporal health evidence, ranging from a wide set of sources, is more feasible, allowing for a more generalized conclusion regarding the health factors of the period. These generalized conclusions can supplement the stature results achieved in this study in the later chapters, for as discussed earlier (see chapter: 3.1.1), external factors, e.g., nutrition intake, disease, living condition, and physical exertion during the formative years, constitutes a factor of up to 20% of the stature reached in adulthood (Silventoinen et al. 2003, 2004; McEvoy &

Visscher 2009).

Evidence of physical trauma forms an important part of the demography of a population, e.g., the excessive frequency of physical trauma recorded at the penal cemetery of Weyhill (Walker et al. 2020: 159, 182; Clough 2020: 84-85). Severe trauma in adolescence can cause metabolical stunting, hence affecting the development of stature (Jantz & Jantz 1999: 66; Naaz & Muneshwar 2023: 6). However, trauma that occurs during the formative years of an individual (if set and fused correctly) is difficult to detect in the remains of an adult, due to long term bone remodelling (Sealy et al. 1995: 291; Hadjidakis. & Androulakis 2006: 386-390). Hence when analysing stature on the level of a whole population, trauma is of secondary consideration.

The following discussion in this chapter is not a complete digression on the health status of the early medieval population, as there is a lack in contemporary sources addressing the issue of health, but furthermore, the vast majority of diseases identified in modern medicine, do not leave any traces on the bones (Lee 2012: 704). This chapter will rather focus on the identifiable evidence of external stressor factors, e.g., settlement patterns and diet, which can affect the development of stature in the formative years of an individual, which is prevalent in the available pathological data, e.g., calculus, enamel hypoplasia, and cribra orbitalia. Yet some further exceptions need to be drawn, as many extreme metabolical pathologies, e.g., rickets (vitamin D deficiency), i.e., shaft deformation and bowing (Waldron 2008: 127-129; Diwnwiddy 2019: 209), prevent the full measurements of the long bones to be recorded, hence is not addressed in the discussion following here.

## *5.1 Diet and Stressors*

Diet is a leading factor in the prediction of the development of an individual throughout their formative years, and further later in life a predictor of risk regarding health, and the full stature achieved in adulthood (Steckel 1995: 1903-1920; O'Brien 2015: 565-566; Perkins et al. 2016: 153; Hannah et al. 2018: 26; Brødholt et al. 2022: 11). According to primary sources, e.g., *Ælfric* (c. 955-1010 A.D.), along with food macro (e.g., butchered animal remains in a midden or carbonized remains) and micro (e.g., analysis of residues in storage pottery vessels) evidence, the general early medieval diet was fairly diverse. The main portion of the daily dietary intake was bread, but (depending on the site) commonly accompanied by salted meats, dairy products, and a number of both wild and domesticated plants, e.g., cereals, legumes, nuts, fruits (e.g., apples) and vegetables (e.g., root vegetables such as carrot, uncovered at Abbot Worthy, Hampshire) (Hull & O’Connell 2012: 668).

### *5.1.1 Calculus*

The second most recorded pathology in human remains, following joint diseases, is dental diseases, with the major contributing factor in its formation being eating and drinking (Lee 2012: 707). Compared to the Roman period, dental diseases appear to generally decline during the early medieval period, except for calculus, which increases, suggesting a regression towards a more carbohydrate rich diet than the previous period (Roberts & Cox 2003: 390), as a diet rich in carbohydrates increasing the risk of calculus (Mays 1998: 149). Calculus is long-term dental plaque which has been allowed to mineralise, hence forming a deposit on the crown, or the exposed roots (Waldron 2009: 240-241).

The average occurrence of calculus at early medieval sites, as calculated by Roberts and Cox (2003: 193-194), were on average 39.2% of the individuals recovered within a cemeterial site. However, calculus is easily damaged post-deposition, and upon recovery and during the cleaning process, hence calculating a final percentile occurrence for each site may be challenging (Waldron 2009: 241; Dinwiddy & Stoodley 2016: 80). Three of the sites included in this study, far exceeded the aforementioned percentile calculus occurrence, which ranged from moderate to severe: Leadenhall 84.5% (Schofield & Lea 2005: 256), Barrow Clump 75% (Dinwiddy & Watts 2019: 206) Collingbourne Ducis 89.1% (Dinwiddy & Stoodley 2016: 79-80), compared t, Weyhill, which only had merely 35% (Clough 2020: 91). A high prevalence of calculus for a site's population may suggest a site-wide diet which was rich in carbohydrates, yet lacking in fibers. Hence a high occurrence of calculus within a population, on its own, may be suggestive of greater poverty, as it would indicate a lesser access to a varied diet (Schofield & Lea 2005: 260).

At Leadenhall, the prevalence of calculus appears to have been connected to the social hierarchy, as it was a more pronounced issue with those individuals buried in simpler, non-cist graves; whilst individuals in cist-graves, exhibit lesser frequencies of calculus, hence may have had access to more varied and fibre rich sustenance. Furthermore, there was a divide in periodontal disease frequency with those in modest graves, compared to those in cist-graves, with 84.7% of the individuals buried in the former exhibiting some form of periodontal disease, whilst this was only present with 33% of the individuals buried in the latter. This is not surprising, as periodontal diseases tend to be correlated with the presence of calculus, as the latter is commonly a factor in the formation of the former. Hence at the site, along with the more illustrious burial expressions, these individuals in the cist graves may have been of higher social status, allowing for greater access to a more varied diet. This is consistent with further pathologies, as those in more modest graves exhibit a greater frequency of physical trauma, lesions, schmorl's nodes (i.e., lesions on the proximal and distal surface of the vertebral disks caused through compressions of the vertebral column), and periostitis (i.e., inflammation of the periosteal lining (outer layer of the bone)), each a typically symptom of excessive physical exertion or minor trauma. These pathologies of the lower classes at the site are likely indicative of repetitive and demanding physical labour (Conheeney 2005: 260-262).

At Barrow Clump, not only was calculus a common dental pathology but furthermore, so were dental caries and antemortem tooth loss; 31% of the adult individuals at the site had lost one or more teeth, compared to the period average of 8% (Roberts & Coc 2003: 191; Dinwiddy & Watts 2019: 206-208). Dinwiddy and Watts (2019: 208), suggest that this is indicative of a diet not only rich in carbohydrates, but also fruits, nuts, and honey, which were consumed in greater quantity than at other contemporary sites.

The generally poor dental health of the individuals recovered at Collingbourne Ducis, including the high prevalence of calculus, is likely linked to the general poor health, and childhood stress of the population. Moderate to severe enamel hypoplasia (i.e., the disruption of enamel production due to nutritional or pathological stressors in childhood) was recorded in 13 males (67.2% of the sample) and 16 females (53.3% of the sample). Further pathologies linked to infection, malnutrition, and parasitic infestations were likely contributing factors (Dinwiddy 2016: 79-92).

### *5.1.2 Enamel Hypoplasia*

Teeth can record and mirror periods of nutritional deficiency and severe infection, which manifests as deficiencies in the enamel thickness of certain areas, these phenomena are referred to as dental enamel hypoplasia, which is caused by the secretory phase of amelogenesis being disrupted by metabolically related stressors (Goodman & Rose 1990: 59; White 2000: 402; Lee 2012: 708). Combining the studies of dental developmental phases and the studies of dentitional defects, then it allows for the period(s) when the defect(s) appeared and its extent to be estimated. This is possible through examination of the location of the hypoplastic bands that have been formed on the dentitional, their length along the vertical axis of the dental and how many perikymata bands (i.e. horizontal lines on the crown surface, representing the dental growth patterns) it affects (White 2000: 402; Waldron 2009: 244-245). These defects on teeth can appear as large areas of missing enamel, however, the most common defects that are observable on a tooth crown surface come in the shape of furrows, although, steps and pits may occur as well.

(Hillson 1992c: 461; Hilson 2008: 303; Waldron 2009: 244).

Compared to the Roman period, the quantity of dentitional defects, including enamel hypoplasia, increased during the early medieval period, suggesting greater stress experienced during the formative years (Roberts & Cox 2003: 390) The average percentile prevalence of enamel hypoplasia per population during the early medieval period, has been estimated to c. 22% (based on the average of 30 sites) (Gowland & Western 2012). Similar to the wider limited published pathological data, enamel hypoplasia data is limited, and is commonly omitted from pathological reports.

With the population of Leadenhall, compared to the prevalence of calculus, the enamel hypoplasia results were reversed, as it was far less common in those buried in the more modest graves (15.4%), compared to those buried in the more elaborate cist graves (83.4%). However, only six individuals from the latter cist category recovered with dentition. Compared to other contemporary church adjacent cemeterial sites, the general enamel hypoplasia of 15.4% is fairly low, with 50.9% of the individuals excavated at the Franciscan friary at Chester, and the hospital cemetery of St Mary Spital, London, exhibiting a frequency of 16.7-20% (Conheeney 2005: 260). This generally low level of LEH at the site is fairly surprising, as the site of Leadenhall would expectantly been more urbanized than most other contemporary sites. During the Roman era, this area was located in the northeastern section of the walled city (Londinium). These same walls formed the basis for the later medieval wall, hence even in the post-Roman era, the area continued to form an urbanised area. However, the area where the site is located has been described as a backwater area during the early medieval period, as the development of the city continued further westward in the old walled city (Schofield & Lea 2005: 12). Did this level of urbanisation negatively affect the health of those who inhabited the area, and who were later interred within the cemetery? The frequency of LEH appears to suggest no, yet the prevalence of traces of tuberculosis in two individuals (one of whom, individual 481, a female, is included in this study), suggests that the greater density of the population may had a negative effect on their health (Schofield & Lea 2005: 262). As tuberculosis is described as a disease caused by poverty, overcrowding, and malnutrition (further discussed below) (Waldron 2008: 91), hence is not a surprising occurrence in an urbanized "backwater" area of a larger settlement of the period. Throughout history, greater levels of urbanization has many times been associated with negative health factors for archaeological populations, in comparison to their rural counterparts. This is typically a result of failure of a population to adapt to the new reality of urbanization usually results in higher rates of mortality, morbidity, higher levels of stressors, greater prevalence of metabolic and infectious diseases, and even stunted growth (Steckel 1995: 1919; 2004: 214).

At Barrow Clump, 43 out of 81 individuals (53%, 16 female, 14 male, and 13 immature) exhibited varying degrees of enamel hypoplasia. In 58.1% of the individuals affected, defects formed from the age of one to four, which may reflect the poor health of the mother throughout the breastfeeding phase; the vast majority of the individuals (90.6%), had defects which would have formed around the age of four to seven, and another 30.8% exhibiting further defects which would have formed around puberty (age 10-13) (Dinwiddy 2019: 208-209). This is suggestive of long-term external stressors affecting the majority of the individuals of Barrow Clump throughout their formative years and development.

The rate of enamel hypoplasia for the Collingbourne Ducis population concurred with the high prevalence of calculus. The majority of individuals, 67.2%; 65% in males, and 53% in the female population. Similar to Barrow Clump, multiple episodes of excessive stress are indicated, with the weaning age of two to four being the most common. These reoccurring episodes of enamel hypoplasia suggest that those who suffered from poor health at a young age were prone to further episodes, due to their already weakened immune systems. This could also be indicative of the general poor health of the site's population (Dinwiddy 2016: 81).

Only 5.4% of the individuals uncovered at St Peter's Tip exhibited enamel hypoplasia, yet this is a very tentative result, as the enamel uncovered at the site commonly exhibited erosion, causing loss of surface detail, hence preventing a full percentile recording (Duhig 1996). Another site with fairly low rates were Llandough, where only 10.3%, (47 individuals: 19 males, 13 females, 15 unsexed) of the individuals recovered with dention, with the male sample exhibiting slightly higher rates, especially in the more severe cases, with two or more lines (six males) (Loe 2003: 235).

### *5.1.1 Cribra Orbitalia*

Cribra orbitalia refers to the formation of lesions on the exocranial surface around the eye socket. These lesions are caused by the increase in red blood cell production, which causes marrow hypertrophy (i.e., marrow expansion) hence producing lesions on the crania surface (Walker et al. 2009: 109-125; Lee 2012: 708).

In the past, the prevalence of these cranial lesions was diagnosed as being caused by iron deficiency anaemia linked to, e.g., a drastic change towards a diet lacking iron. However, Walker et al. (2009: 109-125) conclude that iron deficiency anaemia rather has the opposite effect, as the production of red blood cells decreases, hence cannot be the cause for such lesions. These lesions are rather caused by a myriad of different factors, e.g., scurvy (vitamin C deficiency), rickets (vitamin D deficiency), megaloblastic anaemia (i.e., the lack of B12 vitamins or folic acid causing the development of larger but less mature red blood cells, hence expanding the marrow). These lesions can be correlated to the weaning process, unsanitary living conditions, and some diseases (Schofield & Lea 2005: 261-262; Walker et al. 2009: 119). Megaloblastic anaemia has been linked to many health complications with high mortality rates (Lawson & Parker 1976), hence infantile mortality rates of past populations during the weaning period are commonly high, this can be exacerbated through exposure to contaminated water sources and lack of animal protein in the diet. These issues can arise even before the weaning process, as e.g., if the mother is suffering from nutritional deficiencies in their diet (see chapter 3.1), then these may be transferred to the foetus already during pregnancy, and later to the infant through the breastmilk (Walker et al. 2009: 120). With the above factors in mind, cribra orbitalia is a good metric of metabolic stressors of an individual or population, especially in the study of growth developmentt, as the condition is believed to reflective of the health during the formative years (Loe 2003: 221)

Cribra orbitalia is a commonly encountered pathology at early medieval British sites, e.g., Blacknall Field: 50%, Barrow Clump: 50%, Collingbourne Ducis 40.2%, Llandough 35.8%, Melbourn 32%, St Peter's Tip 13%, Twyford School 25% (Duhig 1996, 2003b; Dinwiddy 2016: 83). In the case of Barrow Clump, the male rate of 64.7% is more than double data of the female rate of 31.8% (Dinwiddy 2019: 208), this follows the pattern that the female body is more resistant to stressors and changes (Wolanski & Kasprzak 1976: 548; Jantz & Jantz 1999: 65). At Llandough, cribra orbitalia was more prominent with females (37.1%), compared to the males (21.5%)At Weyhill penal cemetery (only males), the prevalence of cribra orbitalia was surprisingly low, at only 12.2%, suggesting a low prevalence of metabolic stressors within the population. Equally low levels were encountered with those individuals interred at the contemporary site at Ridgeway Hill, which is believed to be a mass grave of Viking raiders (Clough 2020: 80).

### *5.1.2 Infectious Diseases*

Infections, viral or bacterial, are likely the biggest cause of mortality in the past, with gastrointestinal infection likely being the most common. However, these are typically difficult to detect in the osteological material, as many infections that would have led to a relatively quick death, would not have left any trace through a bony reaction. When traces are left on the bones, e.g., lesions, it is commonly difficult to prescribe which specific disease is the cause (Waldron 2008: 83; Dinwiddy & Watts 2019: 210). For example, at the sites of Llandough, out of the 573 adults individuals, not a single one individual were diagnosed with skeletal changes which can be attributed with specific infectious diseases (Loe 2003: 237).

The typical infections to be found trace of in the skeletal remains are tuberculosis, poliomyelitis, leprosy, and syphilis. However, in smaller rural communities, the main infectious diseases are likely to have been diarrhoea, and infectious diseases that are transmitted from living in close proximity to domesticated animals, such as anthrax, cowpox, and bovine tuberculosis, with the latter being the only infection leaving traces on the bones (Duhig 1996; Roberts & Cox 2003: 40-42; Dinwiddy & Watts 2019: 210). Roberts and Cox (2003: 184) list 18 known cases of tuberculosis dating to the early medieval period. A single case from Barrow Clump, an older female (not included in this study), and another female from Leadenhall (individual: A 481, included in this study), exhibited traces that possibly could be attributed to the development of tuberculosis (Conheeney 2005: 262; Waldron 2008: 90; Dinwiddy 2016: 86). Leprosy, a chronic infection which spreads through skin-to-skin contact of humans, is a further infectious disease which can leave traces on the bone. Similar to tuberculosis, Roberts and Cox (2003: 218) list 18 cases of Leprosy recorded dating to the early medieval period; three possible cases were recorded in the assemblages of Collingbourne Ducis (none of these individuals are included in this study) (Waldron 2008: 97-101; Dinwiddy 2016: 87).

Infectious diseases are cited as one of the causes that can stunt the growth and development of an individual throughout their formative years (Perkins et al. 2016: 153-154), as severe infections can absorb nutrients and cause nutritional deficits. Yet as discussed above, this is often a difficult factor to analyse in skeletal remains.

> Unfortunately for the palaeopathologist, the infections that are likely to have accounted for the death of children leave no stigmata on the skeleton and until we are able to extract bacterial of viral DNA or RNA from the bones of their victims, we will remain ignorant of if, and how often, infectious diseases might have caused death [or nutritional deficits] (Waldron 2008: 83).

## *5.2 Stable Isotope Analysis*

The diet of past populations can be investigated further in greater detail through stable isotope analysis (as previously discussed concerning population range in chapter: 4.1.1 & 4.1.2). Stable isotope values of carbon 13 ($\delta^{13}C$) and nitrogen 15 ($\delta^{15}N$) from bone collagen serve as a source which may be used to investigate an individual's dietary intake (O'Brien 2015: 565-566; Hannah et al. 2018: 26), hence can be used as an inference of an individual's health along with other pathological evidence.

Carbon in food stems from atmospheric $CO_2$ and is taken up by plants through photosynthesis. The variation in plants' physiology and range of photosynthesis produces the variability in carbon biomarkers between different species, e.g., plants inhabiting marine environments possess elevated carbon isotope values (similar to marine nitrogen values), hence producing characteristic values for marine diets. When animals, both terrestrial and marine, consume plants, the carbon isotope values of the plants is incorporated into the tissue of the animal (O'Brien 2015: 570-571).

Nitrogen's isotope ratios serve as a reliable biomarker of protein intake, as nitrogen in tissue is almost solely derived from dietary protein; nitrogen derived from animal protein is elevated compared to plant proteins. Similar to carbon, marine nitrogen values are far higher than that of protein derived from terrestrial species, due to the increase in trophic (level of the food chain) levels of the marine sources (O'Brien 2015: 571-572).

### *5.2.1 Weaning*

Infants, whilst breastfeeding, effectively completely meet their the nutritional requirements through breastfeeding (Hull & O'Connell 2012: 678). However, if the mother who is breastfeeding the child does not have their nutritional requirements met, or is suffering from other health issues, the child's development may yet still be stunted, through breastmilk less rich in nutrition (Hoppa 1992: 283; Perkins et al. 2016: 150).

Weaning a child of breastmilk, and introducing it to solid food similar to that of the adult population, results in a steep decline in the child's growth rate. A poor adaptation towards solid food, or food rich in carbohydrates yet lacking in nutrition, can cause an increase in morbidity and mortality, more typically, it may further stunt the child's long term development (Hoppa 1992: 283; Jantz & Jantz 1999: 66; Walker et al. 2009: 120; Soliman et al. 2021: 1-4).

Haydock et al. (2013: 604-612), investigated the nitrogen ($\delta^{15}N$) values extracted from rib collagen of 60 younger individuals (age range: 0-7 years old at the time of death) from the early medieval site of Raunds, this to asses at what age within the population the weaning process would have commenced. The results showed that between the ages of two and three years old, the nitrogen isotope values saw a sharp decline, hence suggesting a significant change in diet, i.e., the individuals would have transitioned from breastmilk to solid food; whilst individuals three years old, or older, exhibit values which are adjacent to, or start to fall within the mean adult values of the site, suggesting a switch towards the diet of the adults (Haydock et al. 2013: 604-609). These results mirrored those of Privat and O'Connell's (2002: 785) study of the diet of the contemporary site of Berinsfield's population, and Hull's (2008) study of the four sites of Sharvard's Farm (included in this study: two individuals), Worthy Park, Westgarth Gardens and Portway (included in this study (Portway East and West): four individuals), where the weaning process appears to have happened at a similar stage of the formative years of the individuals, hence possibly suggesting a wider tentative temporal pattern in regards to the weaning of children at the age of two years or older (Hull O'Connell 2012: 678). At the site of Llandough, based on the prevalence of linear enamel hypoplasia, the dental defects were the most prevalent in the cervico-middle regions of the canines and first molars, which develops around the age of three to five years old, suggesting a possible later weaning than the above-mentioned sites. The extended period of breastfeeding has been suggested not only for the benefit of the child but also for the family unit, as during breastfeeding, the fertility rate of the mother is significantly decreased, i.e., *lactational amenorrhoea* (postpartum infertility), hence extended breastfeeding served as a form of contraception (Kennedy & Visness 1992: 227-230; Vekemans 1997: 105-111; Loe 2003: 349). Comparatively to later periods, e.g., the high medieval and later renaissance site of Wharram Percy (10th to 16th century), the weaning process appears to have started a full year earlier than that of medieval Raunds (Mays et al. 2002). The decreasing nitrogen values of the younger individuals of Raunds are corroborated with osteological stress indicators, such as cribra orbitalia (as previously discussed) (Haydock et al. 2013: 604).

This is of great significance, as the duration of breastfeeding is a predictor of the infants' short and long-term health outcomes; not only is breast milk high in nutritious content but also contains antibodies that are crucial for the development of the infants' immune system. Too early weaning may be associated with the increased risk of *otis media* (middle ear inflammation), diarrhoea, lower respiratory tract infection, sudden infant death syndrome, leukaemia, and type one diabetes. Further risks of early weaning (<six months) does not only affect the child's development negatively, but also the mother, as it increases the risk of breast cancer, ovarian cancer, diabetes, hypertension, and myocardial infarction (i.e., heart attack) (Lee 2012: 709; Stuebe et al. 2014: 404). Even more extreme examples can be found at the early medieval sites of Polhill (Kent) and Melbourn (Cambridgeshire), where individuals who were less than six years old at the time of death, exhibited nitrogen values far higher than the site average, suggesting that some individuals may have been weaned as late as six years old (Hannah et al.

2018: 29). However, the possibility of enrichment of the nitrogen values should not be ruled out, as this may be caused by long term sickness or nutritional stress (Katzenberg 2000; Dupros et al. 2001).

It is possible, that the early medieval populations may have had health benefits associated with later weaning periods, which would have both affected the children in their formative years and lessened the mothers' risks of health complications in relation to child-rearing; yet the possibility of isotope value enrichment through disease should not be ruled out. Yet the benefits gained by the child from breastfeeding is reliant on the nutritional intake of the mother (Coly et al. 2006: 2417).

### *5.2.2 Post-Weaning Diet*

Throughout the weaning process, the maternal milk is supplemented by other food types, and eventually completely replaced by a diet more similar to that of the adult population, hence a decrease in the nitrogen values is evident as the source is gradually (weaned) removed. Many juveniles' nitrogen and carbon values will be lower than the adult average during this transitional period. Yet over time, when the individual reaches adolescence, these values tend to reflect the wider values of the site's adult population. The wider site values are dependent on whether a hierarchical pattern of access to certain types of food is in place, hence can obscure the establishment of a site average isotope set of values. Furthermore, when attempting to establish the mean isotope values of a site, younger juveniles are excluded from the sample, to avoid contamination through the elevated values caused by the *nursing effect* (i.e., the heightened nitrogen values caused by consumption of breastmilk as the sole dietary intake (as discussed above)) (Privat & O'Connell 2002: 785; Hull & O'Connell 2012: 678).

Mays and Beavan (2011) analysed the isotope data of 76 early medieval individuals (fifth to seventh century), from 18 different contemporary sites (out of the 18 sites, three sites are included in this study: Appledown: 49 individuals; Melbourn: 22 individuals; St Peter's Tip: 36 individuals, see material chapter), with the main aim of the study to investigate how geography affects the diet of the different populations of the period. The results suggest that geography had little effect on the sustenance strategies of the different sites, with terrestrial foods being the dominant source of sustenance at all of the sites, with slightly elevated $\delta^{13}C$ values for populations of coastal regions, where marine food was more easily accessible, and elevated $\delta^{15}N$ values for those who inhabited riverine regions, suggesting a more mixed diet with freshwater marine resources included. The early medieval economy was agrarian in nature, hence the dominance of $C_3$ plants in the diet is not surprising, yet with local wild resources, when available, substituting the agriculturally produced foodstuff (Mays & Beavan 2011: 873). Two examples to highlight the complimentary use of local resources to the period base diet are the mid-seventh to early-eight century site of Bloodmoor Hill, Carlton Coville, Suffolk (Lucy et al. 2009), and Berinsfield (further discussed below), Oxfordshire (Privat et al 2002) where the main source of the diet for both sites consisted of $C_3$ plants and frequent consumption of animal protein, yet with the adage of freshwater resources; the River Waveney is located a mere two km north of Bloodmoor Hill, and the River Thames runs less than one km southeast of Berinsfield (Privat et al. 2002: 786-788; Lucy et al. 2009: 317-328). In those instances where regional differences in nitrogen and carbon values differ from the temporal norm, the local faunal levels should be considered, as cultural and sustenance strategies, along with e.g., the regional geology, climate, precipitation, and naturally occurring vegetation may contribute to elevate or depress the isotope values of a population (Hull & O'Connell 2012: 679).

As have been outlined in previous historical chapters, the early medieval period in Britain experienced many great, even cataclysmic changes, ranging from, e.g., religious, socioeconomic, demographic, and political fluctuations, hence these events are not only expected to be visible, and chronicled in the archaeological assemblages, but also the dietary intake and strategies over time. Hull and O'Connell (2012: 681), illustrate this by comparing six early phase sites (Bergh Apton, Morning Thorpe, Oxborough, Spong Hill, Swaffham, and Westgarth Gardens) with three later sites (Castor-by-Yarmouth, Burgh Castle and South Acre). The three later sites exhibited elevated carbon and nitrogen values compared to the former six. This enrichment is likely due to a shift towards greater exploitation of marine and freshwater resources in the middle and later centuries of the period (Barret et al. 2004: 618-636; Hull & O'Connell 2012: 681-683)

A more narrowly focused study, by Hannah et al. (2018), further investigated the early medieval paleodiet of the populations of Melbourn, Cambridgeshire, and Polhill, Kent, with 116 individuals (Melbourn: 51 individuals (22 individuals included in this study); Polhill: 65 individuals (only a single individual included in this study)). The diet of the Melbourn population appears to have been fairly uniform throughout the period, with individuals buried in elaborately furnished graves having similar isotope values to those of more modest burial. The main sustenance consists of terrestrial $C_3$ plants and animal protein, with little or no marine source food, however, freshwater fish cannot be fully ruled out (Hannah et al. 2018: 26-30). The $\delta^{13}C$ and $\delta^{15}N$ range of Polhill exhibited a far greater variation, suggesting a more pronounced disparity in access to resources between the different strata of the social hierarchy. Yet surprisingly, those individuals buried in modestly furnished graves, exhibited the highest nitrogen values, whilst those buried in group burials exhibited the lowest nitrogen value, suggesting that those in the middle of the hierarchy consumed the greatest amount of animal protein (Hannah 2018: 30-31), these results are echoed with the population uncovered at the contemporary site of Berinsfield (Privat et al. 2002; further discussed in the next chapter).

### *5.2.3 Diet in Relation to Status*

A common feature within many past societies, as far back as the Neolithic, is that those individuals prescribed as having been of higher social status, e.g., due to their burial contexts or grave goods, tend to have corroborating paleodiets evidence, i.e., isotope results indicating higher animal protein intake, compared to those prescribed as belonging to the lower social strata (Knipper 2015: 579; Hannah et al. 2018: 30). Yet in early medieval Britain, establishing the social hierarchy through the dietary intake (as discussed above), have proven difficult, as the archaeological assemblages associated with the grave, e.g., grave goods, does not always find distinct and corroborative evidence in the isotope results. At the site of Melbourn, the nitrogen results were fairly uniform when comparing individuals buried in simplistically furnished graves and those given more elaborate burials. Comparatively with the contemporary site of Polhill, where those individuals buried in the more meagre or modest graves, i.e., those individuals believed to have belonged to the lower to middle strata of the social hierarchy, proved to have higher nitrogen values, than the site average and those of the richer graves, hence suggesting a greater intake of animal protein (Hannah et al. 2018: 31). Similar evidence of higher nitrogen values of those believed to have belonged to groups of lower social status based on the burial gifts were uncovered at the contemporary sites of Berinsfield, Alton (included in this study: nine individuals), Droxford (included in this study: 15 individuals), Worthy Park, Bergh Apton, Morningthorpe, Westgarth Gardens. This may suggest that these individuals' diet consisted of higher protein food, yet which were deemed as lower status sustenance, e.g., freshwater fish or riverine resources (e.g., at Berinsfield this may have been sourced from the river Thames) or as have been previously suggested the consumption of pork meat by the lower classes (Privat et al. 2002: 786-788; Hull & O'Connell 2012: 675-677), which based on primary sources was part of the diet of the elites as well. Pork was notoriously known to have been difficult to store and quick to spoil (was not consumed during the hotter summer months), but furthermore, commonly the carrier of disease and parasites (e.g., whipworms), hence pregnant women were advised to avoid pork in their diet (Hagen 1995: 66, 189, 226; 235; Albarella 2006: 73; Banham & Faith 2014:

106). Furthermore, of the faunal remains uncovered at early medieval sites, pigs are the least common of the three typical domesticated animals, i.e., sheep, cattle, and pig, hence due to the scarcity of butchered pig remains uncovered, pork meat was likely unavailable to those belonging to the lower strata of the hierarchy at many sites (Hull & O'Connell 2012: 673-677). However, it was not necessarily the norm across all sites, throughout the entirety of the period, that those of the possible lower strata of the hierarchy consumed greater amounts of animal protein and riverine resources, as at the contemporary sites of Portway (as mentioned above), Shavard's Farm (included in this study: two individuals), Winnall II and Swaffham, where those individuals buried in more illustrious furnished graves, including weaponry as burial gifts, exhibited far higher nitrogen values than those interred in more modest graves (Hull & O'Connell 2012: 675).

Another factor that complicates the nitrogen dietary analysis of the period, is the likely practice of heavy manuring of the arable fields to increase the yearly crop yields. This has the inadvertent effect of enriching the nitrogen values of the soil, which in turn, increases the values of the cereal, and that of those individuals who consume it. This may cause the disparity in the higher nitrogen values of those in modest graves compared to the lower values of those interred in the richer graves. Another source of protein that may have been consumed to a greater degree by those of poorer means, is domesticated birds, e.g., chicken, fowl, and geese, and their produced eggs. Compared to other domesticated animals, chickens are relatively non-resource intense in their upkeep and feed, hence available as suitable sustenance for the lower classes as well as the elites (Hagen 1995: 242; Hull & O'Connell 2012: 677). Leggett and Lambert (2020) reached a concurring conclusion in their large study of early medieval diet in England, where it was not possible to establish a clear link between the perceived social status based on the grave goods, bodily position, and the sex of the individual, and their isotopic diet markers. This evidence rather suggests a more homogenous diet across the social strata of the period, and was rather determined through the regional and seasonal access food stuff (Leggett & Lambert 2020: 194-196; Leggett 2021: 19).

## *5.3 Chapter Summary: Health and Diet of the Early Medieval period*

Early medieval England appears generally to have been less dependent on diets which may have been prescribed as being of elite status in other periods and cultures (with the four exceptions mentioned above), this may be explained through the socioeconomic fluctuations and greater access to food (Knipper 2015: 586). Hence paleodiet studies do further the understanding of the period, yet in many cases is a poor basis for status inferences, rather the stable isotope analysis should be correlated to the archaeological context of the graves. Nor is there any evidence to suggest a discriminatory gender-based diet for the majority of sites where stable isotope analysis has been conducted on the remains of those interred in the cemeteries. However, seven sites exhibit nitrogen values that prove to be exceptions to the norm: Caistor-by-Yarmouth, Swaffham, Morningthorpe, and Winnall II, where the adult males had nitrogen values that exceeded that of the adult female individuals of the sites. Shavard's Farm and Westgarth, where the results were the reverse compared to the former four sites, with the adult females nitrogen values exceeding that of the adult males (Hull & O'Connell 2012: 674-675; Leggett & Lambert 2020: 194-196; Leggett 2021: 19).

# 6. Mortuary Practices

The modern scholarly discipline of early medieval studies, had its inception more than three centuries ago (previously discussed in Chapter 2; further studies concerning early medieval mortuary practices e.g., weaponry and warrior graves: Härke 1992 & 1997; gender: Stoodley 1999; social structure: Lucy 1998; osteological and social: Evison 1987; Sherlock & Welch 1992; Boyle et al. 1995; Malim & Hines 1998).

The mortuary practices of the British early medieval period can be divided into three phases:

- Early phase (pre-Christian or migratory period, i.e., *Adventus Saxonum*): c. mid-fifth to mid-sixth century A.D.
- Middle Phase (conversion period, i.e., Final Phase): c. late-sixth to early-eighth century A.D.
- Late Phase: c.mid-eighth to mid-eleventh (1066, i.e., Norman Conquest) century A.D.

The characteristics of each phase do frequently overlap, and vary between regions (Dickinson 2012: 228-229). Hence as many times in archaeology and history, this division of three phases (i.e., a *tripartite* division) is merely an arbitrary attempt at organizing the period by tentative temporal boundary distinctions. Below, a brief outline and discussion of the different phases will follow. This will later be harkened back to in the material section concerning the dating of the materials and individuals, as this phasing allows for greater ease when organizing the stature results in later chapters.

### *6.1.1 Early Practices*

The early phase is considered to have started shortly following the Roman withdrawal from Britain, around the mid-fifth century (Heather 2007: 237; Morris 2021: 22), concurrent with the large-scale incursions and migrations of foreign Germanic groups in the early fifth century (migration, i.e., *Adventus Saxonum*, further discussed below). Not only were distinct changes apparent in the cultural artefactual expression but furthermore, the mortuary practises at many sites at large took on the character of contemporary continental Europe. This is apparent in the greater quantity of grave goods, and the reintroduction of cremation graves. These burial practices have commonly been labelled as being of "*pagan* (non-Christian)" nature. Yet these practices are not possible to attribute to any specific pagan ideology, as no apparent codification of mortuary practices was in place, nor would be for the following centuries (Williams-Ward

2017: 14-18).

> "[…early medieval mortuary practices] provide no single window into ethnic origins, religious beliefs, or social structure […] there was no single 'Anglo-Saxon way of death' […] with no single 'Anglo-Saxon' society behind it (Williams 2012: 259)".

Many of the early phase cemeteries which are dominated by cremation burials, tend to be located near, or even within the living space of the settlements, whilst those cemeteries with a greater frequency of inhumations are commonly separated from the settlements, i.e., field cemeteries (Williams-Wards 2017: 15-16). Even with the reintroduction of cremation burials into the British Isles, inhumations remained the normative type of burial practice during the period, especially in eastern and southern Britain. Cremation remained in general a secondary practice, except for some regions, e.g., East Anglia, where it was the dominant rite in the early phase. However, cemeteries did not tend to demarcate between the two practices, as commonly both cremation and inhumation burials tends to be uncovered together within cemeteries of this period, i.e., "*mixed rite sites*", typically with one of the two practices being the dominant (Lucy 2000: 140-152; Williams (2012: 249; Williams-Wards 2017: 17). It is important to note, that the prevalence of cremation as a common mortuary practice during the early phase, mean that the osteological assemblage which can be utilized for stature estimation is incomplete. Why one practice was chosen in favour of another, remains elusive. Williams (2012: 242) argued that the choice between either of the two mortuary practices was a mnemonic choice, i.e., a practice performed to define cultural or ethnic boundaries. Two examples of a mixed rite site dominated by inhumations included in this study, Collingbourne Ducis, Wiltshire, with 115 inhumations and only four cremation burials (Dinwiddy & Stoodley 2016: 6-7, 53), and Apple Down, West Sussex, 96 inhumations and 54 cremation burials (Down & Welch 1990: 14-15). Even though cremation graves were a common practice in the early phase of the period, it will not be addressed in great detail here (for further discussion on cremation practices see, e.g., Richards 1987; Ravn 2003), as the relative chance of being able to extract useable stature metrics from cremated remains is incredibly rare, in many instances nearly impossible.

Early-phase cemeteries are commonly aligned or organized in relation to older monuments, e.g., Bronze Age barrows (Williams 1998: 99), this is apparent with several of the sites included in this study: Apple Down, West Sussex (Down Welch 1990), Portway East, Hampshire (Cook & Dacre 1985), Collingbourne Ducis, Wiltshire (Dinwiddy & Stoodley 2016), Barrow Clump, Wiltshire (Andrews, *et al.* 2019) and Melbourn, Cambridgeshire (Duncan et al. 2003).

Further organization is rarely seen in the cemeteries during this period, beyond occasional burial clusters and rows, these cluster may indicated hierarchical or group delineation (Williams 2012: 249), e.g., the possible demarcated burial plot at Apple Down, where a cluster of graves in rows are surrounded by postholes (Down & Welch 1990: 16). Earlier monuments, e.g., mounds from the bronze age, were commonly a focal point of the cemeteries, with the burial organized around, or near the feature, this has been suggested to likely have been done to anchor the current community with the mythology of the past (Sayer: 2020: 39-43), hence claiming the area for the present. Typically, the human remains were placed in an extended supine position, with occasional placement in a crouched position. Unlike the later Christianized periods, the orientation of the graves tended to be fairly diverse and appears rather to have commonly been dictated by the topography of the cemetery. However, burials orientated towards the west appear to have been the most numerous (Williams 2012: 249-254).

Little is known about the post-burial commemorative practises, e.g., if any standing monuments were raised to mark the graves. Within the cemeterial bounds of the two sites of Apple Down and Melbourn (both included in this study), the foundation of structures and postholes were uncovered. The precise function of these structures is not entirely clear, e.g., wooden monuments on the surface of the cemetery denoting it as a burial ground, or in the case of Apple Down where cremation burials occurred, this may simply have been the foundation and postholes of cremation platforms (Down & Welch 1990: 15; Duncan et al. 2003: 91-95).

### *6.1.2 Middle Phase (or Final Phase)*

The term “Final Phase” was first coined by Leeds (1936), and refers to the transition period between the pre-Christian to Christian Saxon era (late-sixth onward). This coincides with the re-establishment of Christianity in the British Isles following the arrival of St Augustine (597 A.D.) in Kent, who initiated the painstaking process of converting eastern England to Christianity (Campbell 1991a: 21). From the mid-seventh century, and onward, the majority of the Saxon kingdoms had been Christianized. The burial norms were still far from codified during this phase, yet greater organization started being visible in the organization of the cemeteries, and with the complete phasing out of cremation burial rites. However, the Christian mission’s efforts were not even throughout southern Britain, as e.g., cremation burials continued to be practised at Apple Down into the second half of the seventh century (Down & Welch 1990: 14-15; Williams 2012: 234-240; Welch 2012: 267-268, 282).

Perhaps the most typical and striking characteristic of this phase is the prevalence of minimal grave goods, or even none, compared to previous periods where the number of grave goods could vary significantly depending on the status of the individual in life. As the name suggests, this was the final phase in the British Isles of widespread normative burial practices which included burial gifts (Stoodley 2006: 74; Stoodley 2007: 154, 160). Through the sixth and early seventh century, grave furnishings were slowly phased out, and almost completely missing from the mid-seventh century onward. However, this transition was more pronounced in certain regions and was not necessarily adopted by each strata of the social hierarchy to the same degree. This is apparent, as many of the rich princely graves of the early medieval period date to the seventh century, e.g., the Sutton Hoo princely ship mound burial, which is dated to the first quarter of the seventh century. The larger furnished barrows of this period are believed to have been the burials of the elite and landed gentry, which continued to be practised into the early eighth century, hence the burials of the elites appear to have been an exception to the rule of modesty. These mortuary practices were likely inspired by those practiced in contemporary Scandinavia. Towards the end of this phase, these elite burial mounds had fallen out of fashion, and similarly to the clergy, the elites began to favour being buried within consecrated grounds (Welch 2012: 267-283; Williams-Ward 2017: 25).

The typical lack of grave furnishings (with certain elite exceptions), and further typical lack of accompanying churches and churchyards (further discussed below in the last phase), means that this middle phase is the least understood of the three. Another challenge of this phase is that many of these likely burial grounds lay beneath later settlements and churches, hence truncated and inaccessible by later periods (Williams-Ward 2017: 23).

Cemeteries during this period were typically located near older cemeteries of the previous phase, later parish and Christian field cemeteries tended to be located by the boundaries of previous non-Christian graveyards (Hamerow 1991: 11), occasionally only separated by a few hundred metres, e.g., Portway West (Stoodley 2006: 65-74), dated early-seventh to mid-eight century, which is located c. 800m west of the older cemetery of Portway East (Cook & Dacre 1990: 1985: 91), late-fifth to early/mid-sixth century. Another example of this occurrence is Apple Down (Down & Welch 1990: 13-16), whose two cemeteries, cemetery 1: sixth to late-seventh century, lie less than 200m north of Cemetery 2: seventh to eighth century. The reason why cemeterial units during this phase are located near older cemeteries is likely that cemeteries tended to be placed in the centre of the territorial units. These central points commonly changed with time, e.g., settlements shifting to other areas due to infield areas losing their

fertility because of soil exhaustion or erosion over time, hence shifting the central point of settlement terroir, hence necessitating moving the accompanying field cemeteries (Hamerow 1991: 1-11; Welch 2012: 280-281).

Other known surface markers for graves were smaller mounds, surrounded by shallow penannular ditches (i.e., ring ditches). This has were recorded at four sites included in this study: Portway West, Hampshire (Stoodley 2006: 65, 74), St Peter's Tip, Broadstairs (Hogarth 1973: 104-108), Updown, Eastry (Welch 2008: 10-11), and possibly present at Apple Down (Down & Welch 1990: 14-15; Harman 1990: 195-200), due to the shallow depths of many of the burials in these areas, hence without a mound, the graves would have been almost at the surface level. Penannular ditches in cemeteries appear first towards the late seventh to early eighth century A.D. and have been uncovered at other contemporary cemeteries e.g., Cook Street cemetery, Southampton (Garner 2001: 181).

### *6.1.3 Late Phase (Christian Era)*

The practice of burials in churchyard, i.e., consecrated grounds, with clearly marked cemeterial bounds, emerged first in Saxon England during the 7th century A.D. (Walker et al. 2020 161; Hadley 2010: 103; Cherryson 2005: 211-217). But it would take another three centuries before this became the normative burial practice. The first primary source mentioning a churchyard burial dates to the late-ninth century, and relates to the payment of a burial tax (Hadley 2012: 291).

Another burial practice that developed during the 7th to 9th century A.D., was the practice of more integrated burials within the actual settlements' bounds, hence it's easier to attribute the actual living environment for this period to those who have been buried in the burial grounds, rather than earlier periods where it was common to use isolated cemeteries in the landscape. However, this practice excludes punishment cemeteries, e.g., Weyhill Road, as in all likelihood, due to superstition, outcasts, and criminals were buried away from the living space to prevent them from returning after death and wreaking havoc on the living (Walker *et al.* 2020: 160 & 168-169). Yet this further incorporation of the burial grounds with the living space commonly led to later disturbances, either by later intercutting of graves, or exploitation of the area (Hadley 2012: 290), e.g., this is visible with the site of Leadenhall (Schofield & Lea 2005), where later exploitation of the area has damaged burials.

Further uniformity and organization in the burial rites took place during this phase (except for deviant burials), with the vast majority being buried in extended supine positions, west-east oriented, with the head of the individual eastwards, as remains the typical practice within

Christian burial rites till today. Burial clusters, and graves organized in rows, now occur in greater frequency, likely a reflection of a greater emphasis put on distinguishing kinship in the funeral practice. During this phase, variations in the burial rites were encountered in the mode of burial, e.g., burial shrouds (already introduced in the previous phase), different types of coffins, stone linings of the grave cuts, crushed chalk or charcoal in the fill layer, and the occasional inclusion of a stone cover, or grave markers, i.e., tombstones. Grave gifts had ceased to be a factor in the burial rites in the previous phase, rather artefacts uncovered during this period in graves are associated with the clothing and fittings worn by the deceased whence buried (Hadley 2012: 290-295; Williams-Ward 2017: 26), e.g., one of the graves at Leadenhall, likely the grave of an individual of ecclesiastic importance, included a silver pendant cross (Schofield & Lea 2005: 47-48).

Clergy and monks were already buried within consecrated ground, i.e., churchyards or graveyards connected to a church in the previous phase. However, burials near or within consecrated grounds for the laymen would only become the norm in Britain around the tenth to twelfth century, i.e., towards the end of the early medieval period, transitioning into the period following the Norman Conquest. Typically, commoners continued to be buried in detached cemeteries (Hadley 2012: 290; Welch 2012: 281-283). It is likely that following the phasing out of grave goods, the elites decided to distinguish themselves in death by the place chosen for their interment, e.g., a plot closer to a church which was unattainable for a commoner (Williams-Ward 2017: 31).

The burial rites of the early medieval Christian period can be summarized and divided into three main modes of burial practices. (1.) Burials within consecrated grounds, i.e., Christian cemeteries with clear demarcations, with full Christian rites. (2.) Those who could not be considered as members of the Christian community (i.e., lay people), or at least not proper members, e.g., non-baptized individuals, yet in good standing in the community, could be buried in a delineated area near (but never within) the consecrated burial site. (3.) Burials far away from both the living space of the community, the consecrated burial sites, and places of worship (Williams-Ward 2017: 25), e.g., the site of Weyhill, (Walker et al. 2020) which is included in this study, and further examples: Meon Hill, Stockbridge, Old Dairy Cottage, Winchester (Reynold 2009: 152), these types of burials were reserved for the outcasts and the criminals. However, these types of Anglo-Saxon burial grounds for outcasts and criminals seem to generally have fallen out of use in the late 12th century A.D., coinciding with the legal reforms introduced by the English Kings: Henry I and Henry II (Walker *et al.* 2020: 175; 182). Those who suffered from physical ailments, or impediments, do not appear to have been treated differently than the vast majority, except occasionally when buried in deviant areas, e.g., outside consecrated grounds or within outcast cemeteries. Yet these deviant burials of those suffering from ailments were far less common, than those of the high medieval period. This is interesting to note, as physical handicaps have many times been associated with sin. Furthermore, greater care for the actual remains of this period is apparent in the lesser frequency of grave intercutting than in previous phases. When remains were encountered, it appears to have been common to either reinter the remains elsewhere or to stack the remains along the grave cut (Hadley 2012: 295-302), e.g., at the site of Tiddington Road, Stratford-Upon-Avon (at the time of writing the monograph has yet to be published), where remains of previously interred individuals were stacked in neat rows along the edge of later grave cuts.

The burial rites of this last phase of the early medieval period showed less variation compared to the previous centuries. Yet diversity in the mode of burials remains present in the archaeological mortuary assemblages. Codification and ecclesiastic guidelines for what a Christian burial should entail appear not yet to have been in place, or at least not widespread in its enforcement. The notion of what, or how, a proper Christian burial should be, was yet to be defined (Thompson 2004: 32; Hadley 2012: 291).

## *6.2 Chapter Summary: Closing Remarks on the Mortuary Practices*

The importance of mortuary evidence from the early medieval period has proven indispensable for scholarly research in the past, and will prove useful in the following discussion in the chapters which will follow. The spatial and artefactual evidence will be returned to in the next material chapter, which will present each of the major sites used in this study, along with and overview of the osteological material. These mortuary practices will only be addressed secondarily, e.g., in regards to dating, as the artefactual typologies and the chronologies serve as the most reliable dating metrics beyond radiocarbon dating. This *tripartite* phasing will again be returned to in the discussion section, when organising the early medieval stature trends throughout the early medieval period, allowing for a statural comparison between each phase.

# 7. Material

To avoid a too narrowly focused result, in which the resulting regression formulae are only applicable for a smaller regional sample, this due to the effect of secular stature trends as outlined in previous chapters, a wider temporal and geographical coverage were necessary, to represent the wider stature trends of the British early medieval period. In this regard, the human remains from 28 different southern British early medieval sites have been collected (see Fig 7.), dating to varying phases of the period, allowing for the analysis of possible changes in the secular stature trends over time. Some shared secular trends are expected, e.g., a dominance of $C_3$ plants in the diet (Mays & Beavan 2011: 873), hence similarities in the dietary intake, to a certain degree, can be traced between the different sites.

One of the challenges encountered when gathering the material for this study, is the regional variations in the level of bone preservation at each site, as many regions of Wales and southern England are marred by high levels of acidity in the soils (i.e., pH values of ≤6.5, see fig 7.) (Williams-Wards 2017: 21). This means that using the anatomical method, which requires well preserved human remains, for British archaeologically recovered human remains, to rarely be possible (Mays 2016: 647). Hence if regression stature formulae are to be established for the early medieval population of Britain, then both a wide (as to achieve a sufficient number), and a well-preserved and complete material is necessary. As seen in Fig 7., the preservation level is skewed and favours certain regions over others (i.e., pH values of ≥6.5). This means that when gathering and establishing the base sample to be used with the anatomical method, the sole focus lies on the completeness level of the human remains, rather than equal representation from each of the sites, as this is not feasible with the general high levels of acidity in British soil.

The author analysed and measured the remains from 14 sites, and the population of the remaining 14 sites, were analysed by different observers, who provided osteological metric records (see Table 5.), with the permission of utilizing these osteological recordings in this study. Hence the methodology for analysis does vary, and the possibility of inter-observer errors (though limited) does exist. Of these 28 sites, 12 sites contributed 12 and above individuals to the study (either anatomical or regression), hence are considered as major contributing materials and will be discussed in further detail in this chapter. The remaining 16 sites, contributed 12 or fewer individuals each to the full material, hence are considered as minor contributors (see Table. 5).

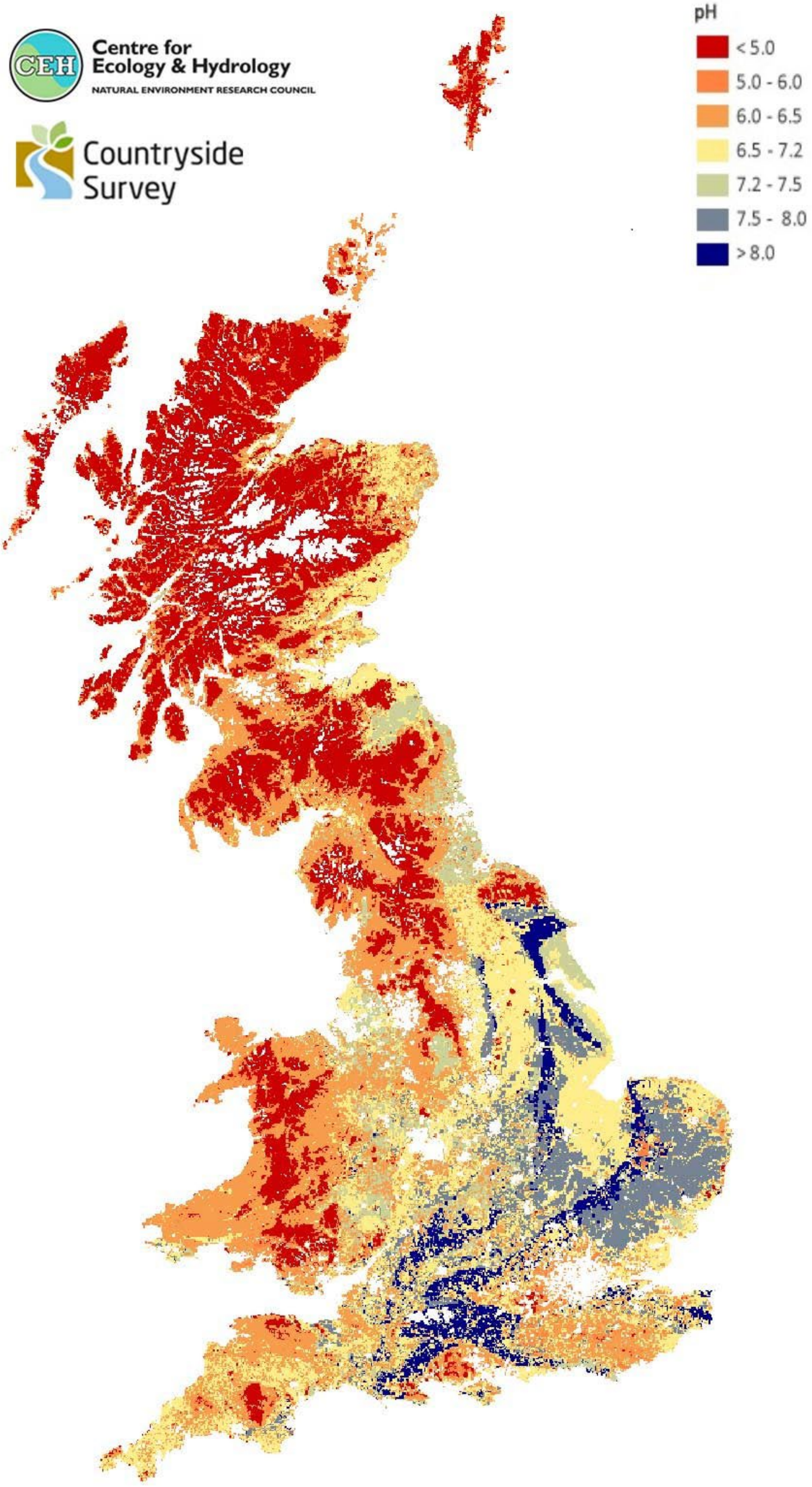

**Fig 7.** Countryside Survey (CS) topsoil pH data, representative of 0–15cm soil depth (2007).

**Fig 8.** Map of Britain with each site used in this study plotted out: **1.** Llandough; **2**. Apple Down; **3**. Droxford; **4.** Weyhill; **5.** Mount Pleasant; **6.** Collingbourne Ducis; **7.** Barrow Clump; **8.** Stratford-upon-Avon; **9.** Godalming; **10.** Melbourn; **11. London:** Leadenhall Street, Long Acre, Peabody, Rangoon Street, Bull Wharf, Fleet Valley; **12.** St Peter's Tip; **13.** Updown; **14.** Blacknall; **15.** Watchfield; **16.** Sharvard's Farm; **17.** Breanmore; **18.** Romsey Abbey; **19.** Five Mile Lane; **20.** Polhill.

The extent to which each site is possible to discuss here varies, as, e.g., the sites of Godalming and Tiddington Road are still under investigation and their respective final reports (at the time of writing) have yet to be published, hence the discussion for these two sites are not complete. The discussion and presentation of materials which follow in this chapter, rely on previously published field reports and monographs, with varying levels of detail.

This chapter will begin with presenting the challenges encountered when sampling human remains for stature studies in Britain, the criteria used in the sampling process, followed by a presentation of the material itself which this study is based on.

## *7.1 A Brief Note on the Preservation of Skeletal Remains*

Many extrinsic factors affect the level of preservation of human remains that can be expected to be recovered at an archaeological site, e.g., the environment itself (Fig 5.) (geography, presence of water and geology), the type of local flora and fauna, and later exploitation of the area of the site (Henderson 1987: 46). Boddington (1987: 27-54) studied the preservation of the human remains recovered from the early medieval cemetery at Raunds (10th to 11th century A.D.), Northamptonshire. Each site in the British Isles where human remains are recovered is unique, hence different considerations need to be taken into account, yet Boddington's (1987: 27-54) results can be used to make general inferences (to a certain degree) concerning the challenges faced by the archaeologist excavating human remains in the British Isles and wider geographically.

There were no significant differences in bone fragmentation between the males and females uncovered at the site. As seen in Table 2., the prevalence of bones being crushed dropped significantly between neonates and adolescents, this is due to the rapid increase in the bone mineral content, i.e., bone structural strength, in adolescence and young adulthood. This

**Table 2.** Prevalence of Post-depositional crushing of the bones excavated at the early medieval site at Raunds, Northamptonshire (Boddington 1987: 30).

| Age category: | Percentile of bone-crushing: |
|---|---|
| *neonates:* | 70% |
| *adolescents:* | 10% |
| *17-25 years old:* | 20% |
| *≥45 years old:* | 43% |

minerality starts to decrease with old age, hence the increase in bone-crushing with the fourth category, ≥45 years old at the time of death, due to the loss of bone mass and density with age (either through osteopenia, i.e., below average bone density for an age category; or, osteoporosis, pathological weakening of the structure and minerality bone, i.e., bone atrophy). The spatial location of the burials should be considered, as this may affect the preservation due to crushing alongside the age factors, e.g., contexts with hard-packed clay produced greater numbers of crushed human remains, than contexts consisting of hard-packed clay mixed with limestone (Boddington 1987: 30-35; Solomons 2013: 159). The cranium is especially susceptible to the effects of post-depositional bone-crushing, which poses a challenge when assembling a sufficiently large enough sample for the anatomical method, as the posterior crania, from the bregma to basion point needs to be preserved, as to allow for the correct measurements to be recorded (Fig 8.).

Each element of human remains does not deteriorate at the same rate (Lee 2012: 705), with a common issue being bone decay, which tends to concentrate on the vertebrae column, especially the lumbar region. The vertebral discs are more susceptible to bone decay, due to their bone structure primarily consisting of cancellous bone, whose structural integrity is affected to a far great degree by the increase in bone porosity (osteopenia or osteoporosis) and decrease in bone density (a common effect of aging), compared to, e.g., the loss of bone mass in long bones which diaphysis in large consists of cortical (compact) bone tissue, which structure is not negatively affected to the same degree. Hence the likelihood of recovery of the spinal column is far lower in many instances, compared to long bones. This is a difficult problem to remedy in stature studies, as the lumbar region can be used to estimate other missing elements of the vertebrae column, but itself cannot be estimated (see the methodology chapter). The majority of osteological studies do suggest that sex plays a minor role in the preservation of bones, rather age and bone density are the major factors that can predict the level and speed of bone decomposition (Henderson 1987: 45). However, unlike the issue of bone-crushing, there is a marked difference between the two sexes concerning osteoporosis, as this phenomenon is exhibited twice as often with older females than older males. In large, this loss in bone mass for older females can be attributed to the cessation of oestrogenic hormone production following menopause (Boddington 1987: 31-37; Solomons 2013: 159-160), whilst in males, osteoporosis is more common to appear a decade or so later. However, menopause (females) and old age (males and females) are not the only causes in the appearance of osteoporosis, as both heredity, environment, physical activity, and diet, especially calcium intake, do contribute to the health status of an individual's bones into the later decades (5th decade and onwards) of life (Anderson 2003: 4278). With this in consideration, it should not be surprising the disproportionally larger older male samples commonly used in anatomical stature studies, than that of older females, whilst the sample category of younger males and females should in theory be equally represented (e.g., Raxter et al. 2006).

With the issues outlined above, exclusively relying on the anatomical method greatly reduces the number of individuals that is possible to use (Ruff *et al.* 2012: 602), hence many times in archaeology (when possible) it may be advisable to combine it with the regression method.

## *7.2 Selection of Material*

The criteria for the sampling of human remains in this study, as to allow stature estimation to be performed for each individual, is a crucial part of the methodology, yet it should be outlined before the presentation of the material section, as to clarify why each individual have been chosen.

When choosing which of the adult individuals to use for this project, from the different sites, these following three criteria had to be fulfilled.

1. The long bone's epiphysis needs to have been fused, otherwise, it is not possible to measure the maximum height of the bones (age range of≥ c. 17-18, at the time of death). The sex of the individual needs to have been established, as stature is subject to sexual dimorphism, hence the physical sexes need to be approached separately with stature formulae. Sjøvold's (1990) argued the opposite, that general formulae for both sexes are possible to produce accurate results with. For the sake of this study, the sexes will be approached separately for the stature estimation, as this approach holds a wider consensus (e.g., Trotter & Gleser 1952, 1957; Trotter 1970; Formicola & Franceschi 1996; Vercelotti *et al.* 2009; Ruff *et al.* 2012). The validity of Sjøvold's (1990) approach will be returned to in the discussion section.
2. Individuals who have an estimated age of ≥60 years old, or older at the time of death (though rare to be able to estimate older age with such precision), would be excluded, as aging processes will affect stature after this point (Trotter & Gleser 1952: 464; Raxter *et al* 2006: 376).
3. Individuals who exhibit severely fragmented bones, severe trauma (e.g., badly healed long bones through the erroneous setting of the bone fragments), pathologies (e.g.,

**Table 3.** Rosenstock's et al. (2019: 5659) collected measuring standards for stature estimation studies using the regression method, based on the standards previously developed by Pearson (1899), Martin (1928), Raxter et al. (2006), and Siegmund (2010) (see Fig 9. through 12.).

| Bone(s) | Description |
|---|---|
| **Cranial Height** | Basion-bregma height of the cranium (BBH). |
| **2nd Cervical Vertebral** | The most superior point of the odontoid process to the most inferior point of the anterio-inferior rim of the vertebral body |
| **3rd-7th Cervical Vertebral** | The maximum anterior height of the vertebral body |
| **Thoracic Vertebral** | The maximum anterior height of the vertebral body |
| **Lumbar Vertebral** | The maximum anterior height of the vertebral body |
| **1st Sacral Vertebra** | Anterior height of the first sacral segment. |
| **Femur** | Bicondylar length, physiological length |
| **Tibia** | Condylo-malleolar length, lateral condylo-malleolar length |
| **Talus-Calcaneus** | Articulate height of the talus, combined with the calcaneus: from trochlea of the superior point of the talus, to the inferior point of the calcaneus tuber |

rickets), or any other factors that prevent the measurement of the maximum height of the bones cannot be used in stature analysis. For example, male individual 655 from Leadenhall, exhibited a healed greenstick fracture on the left femoral shaft, causing the formation of periosteal bone tissue, bowing of the shaft, and swelling (Schofield & Lea 2005: 261). The bowing of the shaft prevented the full measurements of the bone from being recorded, hence only the right femur was used for this individual.

### *7.2.1 Bone Measurements*

The issue of consistency in the manner that the bones are to be measured when used for stature estimation has been a long-running issue, stretching back to Sue's (1750) introduction of stature estimation (as discussed in the previous chapter). In many instances in the past, there was a complete lack of uniform practice when taking the measurements of the bones that were to be used for stature estimation, hence the wide inter-observer errors. Later studies, such as Trotter and Gleser's studies (1952, 1958), included detailed descriptions of how the measurements were to be taken, yet these guidelines were not always followed by Trotter when taking the measurements. Trotter performed all measurements of the bones in the study from 1952, while for the study from 1958, the measurements were taken by various military lab technicians (Trotter & Gleser 1952: 472, 1958: 80). The bone posing the biggest issue for consistency between studies has been the tibia (Trotter & Gleser 1958: 88; Lynch *et al.* 2019: 171), which has shown perhaps the largest inter-observer errors among all of the bones used for stature estimation. Trotter cites several different sources as the references for the measuring methods used: maximum length of the humerus, radius, ulna, fibula, and for the bicondylar length of the femur, Hrdlicka's (1947) measurements standards are cited, while for the maximum length of the femur, Martin (1928) is cited. The measuring method used for the maximum length of the tibia is cited as originating from personal communication from Krogman (1948), these tibia measurement standards are similar to the definitions presented by Martin (1928), and Hrdlicka (1947) (Jantz *et al.* 1995: 759):

> End of malleolus against the vertical wall of the osteometric board, bone resting on its dorsal surface with its long axis parallel with the long axis of the board, block applied to the most prominent part of the lateral half of the lateral condyle (Trotter & Gleser 1952: 473).

The issue does not lie with the definition given for the tibia measuring procedure, instead, there is evidence to suggest that Trotter did not follow these procedures in the study from 1952. When the material was re-assessed by Jantz et al. (1995: 758), Trotter's tibia measurements were systematically on average 13 mm too short. As it seems, Trotter had omitted the malleolus from the measurements, even though the definition states that it should be included (Trotter & Gleser 1952: 473). These systematic errors of measuring the tibia without the malleolus result in the underestimation of the contribution of the tibia's length to the full stature of the individual. As such, when Trotter's tibia formulae are applied to other populations (populations that have their tibiae measured correctly with the malleolus), the estimated stature will always result in overestimated stature. Trotter and Gleser noticed these types of overestimation errors in their study from 1958 when compared to the results from 1952, though these errors were attributed to interobserver errors, instead of caused by the erroneous results from the previous study:

**Table 4.** Measurement standards for anatomical stature estimation proposed in Raxter et al. (2006: 375-383). With several of the measurements based on the standards presented by Martin (1957) (see Fig 11. & 12.).

| Long Bone | Description | Abbreviation |
|---|---|---|
| **Femur** | Caput-condyle-length (maximum length) | F1 |
| | Bicondylar length, physiological length | F2 |
| **Tibia** | Condylo-malleolar length, lateral condylo-malleolar length | T1 |
| **Humerus** | Maximum length | H1 |
| **Radius** | Maximum length | R1 |

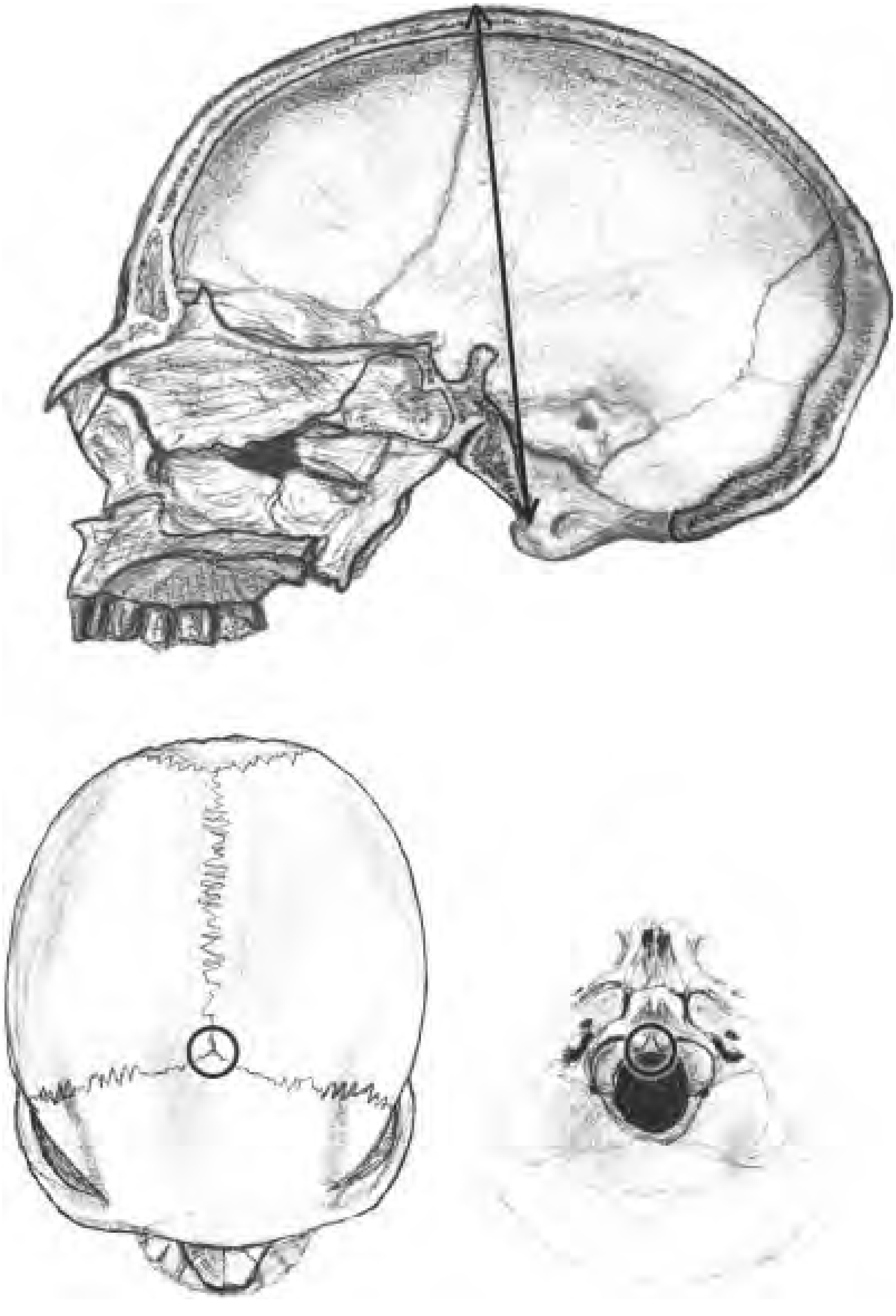

**Fig 9.** Cranial height measurements (BBH) using spreading cranial calipers, the basion (i.e., bottom of the skulle, occipital bone, point anterior of the foramen magnum) to bregma point (i.e., top of the scalp, where the sagital sagittal and coronal suture lines meet in a single point) (Raxter et al. 2006: 382: Fig 3).

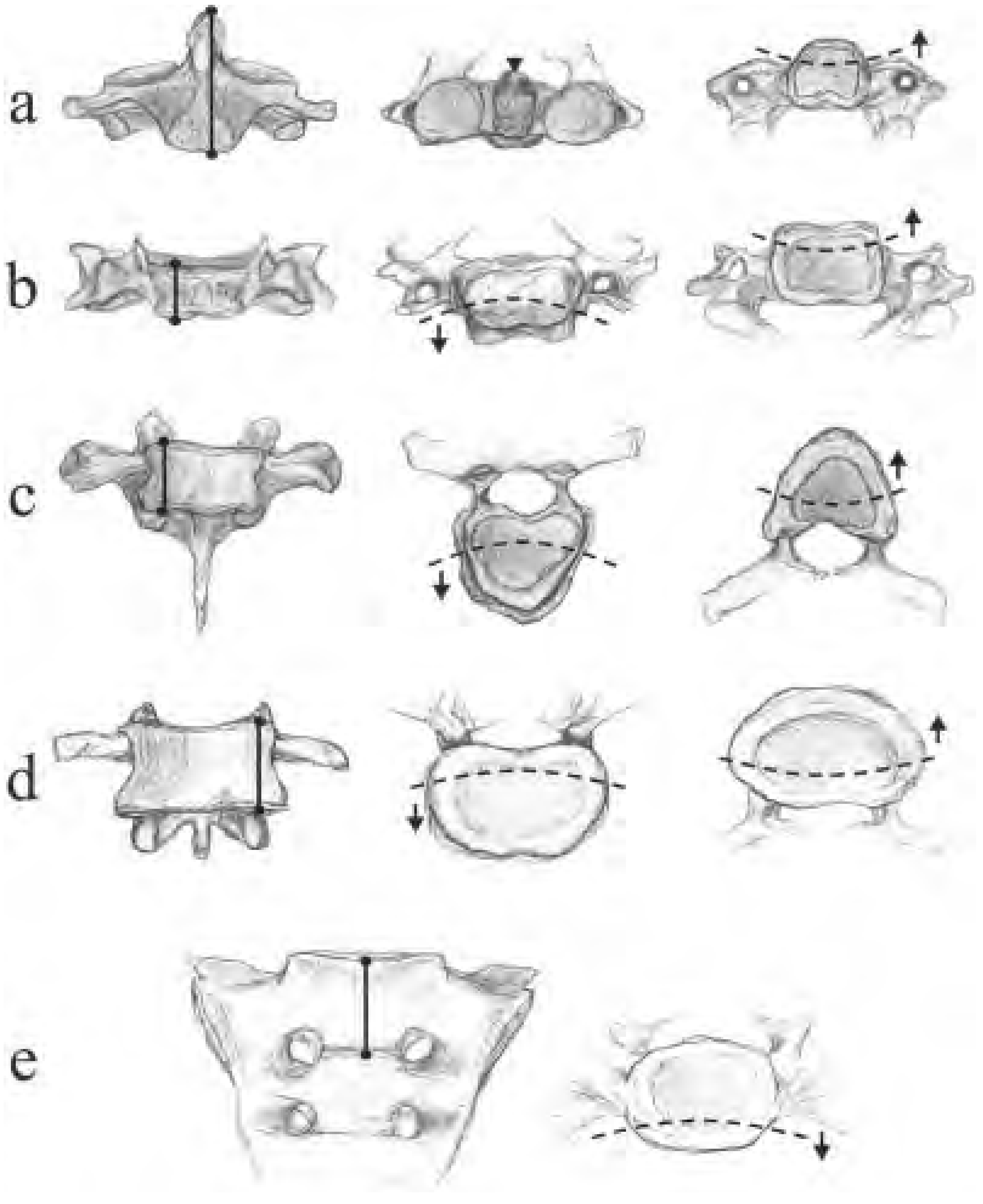

**Fig 10.** Vertebral measurement; Veterbal disks: **a.2nd** cervical, using spreading calipers, measuring the most superior point of the odontoid process to the most inferior point of the anterio-inferior rim of the vertebral body **b. 3rd** to **7th** cervical, measuring the maximum anterior height of the vertebral body (repeated process for the thoracic, lumbar and the the first sacral segment) **c.** thoracic, **d.** lumbar, **e.** 1st sacral. (Raxter et al. 2006: 382: Fig 4).

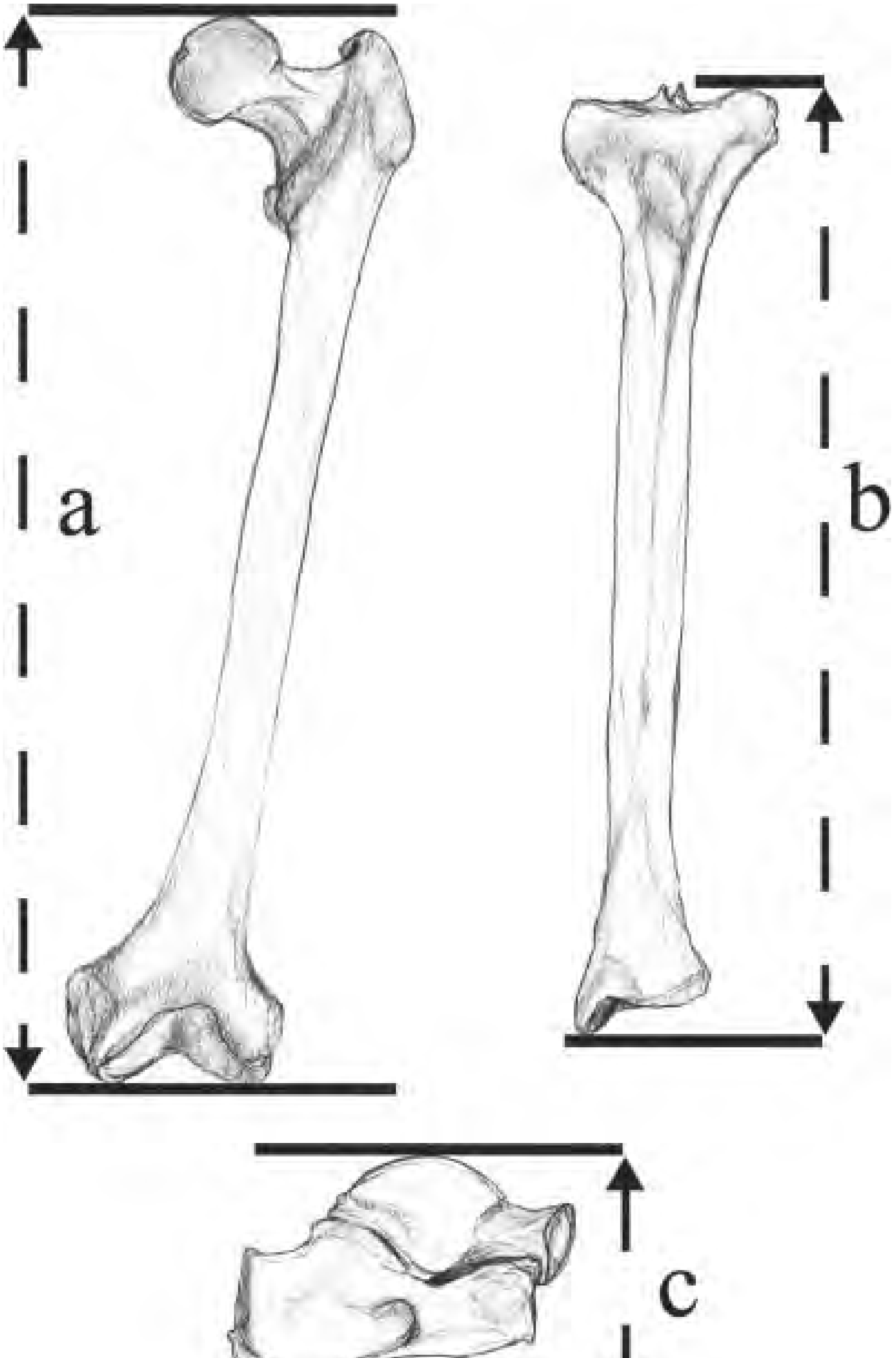

**Fig 11.** Lower limb measurement, **a.** femoral bicondylar height (F2), **b.** tibiae condylo-malleous height (T1), **c.** taluscalcaneous articulated height (Raxter et al. 2006: 383: Fig 5).

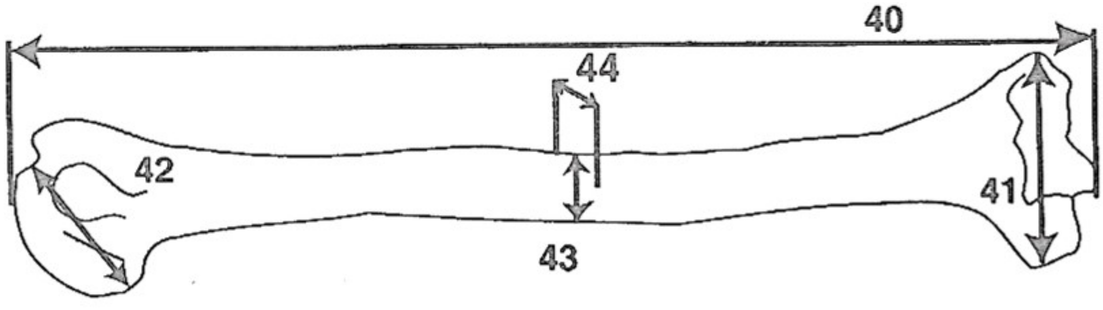

Figure 49. Measurements of the left humerus, anterior view (after Moore-Jansen et al. 1994).

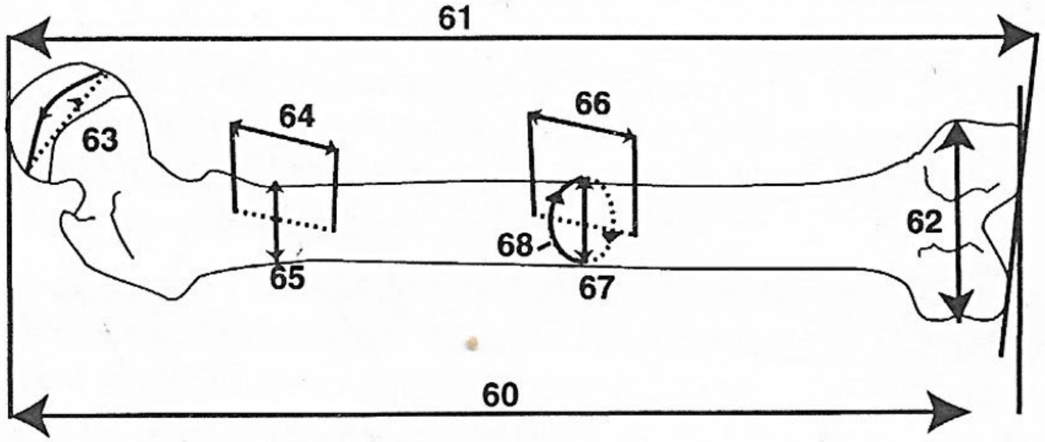

Figure 54. Measurements of the left femur, posterior view (after Moore-Jansen et al. 1994).

**Fig 12.** Measurements standard for the maximum height of the humerii (H1) (40) and the maximum height of the femora (F1) (60) (Buikstra & Ubelaker 1994: 80, 83: Fig 49. & 55.).

> … the tibia is longer on average than the fibula, whereas in the previous study, the reverse relationship was found. Possibly this difference between the two studies may be accounted for by different technicians measuring the maximum length of the tibia… (Trotter & Gleser 1958: 88).

To avoid previous mistakes, measuring methods that have seen wide applications, and have a consensus as being an authority mode of recording the metrics, should henceforth be the sole measuring methodology applied in stature estimation studies moving forward. Rosenstock et al. (2019) presented a collection of measuring standards, collected from reliable bone measuring methodologies, hence the list presented below (Table 1), can be seen as reliable for future stature estimation methods, which utilize the regression method.

Similar recording issues have been encountered regarding the anatomical method. As discussed in previous chapters, Fully's (1956) initial publication regarding the anatomical method, did not include any explicit measurement standards (Raxter *et al.* 2006: 374), hence resulting in the method being difficult to replicate. The revised anatomical method by Raxter et al. (2006, 2007), however, includes clear measurement standards, based on previous reliable publications (Table 4).

## *7.3 Wales*

### *7.3.1 Llandough*

The village of Llandough is located 2.5km northwest of the town of Penarth and 3.5 km southwest of central Cardiff. Saint Dochowy's church, lies north of central Llandough and was successively built over several centuries, but the structure (as it is today), is largely built in the mid-19th century and onward. The church and its surroundings inhabit a gentle slope and overlook River Ely (Holbrook & Thomas 2005: 1).

The archaeological potential of Saint Dochowy's church and its surrounding areas has long been recognized, with the first archaeological excavation taking place in 1963 (Beare 1963). In 1990, the area north of the churchyard was scheduled for commercial development, and due to the area's adjacency to the monastery, an archaeological investigation was required before the new development would be permitted. In March of 1994, the excavations commenced and lasted until September of that year. The excavation area lies north of the church boundary walls and extends to the edge of the ridge. The excavation covered an area of 0.22ha, the furthest boundary was not possible to uncover (comparable to Portway East (Cook & Dacre 1985), and Eastry (Welch 2008); see below) within, 1026 graves were found. These graves included: 814

A MONASTIC CEMETERY AT LLANDOUGH 27

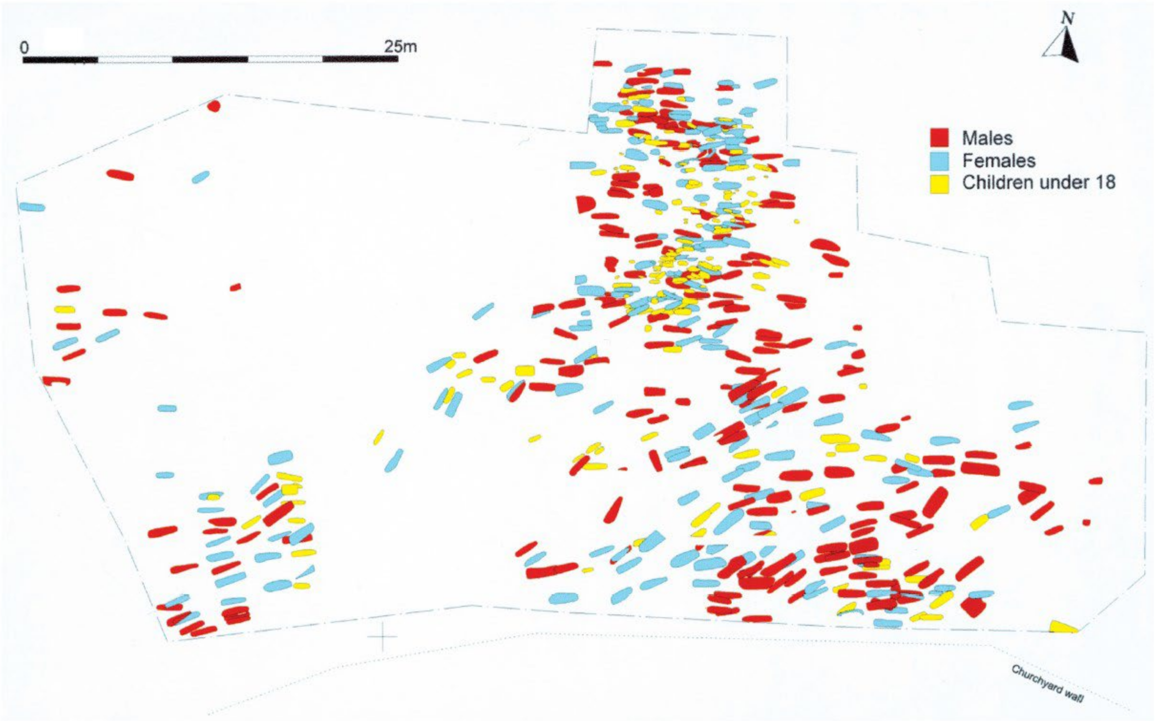

FIG. 12

**Fig 13.** Distribution of males, females and children under 18 within the Llandough cemetery (Holbrok & Thomas 1994: 27).

articulated skeletons and 212 disturbed (unarticulated) skeletons. Later activity in the area had shaved off the overlaying stratigraphy, hence many of the graves were only a few centimetres below the modern surface; this was caused by activities, e.g., post-medieval quarrying, later levelling for construction works and cutting of shallow ditches (Loe 2003a: 15-22; Holbrook & Thomas 2005: 1-2, 8-9).

All of the graves uncovered in the cemetery were inhumations (Fig 13.), with the vast majority having a single individual interred. The exception to this norm were two double graves (Grave 10/11 and Grave 206/212), in which each of the double graves included one adult male and one child (Holbrook & Thomas 2005: 10). Through radiocarbon dating, it is believed that the majority of burials uncovered, dates to the early medieval period (mid-fifth to late-10th century A.D.). (Loe 2003: 25; Holbrook & Thomas 2005: 41). Regarding the orientation of the graves, the vast majority of the graves were oriented east-west (head towards west), a minority of the graves ranging in their orientation from northeast-southwest to north-south (Holbrook & Thomas 2005: 38). This normative orientation along with the slim artefactual evidence, and dating, places the Llandough cemetery as an early Christian cemetery

#### *7.3.1.1 Llandough's Human Remains*

In 1998, Cadw: Welsh Historic Monument, provided funding for stratigraphic analysis of the site, and the National Museums & Galleries of Wales facilitated the finishing of the analysis and reports of the artefacts (Holbrook & Thomas 2005: 2). Louise Loe along with Kate Robson-Brown (2005: 42-53; Loe 2003a & b) performed the osteological examination of the remains of 801 individuals uncovered in the cemetery, under the auspice of the Paleopathology Study Group, University of Bristol. This analysis ranged from demographic, pathological to stature analysis.

Of the 801 skeletons, 573 were determined to have been adults; 233 males and 194 females, and 148 unsexed. 280 skeletons were considered to have been recovered in a fairly good state of preservation, out of which, 133 skeletons were recovered with 75% or more of their bones. However, no complete skulls were recovered, nor were the recovery of complete long bones good, as only six percent of the recovered were in a non-fragmented state. This commonality of long bone fragmentation limited the number of which could be considered for stature estimation. Trotter and Gleser's (1952 & 1958; Trotter 1970) regression formulae were used to estimate the stature of 151 individuals, 80 males, and 71 females; average stature of males: 169.6cm, average stature of females: 156.8cm (Loe 2003a: 174, 274; Loe & Robson-Brown 2005: 43-46). No error ranges are provided for the estimates, as is a common case with the majority of stature studies of British early medieval populations.

The human remains from Llandough cemetery were re-examined by the author. 38 adult individuals were determined to have complete lower long bones which would allow for stature estimation (21 males and 17 females).

## *7.4 England*

### *7.4.1 Apple Down (West Sussex)*

The majority of the site of Apple Down is located within the parish of Compton, but extends into East Mardens, in West Sussex. The site is situated on top of a ridge, commanding a view over the Sussex Downs, Harting Beacon, Chichester Harbour, and the Isle of Wight. The crest of the ridge is flat, and similar to many other early medieval sites, it used to be occupied by several Bronze Age barrows, as recorded by Greinsell (1934: 244). None of these barrows have been preserved due to later exploitation of the area (Down & Welch 1990: 16), unlike other contemporary sites used in this study, e.g., Barrow Clump (Andrews, *et al.* 2019), or Portway East (Cook & Dacre1985).

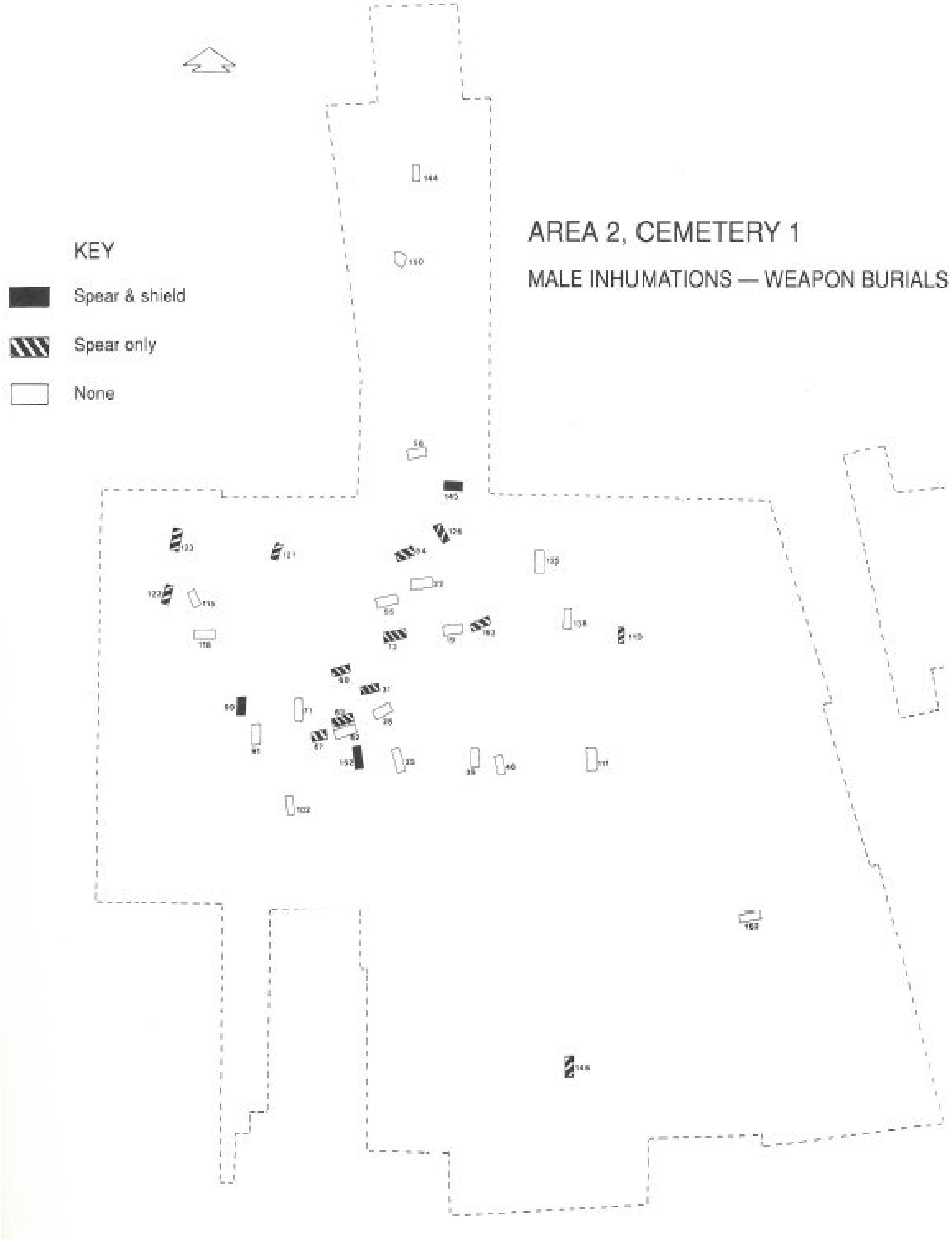

**Fig 14.** Apple Down, plan of Area 2, Cemetery 1 (Down & Welch 1990: 21, Fig 2.8.).

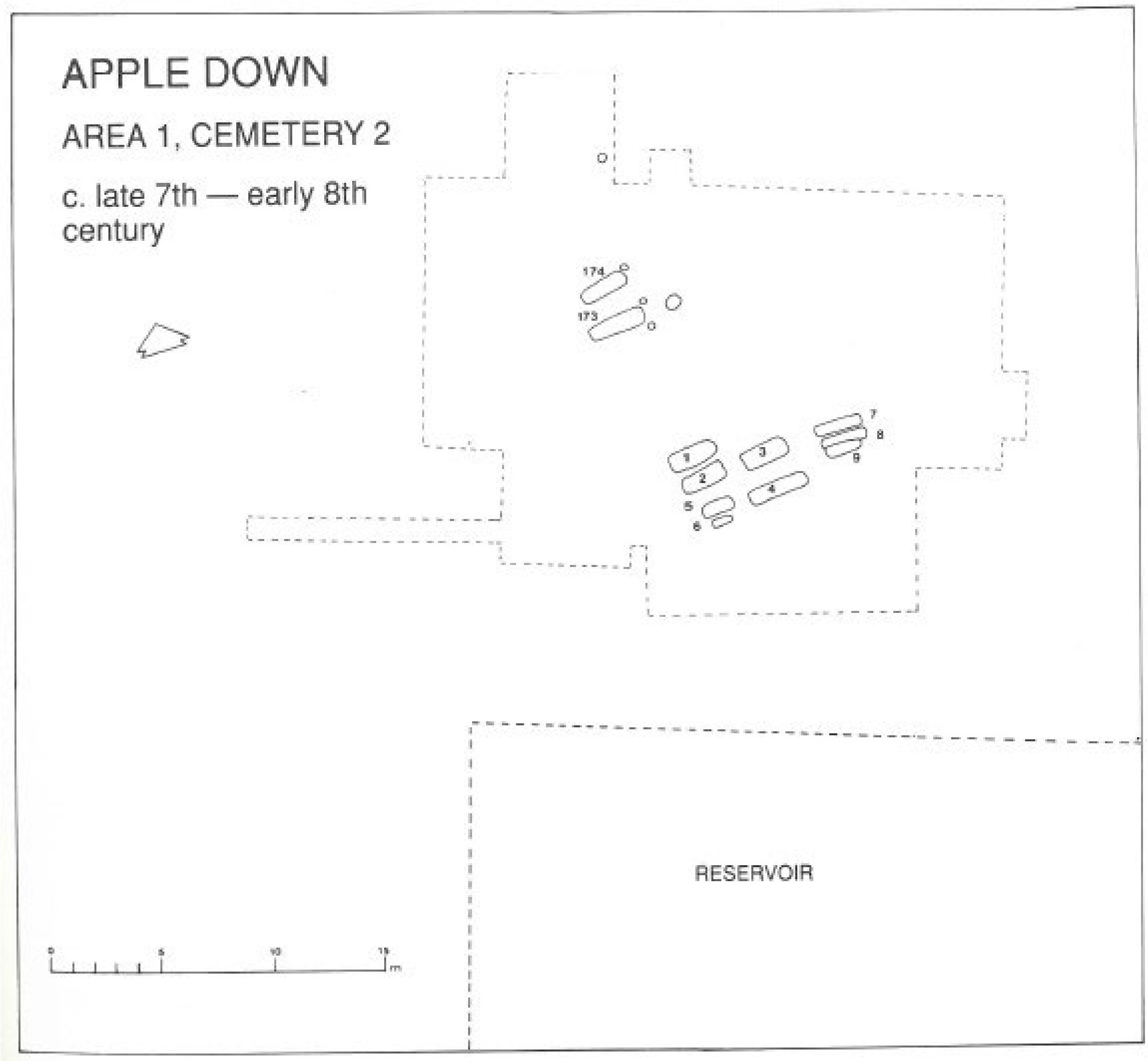

**Fig 15.** Apple Down, plan of Area 1, Cemetery 2 (Down & Welch 1990: 13, Fig 2.5.).

The six excavation seasons revealed two early medieval cemeteries, with Cemetery 2 (Fig 14.) estimated to be the younger of the two, with an estimated period of use stretching from the seventh to eighth century A.D. In cemetery 2's area, eleven inhumations were uncovered, five of these had been buried in coffins. The artefactual material were fairly scarce, with only three of the graves being furnished with modest grave goods. (Down & Welch 1990: 13-14).

Cemetery 1 (Fig 15.), the larger of the two excavated areas, is believed to have been the older of than the former, with an estimated period of use dating to the early sixth to late seventh century A.D. A total of 166 graves were uncovered in the area of the cemetery 1; 96 were single inhumations, out of which 18 may have been buried in coffins, two double inhumations, and eight reused graves (those previously interred are believed to be among the disarticulated material), six empty graves (remains are believed to have been destroyed, hence unlikely cenotaphs) and 54 cremation burials. Many of the burials would likely have been covered by smaller mounds, which have since been destroyed by the plough. Out of the 166 graves, 82 were furnished, and 17 held weaponry (Down & Welch 1990: 14-15; Harman 1990: 195-200).

The vast majority of the graves are oriented north-south (head towards south), or east-west (head towards west). Interestingly to note, is that the majority of the east-west oriented burials in Cemetery 1 are dated to the late fifth to sixth century A.D., hence predating the initial Christianisation of Saxon Britain, which happened in the late sixth to early seventh Century A.D. (Down & Welch 1990: 16; Magennis 2011: 16-29). Cemetery 2 which dates fall within the Christian period, has all of the graves oriented east-west (head towards west), and the grave goods are fairly scarce, hence those interred in this area may have been baptised Christians.

With regards to the dating of the two cemeteries, it have mainly been based on the artefactual typologies of the finds uncovered within the cemeterial bounds and the furnished graves (similar to the majority of the sites discussed in this chapter). One example of this is the sword beads which were uncovered in one grave (Grave 12A), these types of weapon decoration are typical for Frankish swords imported from France, dating from the fifth to the sixth century A.D. Another Frankish weapon import found in the cemetery (Grave 63) are three seax blades, which can be dated through their continental counterpart's typology from the sixth to seventh century A.D. Many of the non-weaponry finds do also offer dateable typology ranges, e.g., the square-headed bow brooch uncovered in Grave 14, whose continental counterparts have been uncovered in Germany, Switzerland and Scandinavia, each given a similar dating phase of early to mid-fifth century A.D. Five spiral rings were found (Grave 13, 51, 88, 128, 130), two such rings were previously uncovered at a fifth till sixth century A.D. cemetery in Reading (Hawkes & Dunning 1961: 45; Down & Welch 1990: 91-100).

To summarize the dating of Cemetery 1: the earliest burial is believed to date to the late fifth century A.D., with the latest burial dating no later than late seventh century A.D.. Cemetery 2 is in large lacking in artefactual finds, hence have been suggested to reflect an early Christianization period (the orientation of the graves is also considered here), i.e., the final phase period, hence is estimated to date to late seventh till early eight century A.D. (Down & Welch 1990: 109).

#### *7.4.1.1 Apple Down's Human Remains*

The human remains uncovered at Apple Down's two cemeteries were analysed by Mary Harman (1990: 183-200). A total of 87 individuals from Apple Down's two cemeteries were possible to establish sex for, out of which 76 individuals had their stature estimated (39 males and 37

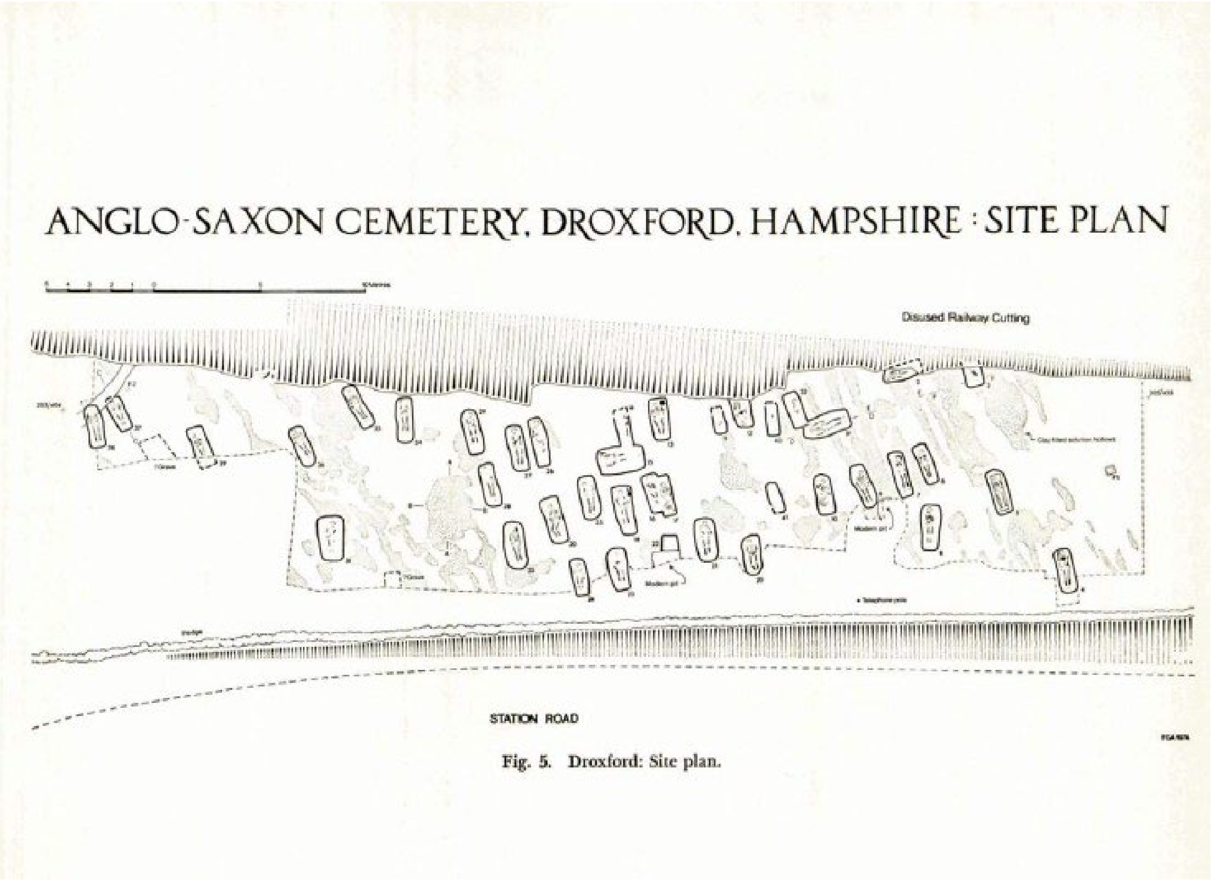

**Fig 16.** The excavated area of the early medieval cemetery at Droxford, Hampshire (Aldsworth 1979: 100).

females), using Trotter and Gleser's lower limbs stature formulae both from 1952 and 1958; male average stature: 164.9cm; female average stature: 160.6cm (Harman 1990: 183-193). As commonly is the case for many previous stature studies, no error ranges have been included here.

For this study, 49 individuals (24 females and 25 males) were available for analysis, which were re-examined by the author and measured. Of these 49 individuals, 25 were considered to have been recovered fairly complete (15 females and 10 males), and hence could be considered for anatomical stature estimation.

### *7.4.2 Droxford (Hampshire)*

The village of Droxford is situated in southeastern Hampshire, along the western bank of the river Meon. The name Droxford, or "Drochenford", as it is named in the Domesday Book, the area is believed to have served as a fording place across the river, hence may explain the origin of the name. The town is mentioned in three early medieval charters, one by King Egbert, in 825 A.D., another one by King Athelstan, in 939 A.D., and the fourth charter was by King Eadwig, dating to 956 A.D. The cemetery itself is mentioned in the earliest charter regarding property bounds, and is referenced as a "heathen burial place" (Aldsworth 1979: 93, 175).

Droxford's early medieval cemetery (Fig 16.) was first discovered in 1900, and was excavated for two seasons to a limited extent by, William Dale from the British Museum. Unfortunately, very little is known about these two seasons, and what came to be uncovered, beyond vague and brief statements, as no records appear to have survived (if there ever were any). The only written accounts chronicling the excavations are two notes written by Dale, where he briefly outlines the excavation work, e.g., he mentions that several burials were uncovered, but no precise number is given, nor is the layout of the uncovered cemetery addressed. What happened to the human remains is not clear, however, 176 artefacts from the site were deposited at the British Museum, where they remains to this day. These artefacts ranged from brooches, belt fittings, beads, and weaponry (Aldsworth 1979: 93-96).

Originally, according to Dale (1905: 175), the cemetery laid on top of a hill, yet little remained of it in the 1970s, after the building of the railway line in the early 20th century, as large sections were shaven off, or completely removed during the construction. In 1974, due to extensive erosion of the area, Hampshire Museum Service conducted another excavation of the cemetery, to protect what remained beneath the hill from further destruction. The excavation uncovered 41 inhumations, and two possible cenotaphs . Many of the graves were furnished with rich grave goods, e.g., spearheads (eight were uncovered in graves and another 33 were found in the cemetery); shield bosses (three were uncovered in graves and another nine were found in the cemetery); one knife which was long enough to be considered a seax blade; at least ten brooches of varying types; 213 beads, all of which were uncovered in female burials. Each of these artefact types appears to concur on a timeframe for the cemetery of the fifth to sixth century A.D. (Aldsworth 1979: 98-102, 164-174).

#### *7.4.2.1 Droxford's Human Remains*

No detailed osteological report of the human remains have to date been published. All of the individuals uncovered in the 41 inhumations in 1974 were re-examined by the author, out of which 15 adult individuals (nine males and six females) proved to be possible to consider for stature estimation, one of the male individuals proved to be fairly complete.

### *7.4.3 Weyhill Road (Hampshire)*

In 2016, ahead of planned construction, a roughly rectangular area of 0.47ha. along Weyhill Road, Andover, Hampshire, were excavated by Cotswold Archaeology. Evidence of human activity in the area stretches as far back as the Palaeolithic and Mesolithic periods, succeeding

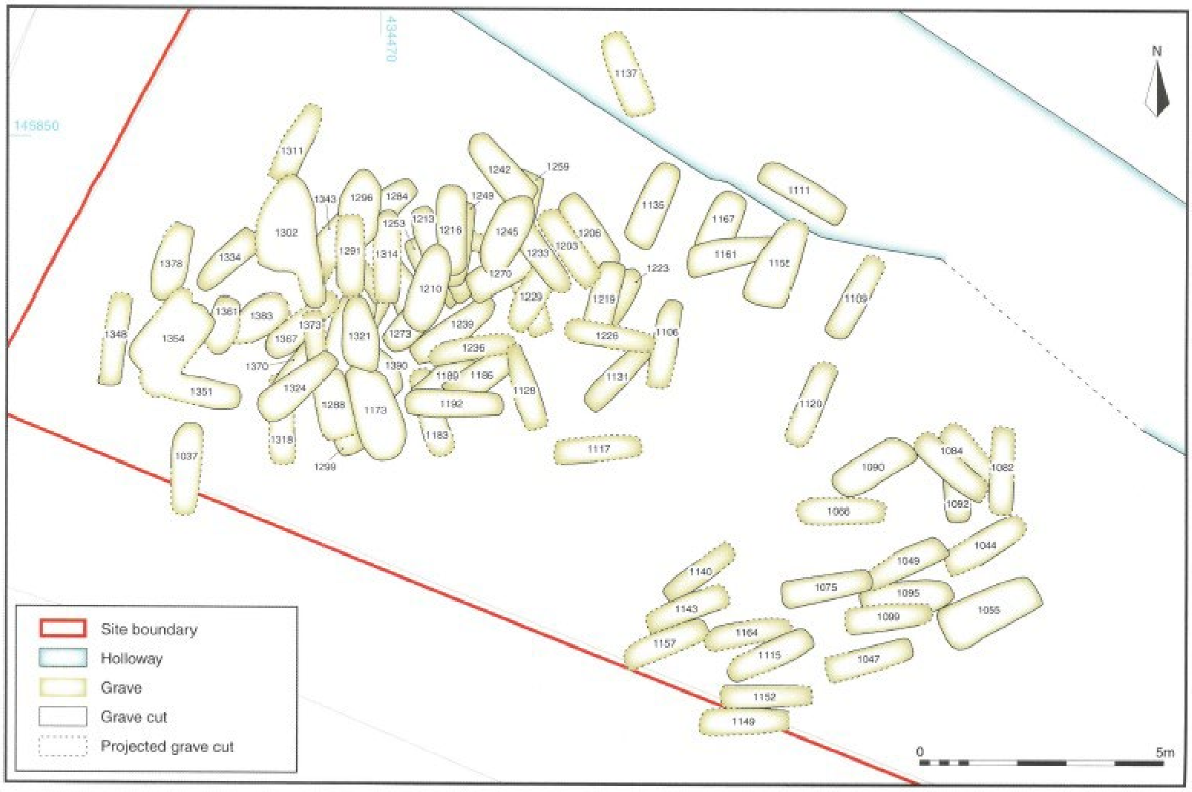

**Fig 17.** Reconstructed plan of the Weyhill cemetery layout (Walker *et al.* 2020: 20, Fig 2.7.).

periods saw an increase in activity. Following the Roman period, Hampshire formed into one of the earliest shires in England. In the six century A.D., the West Saxon kingdom was formed by Cerdic (reigned 519-34 A.D.). The following century saw upheavals, and pressure from the neighbouring regions, both Britons and Mercians threatened the stability. Long-lasting stability in the region was first achieved under king Ecgberht (reigned 802-39 A.D.), who ruled from Wessex, which later would lead to the unification of England as a single domain. But this period was not without tribulations, as it saw large incursions of Norsemen, resulting in several battles fought across the land (Walker *et al.* 2020: 1-10).

The excavations uncovered a total of 91 graves (Fig 17.), which held 124 articulated skeletons, and another 39 individuals were identified through the disarticulated assemblages (Walker *et al.* 2020: 1). The population uncovered in the cemetery proved surprisingly homogenous: 100 sexed individuals: 98 males, and 3 females. The population homogeneity, along with the evidence that some of the individuals were buried with their hands bound, has been suggested as evidence to suggest the interpretation of the Weyhill cemetery as a punishment burial ground. This interpretation find further corroborative evidence in the pathological analysis, as at least nine individuals had been beheaded (sharp force trauma to cervical vertebrae), four individuals whose cervical vertebrae did not show any signs of sharp force

trauma, but who's crania were buried
parallel in the grave with their articulate post-crania remains. Another ten individuals whose post-cranial remains were missing (i.e., only the skulls buried, decapitated?), giving a total of 23 individuals who possibly had been beheaded. Evidence would suggest that these decapitations were peri-mortem, rather than post-mortem, which occasionally were practiced out of superstition to prevent the dead from rising again (Walker et al. 2020: 159, 182; Clough 2020: 84-85).

The amount of artefactual evidence uncovered at the site were fairly limited, hence dating based on artefactual typologies were not possible, beyond a single instance with one silver coin, dateable to 979-985 A.D. (Walker *et al.* 2020: 1). The limited quantity of artefacts uncovered in the cemetery, and in the context of the burials, can likely be explained by the nature of the cemetery as a burial ground predominately for criminals, as contemporary depictions of punishment being meted out against those condemned death, would have forfeited their earthly possessions, and merely wore simple tunics when executed (Walker et al. 2020: 167).

To fill in the gaps left in dating by the lack of artefactual evidence, twenty individuals were dated through radio carbon dating. The calibrated dates gave a date range from the eighth till the fourteenth century A.D, with conservative estimates placing the main use of the cemetery from the 10th through the 13th century A.D. (Healy 2020: 105). The less conservative dating would place the site contemporary with the later period of the formation of the Kingdom of Wessex (sixth-eighth A.D.), and the unification of the Kingdom of England during the 10th century A.D. (Walker *et al.* 2020: 171-174).

#### *7.4.3.1 Weyhill's Human Remains*

The human remains uncovered were all recorded by Sharon Clough (2020: 62-97), in accordance with the standard methodologies by Brickley and McKinley (2004), and Mays et al. (2018). The general age at death were fairly young, placing the majority of the population in a range from 18-25 years old at the time of death (Clough 2020: 67).

The isotope analysis was undertaken by Mandy Jay (2020: 127-141). Twelve sexed individuals were analysed for oxygen isotopes from tooth enamel (2nd or premolars), and carbon and nitrogen analysis of bone collagen; eight out of these individuals were also analysed for strontium isotope ratios. 15 individuals were analysed for sulfur ratios in the bone collagen. These analyses were undertaken to consider mobility, diet, and environmental factors (Jay 2020: 127). The results of the isotope analysis tell of a fairly diverse population; two individuals'

(SK1274 & SK1297) oxygen results would suggest an origin from a colder climate, beyond the bounds of Britain, possibly north-central Europe, or Scandinavia. A third individual's (SK1211) strontium result was higher than that of the British Isles, unless, the individual would have originated from the coastal or island territories with a diet rich in maritime catch, another possibility of origin for this individual may be the coastal regions of Denmark or Norway, as this would also match the strontium levels. With the nitrogen analysis, there was one significant outlier (SK1228), whose oxygen results also suggest an out-of-site origin, from a warmer and wetter climate, possibly southern Britain, Ireland, or France. However, there is a possibility that this individual's origin where from the site, but that their diet differed significantly from the rest of the population (Jay 2020: 141).

The completeness level of the human remains was fairly good, with 35% of the population having skeletons with completeness of ≥75% (Clough 2020: 65). The stature was estimated for 38 male individuals, but it is unclear what stature method was used to achieve these results. The mean stature was calculated as 170.7cm, with a range of 161.1-181.1cm (Clough 2020: 70-71) (see results chapter for new comparative results).

Out of the 100 uncovered articulated skeletons, the metric records by Clough (2020) of 46 individuals (all males) who were dated through radiocarbon dating, stratigraphic or spatial context to pre-conquest era, and who proved to have either complete (fused epiphyses, i.e., adults, and intact diaphysis) femur or tibia (or both), were chosen to be used with the regression method for this study.

### *7.4.4 Collingbourne Ducis (Wiltshire)*

The site is located to the east of the village of Collingbourne Ducis, in Wiltshire, situated on the furthermost eastern edge of Salisbury Plain, c. 16km northeast of Stonehenge, and 13 km northwest of Portway East/West, and c. 10km northwest of Barrow Clump (see below). The site is situated on a southern-facing slope, covered in dense scrubland, bordering private gardens, with farmland to the north. The name, "Collingbourne", is believed to be of old Saxon origin, likely meaning "stream of the dwellers on the [river] coll". Collingbourne is first mentioned in 903 A.D., in the Royal Charter, suggesting that the site would already have been well established at this point in history (Cook & Dacre 1985: 53; Dinwiddy & Stoodley 2016: 4).

The cemetery (Fig 18.) was already discovered in 1974, ahead of planned new constructions in the area, prompting an archaeological investigation to be undertaken. The excavation covered

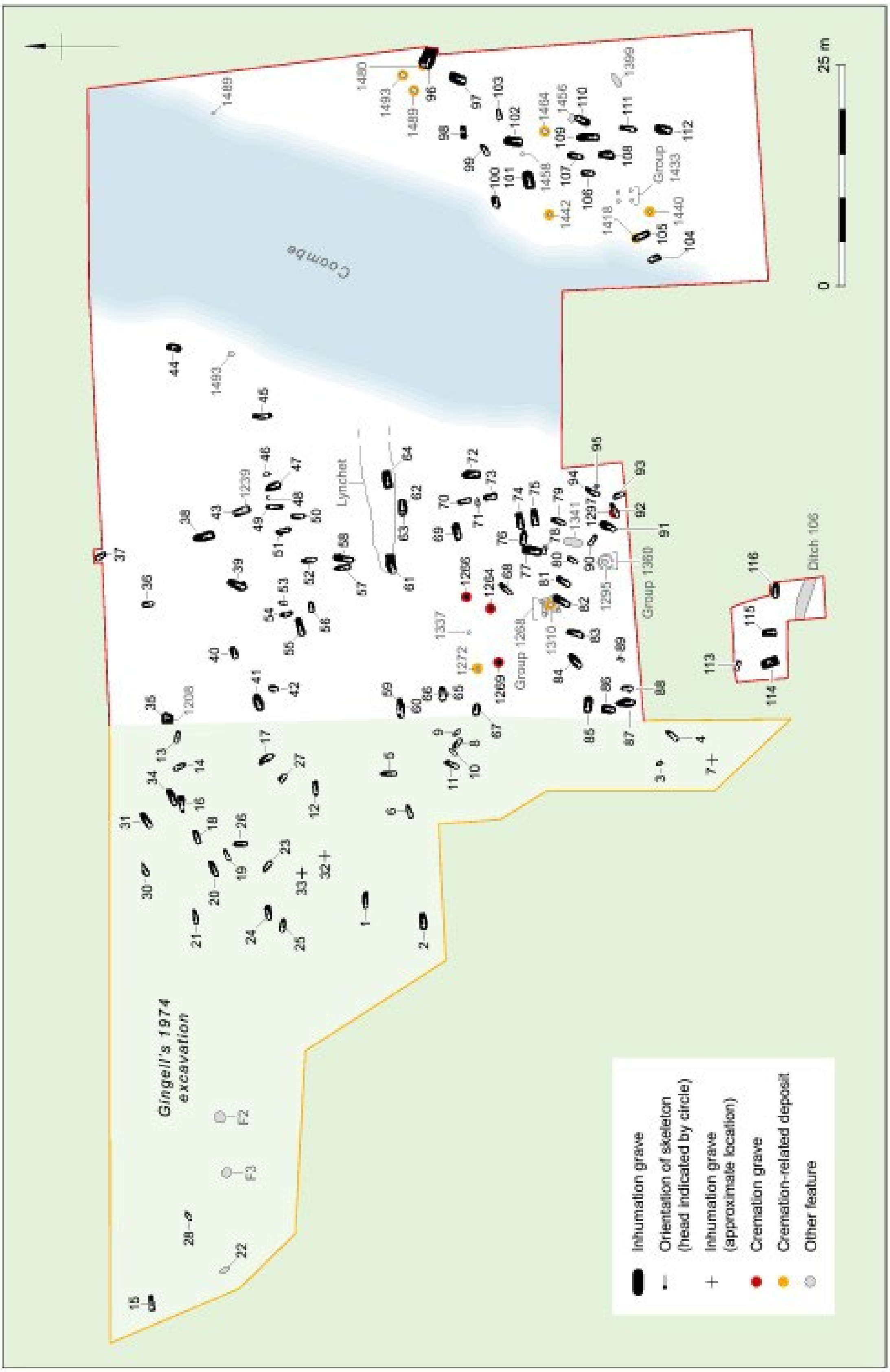

**Fig 18.** The site of Collingbourne Ducis's cemetery plan, illustrating the graves and other features (Dinwiddy & Stoodley 2016: 3: Fig 1.2.).

an impressive are of c. 4840m$^2$, leading to 33 late fifth to seventh-century graves to be uncovered, many of which were furnished with grave goods. In 2006, the site was again archaeologically investigated, with excavations initiated the following year, then again two years later in 2009. Unlike the first excavation four decades earlier, these two seasons were more conservative in scope and uncovered an area of c. 80m$^2$. The cemetery may have been delineated by a penannular ditch, similar to Portway East, however, only a very limited area of the ditch has been excavated, hence remains inconclusive (Dinwiddy & Stoodley 2016: 1-4, 7).

The natural chalk bedrock of the area provides a good environment for bone preservation. The excavated cemetery yielded a total of 115 inhumations, this included the results from 1974, 2007, and 2009, with the majority of the inhumations (82 individuals), being uncovered during the latter two seasons. Beyond the inhumations, four cremations and two possible cenotaphs were also uncovered. Nearly half of the graves are oriented south-north (46.6%), and more than a third is oriented west-east (37.3%); the cemetery appears to be lacking in uniformity which is otherwise seen in the later Christian Saxon cemeteries. The majority of the individuals were buried in supine positions (69.5%), and the remainder were buried in flexed positions; only a single individual was buried in a crouched position (grave 90). There is no evidence to suggest that there were any coffin burials, however, an adult female (grave 96) proved to be a bed burial (i.e., a burial where the individual has been placed on top of a bed-esque platform in the grave), only the iron fittings and nails remained of the platform (Dinwiddy & Stoodley 2016: 6-7, 53).

No radiocarbon dating was performed on any of the remains uncovered in the cemetery, hence the dating of the burials has to solely rely on the typologies of the artefacts, especially the weaponry, as clear and well-established dateable typologies exist in large for Saxon weaponry, brooches, and buckles. Several spearheads and shield bosses were uncovered, each dating to the late-fifth to seventh century A.D.; the typology of uncovered brooches and buckles appears to concur with the dating of the weaponry. The cemetery appears to have two distinct clusters regarding the dating; the western cluster has an estimated date range of late-fifth century to late sixth century, possibly early seventh century A.D., whilst the eastern cluster appears to have seen shorter use, and is predominately dated to the seventh century A.D. (Dinwiddy & Stoodley 2016: 106, 122).

#### *7.4.4.1 Collingbourne Ducis's Human Remains*

The human remains from the 82 inhumations which were uncovered during the 2007 and 2009 seasons were analysed by Kirsten Egging Dinwiddy (2016: 69-100). About half of the remains were considered to have been recovered in a fairly good or complete state, whilst the other half had been negatively affected by erosion and root action. Alongside the articulated remains, there were disarticulated human bones uncovered, which yielded a MNI (Minimum Number of Individuals) of 8 individuals, bringing the total MNI number of the cemetery to at least 90 individuals (123 if including the remains uncovered in 1974; not counting the cremation burials). About 40% of the cemetery proved to be immature, with 13.9% being no older than neonates/infants. For the adult population, the average age at death was ≥45 years (36.6% of the females; 42% of the males), which would be higher than the average age of other contemporary sites, e.g., Blacknall Field, where the average age at death for males ranged from 20-29 years, whilst females 30-39 (Stuckert 2010:114-115; Dinwiddy 2016: 69-77).

The stature was estimated for 46 adults (88.5%; 27 females and 19 males). The females had and average stature of 161cm (range:151-176cm); whilst the males had an average stature of 174cm (range 158-183) (Dinwiddy 2016: 77). However, neither the method nor formulae used are not stated, nor is the error ranges provided, merely the stature result ranges are, which should not be considered as the same or equal as the error range (i.e., 95%CI; further discussed in the discussion chapter). For this study, 18 individuals (12 males and 6 females) were re-examined and remeasured by the author, four of these individuals, all males, proved to be fairly complete, hence could be considered for use with the anatomical method.

### *7.4.5 Barrow Clump (Wiltshire)*

The cemetery site of Barrow Clump lies on the east side of the Avon Valley, in the centre of Salisbury Plain Military Training Area, east of Ablington, c. 6km northeast of Stonehenge, 10km southeast of the aforementioned Collingbourne Ducis, in a patch of forested area, surrounding a Bronze Age barrow, hence the name of the site (Andrews, *et al.* 2019: 11-13). The first archaeological investigation of the site was conducted by William Hawley, in 1898, and this was done in accordance with the acquisition of the area by the British military, sometime between 1895-1898 (Andrews, *et al.* 2019: 13-14). Following Hawley's investigative work on the site, no major work was done on the site for the next nine decades. In 1990, the site was scheduled as a monument of national importance. During this process, it became clear that the site had been damaged by animal activity, hence excavations were deemed necessary to protect any possible archaeological remains that might be uncovered. In 2003, a geophysical investigation took place of the site, revealing 20 barrows in total. The same year, excavations of the site were initiated by Historical England to protect what remained of the site. From 2011 to 2013, another investigation of the site took place by Wessex Archaeology, with the decision being made to completely excavate the site; followed by two more seasons from 2017 to 2018 (Andrews, *et al.* 2019: 13-15, 21; Andrews 2019: 129).

A total of 110 burials were uncovered, of which 68 were inhumations, 40 cremation burials, and two cenotaphs. The EBA barrow at the centre of the cemetery, alongside the contemporary ring ditch surrounding it, heavily influenced the layout of the graves of the later early medieval cemetery. The cemetery was concentrated between the southern border of the barrow and the inner edge of the ring ditch, with a few burials transgressing these arbitrary borders. No real uniformity with regards to the direction of the graves, rather the graves appear to have been cut in alignment with the curvature of the barrow and the ring ditch; hence no Christian uniformity can be inferred with regards to the grave positions. All but three of the individuals had been placed in a supine position in the graves; the other three were: laid on its right side, one on its left side, and one individual laid in a flexed position (Andrews 2019: 129).

Out of the 68 inhumations, 40 included graved goods (58%). Knives were a common item type, as it were found in 15 instances; jewellery were uncovered in 17 graves, out of these 17 graves, one included a Visigothic brooch; 11 graves included weaponry, ranging from shield bosses, spears, and one grave included a sword (grave 7062). The graves that included grave goods were not necessary to perform radiocarbon dating for, as all of the grave goods typology could be established as originating from the sixth century A.D. (Andrews 2019: 133-136). Thirteen graves that lacked grave goods were chosen for radiocarbon dating, four of these were given early medieval dates, ranging from sixth till eighth century A.D., these radiocarbon dated graves could then be used to date the contemporary surrounding grave clusters (Marshall et al. 2019: 54).

#### *7.4.5.1 Barrow Clump Human Remains*

The human remains were analysed by Kirsten Egging Dinwiddy and Emma Watts-Plumpkin (2019: 189-226). The total MNI (Minimum Number of Individual) for the cemetery were estimated to have been 81 individuals; 68 were uncovered in situ, i.e., in graves, and at least another 13 individuals were possible to determine from the disarticulated material. 62 individuals were possible to consider the sex of, 28 males, 30 females, and four individuals whose sex estimates were inconclusive (Dinwiddy & Watts-Plumpkin 2019: 189-197).

Fifteen individuals were subjected to strontium isotope analysis; ten of these individuals exhibited levels in accordance with the local levels, and one individual fell just beyond the lower end of the local range, still likely suggesting a local origin of this individual. Four individuals (one male and three females), had higher strontium levels, which exceeded the levels which could be considered to fall within the local range, hence suggesting a different origin than the previously discussed 11 individuals. These results would suggest that these four individuals at least spent the majority of their formative elsewhere than the actual region of the site. Three of these can likely trace their origins to the Midlands or East Anglia, and the fourth individual (grave 2805; adult female) likely had their origin either in southern Cornwall or Cumbria. However, important to note is that these strontium values also find matches in continental European regions, e.g., southern Germany, Italy, or Hungary (Watts-Plumpkin 2019: 225). The conclusion that can be drawn based on the strontium isotope results would suggest a fairly homogenous population, at least nearly two-thirds based on this limited sample of 15 individuals, with one-third of the individuals having their origin elsewhere in the British Isles or continental Europe.

Stature was estimated for 26 individuals, 10 females, and 16 males. The females had a stature range of 151-173cm, with a mean of 161cm; whilst the males had a range of 164-181cm, with a mean of 174cm (Dinwiddy & Watts-Plumpkin 2019: 199-200). However, similar to the Collingbourne Ducis stature results (also analyzed by Dinwiddy) no error ranges are provided, nor are the method nor formulae utilized made explicit. Twelve individuals were available for this study for re-examination, and were measured by the author; six males and six females.

#### *7.4.6 Tiddington Road (Stratford-upon-Avon, Warwickshire)*

Stratford can be found mentioned in a charter dating back to the mid-ninth century A.D., by the Saxon king, Beorthwulf, of Mercia (reigned 840-852 A.D.). This charter mentions the ministry of *Ilfera Stretford* (Upper Stratford), which is believed to have been established in the area in the late eighth century A.D. The ministry, possibly a Saxon monastery, is presumed to have been Shakespeare) now stands on its high point above the river Avon. The original structure is believed to have been constructed out of wood and later replaced by a structure in stone by the Normans. The original urban area of Stratford is believed to have developed around the ministry, south of where the modern city centre now lies (Ives 2010: 2, 14-15).

Tiddington Road, runs along the southern side of the River Avon, and is located on the slight elevation of the 2nd Avon Terrace (Palmer 2019: 2). The area has been known to produce material of archaeological significance dating as far back as the eighth century, e.g., the early medieval cemetery uncovered at Alveston Manor Hotel (Fieldhouse & Wellstood 1931; Ford 1997; Jones

**Fig 19.** Tiddington Road 79, Saxon cemetery excavations (Photograph by Robert Slabonski, courtesy of Warwickshire Archaeology)

2002; Jones & Greig 2010). In 2019, excavation commenced on Tiddington Road 79. The area excavated was identified as a cemetery dating from the seventh to the ninth century A.D., based on typological chronology (e.g., brooches and pins) of the artefacts uncovered within the cemetery bounds (radiocarbon dating has yet to be performed on the remains). The remains of 450 individuals were uncovered within the cemetery, consisting of individuals buried in crouched and flex (supine) positions, east to west, and included both adults (males and females), and younger individuals, i.e., juveniles, infants, and neonates (Palmer 2019: 1-11).

This cemetery represents one of the largest early medieval cemeteries in the region. and one located where the local parish church of the Holy Trinity (baptism and burial place of William of the largest discovered in England to date, and is believed to be contemporary to the cemetery previously excavated in the vicinity at the site of Alveston Manor Hotel (Fieldhouse & Wellstood 1931; Ford 1997; Jones 2002; Jones & Greig 2010). This good preservation of the cemetery and its interred human remains may in part be due to little interference and exploitations of the area during later succeeding periods (Palmer 2019: 11).

#### *7.4.6.1 Tiddington Road's Human Remains*

The analysis of the artefacts and human remains has yet to be finalized (at the time of writing), and the vast material offers a myriad of opportunities for future analysis, e.g., radiocarbon dating, strontium isotope, and aDNA analysis (Palmer 2019: 12), which may in the future complement the stature results of this study.

Out of the 450 uncovered individuals, 78 adult individuals (52 adult males, and 26 adult females) were chosen by the author, based on the criteria outlined earlier in the chapter. From these, 20 individuals (16 males and four females) were complete enough to be considered for use with the anatomical method.

### *7.4.7 Godalming Orchard Priory (Surrey)*

Godalming is located in southwestern Surrey, c. 48 kilometers southwest of central London, and is situated along the confluence of the River Ock (a tributary of the Thames) which flows down from Oxfordshire in the north-west. The town of Godalming is first mentioned in a written source, in c. 880 A.D., in the will of King Alfred the Great, where he bestows the Manor of Godalming to his nephew, Ethewald (later king of Northumbria and Essex). In the north-western part of central Godalming town, lies the Parish Church of St Peter and St Paul; a church of early medieval provenience, dated to mid-ninth century A.D. (Poulton 2018a: 9; 2018c: 2). The establishment of the Parish church coincides with the earliest excavated evidence for a Saxon habitation of the central Godalming area (Mint Street excavations; Poulton 1998).

In preparations for new housing development in the area, from 2014-2015, an excavation was undertaken, 30 meters southwest of the church. This area had once been a river terrace of the River Ock, the terrace was chosen as a burial plot, which over time grew into a large parish cemetery (Poulton 2018a: 9; 2018c: 2). The cemetery (Fig 20.) bounds were identifiable towards the north, west, and south, but no clear boundary was possible to determine towards the east. Human remains have scarcely been uncovered past the identified cemetery boundaries, which gives the impression of clear visible boundaries that may have been in place at some point of the life cycle (e.g., wooden, stone, or a boundary ditch), but which has since been lost to time (Poulton 2018c: 11).

About 300 individuals (still under analysis) were uncovered, in the cemetery, dating from c. ninth to mid-13th century A.D. Ten radiocarbon dates taken from individuals discovered in what is believed to be the latest contexts of the cemetery, gave dates as late as c.1250 A.D., hence it is likely that the cemetery fell out of use by the end of the early medieval period, or at the latest

**Fig 20.** Overall plan of Godalming's cemeterial site, showing all inhumations uncovered (Poulton 2018a: 10: Fig 2.).

during the early Norman period; with the possibility of continuous use of the cemetery in less intensity or non-excavated areas during later periods (Poulton 2018a: 12; Poulton 2018c: 2).

The burial practice as a whole has a fairly uniform appearance; all aligned east to west (head towards the west), all placed in a supine position, legs extended and arms by their side or hands across the pelvic region. No evidence to suggest elaborate burial clothing (except for possibly with two examples, where belt buckles were uncovered), coffins, or burial gifts (in accordance with the wider burial norm), hence the Godalming cemetery to be attributed as being of Christian origin, associated with the nearby church (St Peter) of Saxon origin (Poulton 2018b: 2-4).

#### *7.4.7.1 Godalming's Human Remains*

The Godalming skeletal material (c.300 individuals), is still under investigation, led by Lia Betti, supervising the analytical work which in large is being conducted by osteological postgraduate students of Roehampton University. Hence interobserver errors may affect the recorded metrics to a certain extent and should be taken into consideration regarding the 86 adult individuals, 56 males, and 30 females, which are used in this study. Twenty of these individuals were analysed by the author, these were those individuals who exhibited far greater recovery rate of their remains than the site average; seven individuals (four males and three females) recovered in a nearly complete state, hence could be considered for analysis with the anatomical method.

### *7.4.8 Melbourn, Cambridgeshire (Cambridgeshire)*

The village of Melbourn, Cambridgeshire, lies c. 13km south of Cambridge, and overlooks the river Mel. In 2000, plans for new housing projects were underway. This prompted an archaeological investigation to be undertaken in the planned area. The selected area had not seen any modern exploitation, and the oldest map of the town, dating to 1839, showed the area as plain agricultural fields (Duncan et al. 2003: 57-59). However, nearby to the west, in 1951, an excavation had taken place, which uncovered 30 early medieval burials (Wilson 1956).

Unlike many other contemporary cemetery sites (Fig 21.), e.g., Portway East (Cook & Dacre 1985), or Barrow Clump (Andrews, *et al.* 2019), this cemetery appears to have been established beyond the bounds of previous cemetery monuments, as two round Bronze Age barrows are to be found in the vicinity, which still to this day are visible from the site. Even though these barrows are standing beyond the bounds of the cemetery, these monuments of bygone eras might still have played a role in the choice of area for the cemetery, as keeping these barrows in eyeshot might have been of importance (Duncan et al. 2003: 60-62).

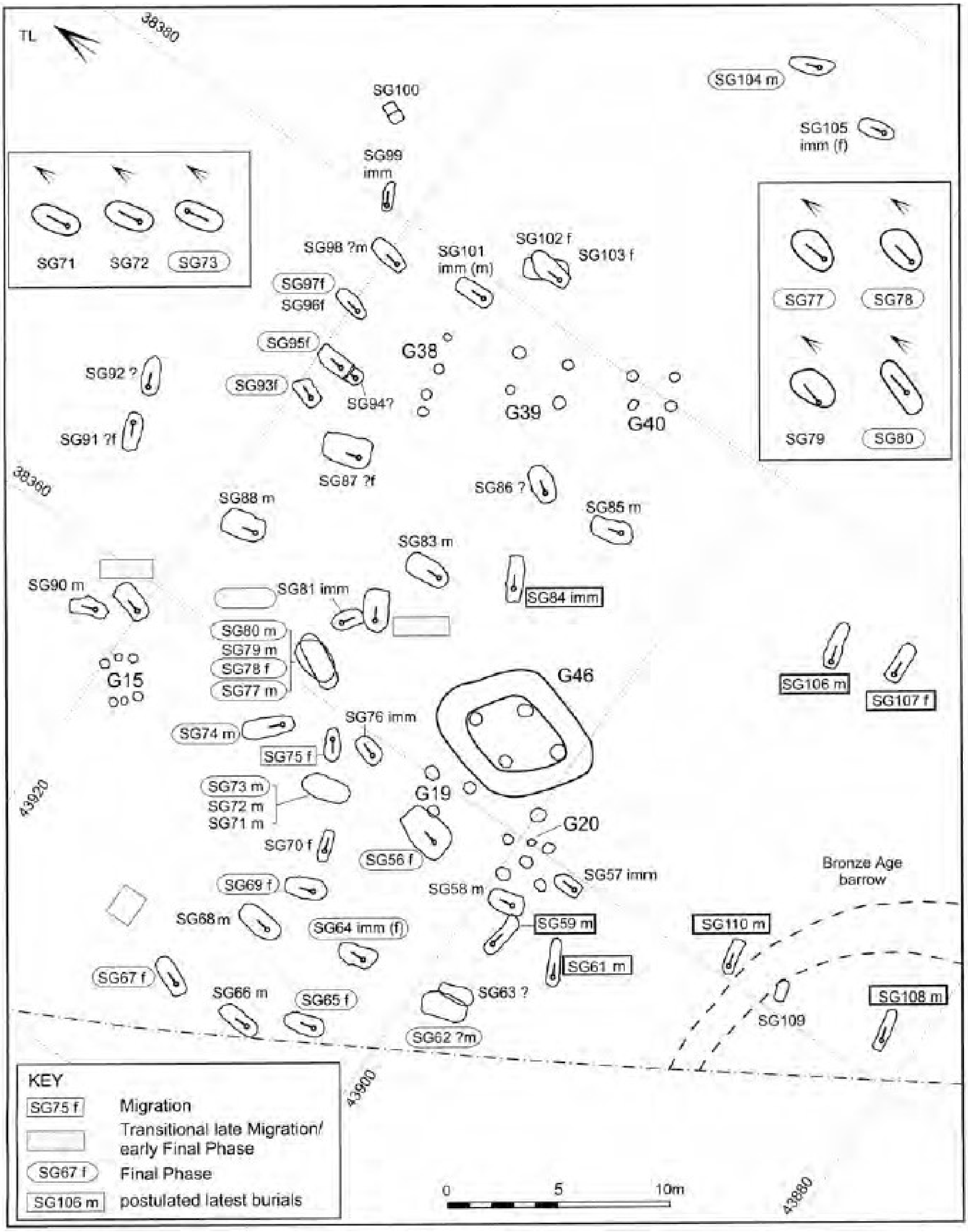

**Fig 21.** Melbourn cemeterial site plan (Duncan et al. 2003: 126: Fig 43.).

The excavation revealed 53 inhumations and two cenotaphs. 27 of the graves were single inhumations, whilst the remainder of the graves bore more than one individual, e.g., grave SH77-80, contained the remains of four individuals. The area appears to have been reused as a burial site for quite some time, as reuse and intercutting of the graves appears to have been a common occurrence, as disarticulated human remains are commonly found within the fill of the graves. The majority of the graves were buried north-south (heads towards south), with a quarter of the graves buried east-west (heads towards west). The common trend were to bury the dead in a supine positions, with only a fifth of the individuals laid to rest on their right side (Duncan et al. 2003: 91-95).

The dating of the Melbourne cemetery ranges from the late-sixth to mid-seventh century. Similar to the majority of the cemeterial sites used in this study, the dating is based on the chronology of the artefactual typologies recovered in the cemetery. The earliest possible date of late sixth century is based on the recovery of a scutiform (i.e., shaped like a shield) pendant, which were recovered in the grave of a female. The pendant typology gives the burial a dating ranging from the late-sixth to the first half of the seventh century. This date range was further emphasized by the typology chronology of the monochrome beads uncovered within the cemetery, are dated to the seventh century. This date range places the cemetery firmly as a final phase cemetery (Duncan et al. 2003: 122-123).

#### *7.4.8.1 Melbourn's Human Remains*

A detailed analysis of the human remains was undertaken by Corinne Duhig (2003a: 95-103), ranging from demography, pathology, and stature. Regarding the latter, the stature of the population was estimated in the initial osteological report, however, neither the number of individuals used, nor the method, nor the error range, were included in the published report. As has been illustrated with previously discussed materials, this is a fairly common deficiency in stature results published for British early medieval populations. The stature results gave an average stature of 177.8cm (range: 165.6-186.9cm) for males, and 162.4cm (range: 155.9-176.9cm) for females (Duncan et al. 2003: 96-97), yet the stature method is not specified.

Duhig provided the unpublished metric recordings for the human remains of the site, which are used in this study to reconsider the stature of the population uncovered in the Melbourn cemetery. After a re-examination of the records by the author, 22 individuals were deemed complete enough to be considered for stature estimation: 16 males and six females.

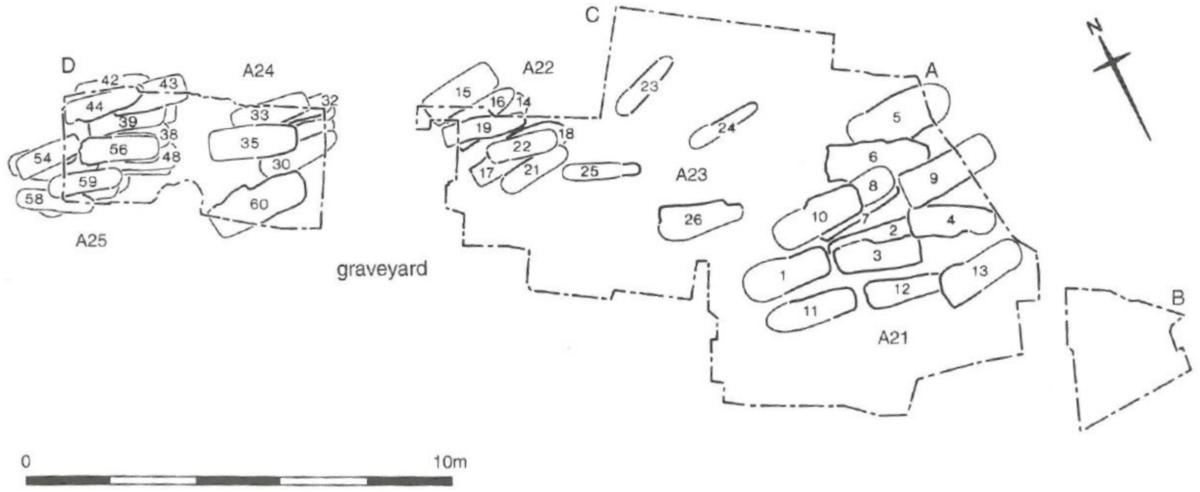

**Fig 22.** Leadenhall, site plan of the Saxo-Norman graveyard of Site A (Schofield & Lea 2005: 44, Fig 39.).

### *7.4.9 Leadenhall Street (London)*

The area of Leadenhall Street 71-77, London (commonly referred to as Holy Trinity Priory, after the early 12th-century cloister that was established here), has been sporadically archaeologically investigated since the early 20th century. Each investigation was undertaken ahead of redevelopment schemes of the district. In the 1970s, another large-scale redevelopment scheme was going ahead, including widening of the roads, hence new investigations of the area were necessary before construction could go ahead. These new investigations included several larger areas of the district, along Leadenhall Street, Mirte Street, Aldgate, and Duke's Place. These excavations would uncover a wide range of structures and artefacts, ranging from Roman-era battlements to 12th to 16th-century building foundations (predominantly related to the Holy Trinity cloister complex) (Schofield & Lea 2005: 1-3).

The parts of the excavation project which is of note for this study, are the excavations of Site A, by the Department of Urban Archaeology under the auspice of the Museum of London, which were undertaken in 1984, along Leadenhall Street 71-77, bordering Mirte Street 32-40. Site A is where an early medieval cemetery, 19m by 14.6m in size, would come to be uncovered, alongside the later 11th century Norman masonry structure which was part of the priory church (Schofield & Lea 2005: 3, 29 41-44; see Schofield & Lea 2005, for further discussion of later periods and the wider district excavations).

Site A's (Fig 22.) stratigraphy was divided into eight periods, with period III regarding the Saxon-Norman cemetery. 61 grave cuts were discovered in this area which had suffered extensive later exploitation; only 33 graves included inhumations, two out of which were double graves (eight adult females and 20 adult males). Regarding the remaining 28 graves without any human remains, it is difficult to ascertain if these graves ever held any remains, or if these graves should be interpreted as cenotaphs. The majority of the graves containing human remains were simple grave cuts, except seven graves which may be considered as cist graves due to the stone lining of the cuts. Another two graves stood out from the norm (Grave 14 and 60) as these two have been interpreted as coffin burials. (Schofield & Lea 2005: 41-46).

Both the grave cuts of those interred with human remains and those of the possible cenotaphs appear to follow the fairly strict orientation of the graves, either in an east-west (head towards west) direction or east-west by northwestern direction. This slight variation is likely caused by the changing of the position of the sun in the sky throughout the year, hence the perceived true western direction alternates throughout the year, i.e., the grave direction exhibited here can be attributed to burials taking place in different seasons of the year (Schofield & Lea 2005: 44). (Schofield & Lea 2005: 47).

The dating of the graves varies from the 10th to 12th century, placing this cemetery as far later than the majority of the other sites discussed in this chapter. The earliest dating evidence uncovered at the site, came in the shape of late Saxon shelly ware, which was uncovered in Grave 23, giving this grave a century and a half range: 10th to mid-11th century. Three other graves (Grave 5, 8, and 26) were possible to date through the typology of the pottery fragments which were uncovered in the graves, their dates range from mid-11th to mid-12th century. One of the later examples from the site, Grave 9, a younger male, who had been buried with a silver pendant cross, suggesting that this young man would have been of some ecclesiastic importance, but furthermore, based on the pendants typology, gives the grave a *post quem* dating of at least 11th century, possible as late as 12th century (Schofield & Lea 2005: 47-48), hence a possible post-conquest dating of this grave, i.e., high medieval period.

#### *7.4.9.1 Leadenhall Street's Human Remains*

The human remains uncovered in Leadenhall Street's cemetery were initially analysed by Barbara West (1986; full report remains unpublished), later reanalysed and published by Janice Conheeney (2005: 255-263). A previous stature estimate was conducted on the remains of the adult individuals, yet, as commonly is the case, no description of the method or regression formulae used, nor the error ranges have been included; the average stature for the males: was 172cm, and the average stature for the females: 164cm (Conheeney 2005: 258-259).

The metric data of these remains were accessed by the author through the Museum of London's archives, due to the inaccessibility of the physical remains held in the museum, at the time of writing, the metric recordings had to suffice. From the metric recordings, 27 individuals were chosen based on their long bone metrics (eight adult females, and 19 adult males).

### *7.4.1 St Peter's Tip, Broadstairs (Kent)*

The cemetery site of St Peter's Tip (Fig 23.) lay north of the coastal town of Broadstairs, in eastern Kent, and can scarcely be detected today, as the area has been completely levelled and overgrown. Maps from the mid-19th century show that the area was used for agriculture. However, in the late 60s, this area was used as a local refuse tipping site, which was planned to be expanded, hence a thorough archaeological investigation of the area was necessary before breaking ground. In 1968, proceeding work was conducted by the Department of Archaeology of Chatman House Grammar School, Ramsgate. Three seasons of excavations were undertaken throughout the next three years (Hogarth 1973: 104, 107).

The burials were located near a south-facing slope, overlooking Dane Valley, where once a river now dried out flowed northeast, towards Margaret Harbour, hence the cemetery was likely established on a terrace which overlooked the now dried out river. The site consisted mainly of chalky sediments, aiding in the preservation of the human remains. 338 inhumations were uncovered during the three seasons, with the majority of the graves oriented in a northwest or northwest-by-north direction. (Hogarth 1973: 104-108).

The general published details surrounding the excavation are fairly scarce, hence the discussion regarding it is fairly brief; this is also the case regarding the furnished burials and their respective artefacts. Among the artefacts uncovered in the graves of the site (exact numbers are not given), a wide range of different artefact typologies were uncovered, ranging from imported Frankish pottery, and weaponry, to brooches, etc. Unfortunately, many of the graves exhibited later interference, hence many of the richer graves might have been damaged by later graverobbing. However, no lists nor quantities are included in the initial publication, nor have any detailed studies been published since, hence there is little to go on to base the dating of the cemetery, except for the given collective artefactually typology dating of sixth till mid-eighth century A.D. (Wilson & Moorhouse 1971: 160).

#### *7.4.1.1 St Peter's Tip's Human Remains*

The human remains of the site were analysed by Corrine Duhig (unpublished report), this

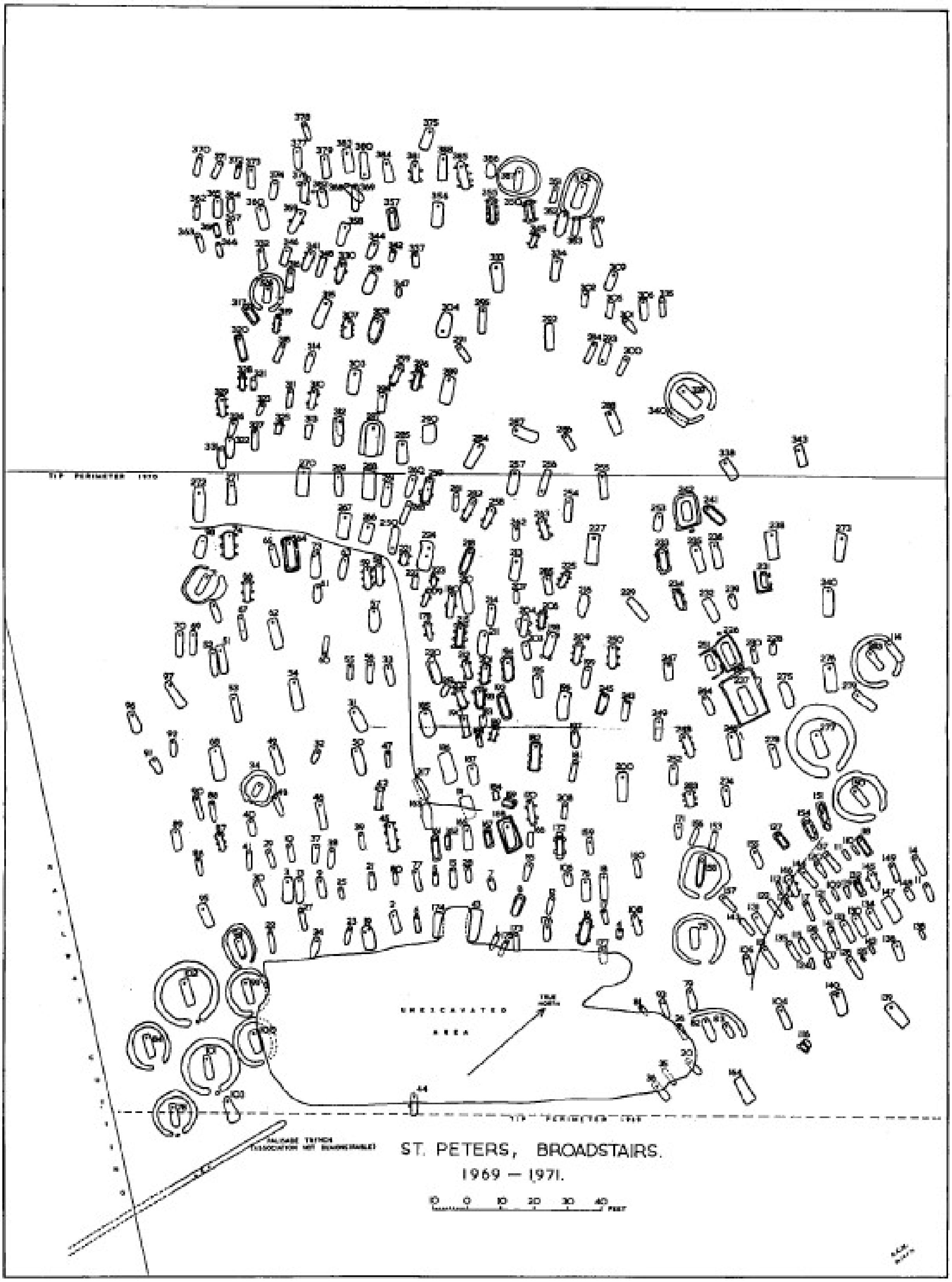

**Fig 23.** Site plan of St Peter's cemetery (Hogarth 1973: 106: Fig 39.).

includes the metrics used in this study. 36 adult individuals proved to have metric recordings that could be used for stature estimation: 24 males and 12 females.

### *7.4.1 Updown, Eastry (Kent)*

The modern village of Eastry occupies a dominant and strategic hill in the Kentish landscape, overlooking its surroundings, as it has done for over a millennia and a half. Eastry has a long-standing history of importance in the region, stretching back to the Roman era, whence Eastry served as the regional prefectural seat. One of the earliest written sources regarding the village is a charter dating to the early ninth century, where Eastry is referred to as *Eastergege*, an Old English contraction of two words: *easter* ("eastern"), and *gē* ("region") (Welch 2008: 3).

The early medieval cemetery of Eastry (Fig 24.), lies 900m southeast of the modern village, in an open field, which slopes gently towards the east; in the past, this area would have been covered in dense forestry (based on historical maps). The area has been known as an old cemetery for quite some time, as already in late 18th century, human remains were encountered upon exploitation of the area and recorded, then again in the mid-19th century, written records speak of human remains which had been dug up, along with ceramics which presumably once had served as burial gifts (Welch 2008: 4). The cemetery was rediscovered again in 1973, when the area was aerially photographed, revealing crop marks in the field denoting the area as a possible cemetery, based on the 20 or so cropmarks suggesting graves surrounded by penannular ditches. Three years later, in 1976, excavations of the area was initiated ahead of planned construction, under the auspice of Oxford University. During this excavation season, 37 graves were uncovered (Welch 2008: 1-2, 10). Twelve years later (1989), a second excavation season went underway, ahead of roadwork which was now planned to take place in the area. An area of 1500m$^2$ was excavated from. During this season, a total of 41 graves were uncovered. Including those graves excavated in 1976, a total of 78 graves have been uncovered in Updown's early medieval cemetery (Welch 2008: 6-8).

Regarding the structure and norms apparent in the cemeterial material, all graves were single inhumations (buried either in supine position or on their sides), which compared to many of the other cemeteries discussed here is fairly unique. Furthermore, each of the graves followed clear norms with regards to the orientation of the grave cuts, east-west (head towards west), again, this practice of normative orientation of the graves across a cemetery is fairly rare in a pre-Christian Saxon cemetery (see below the discussion of the dating). The treatment of the dead saw a certain degree of variations, e.g., 38 graves have been suggested to have been coffin graves

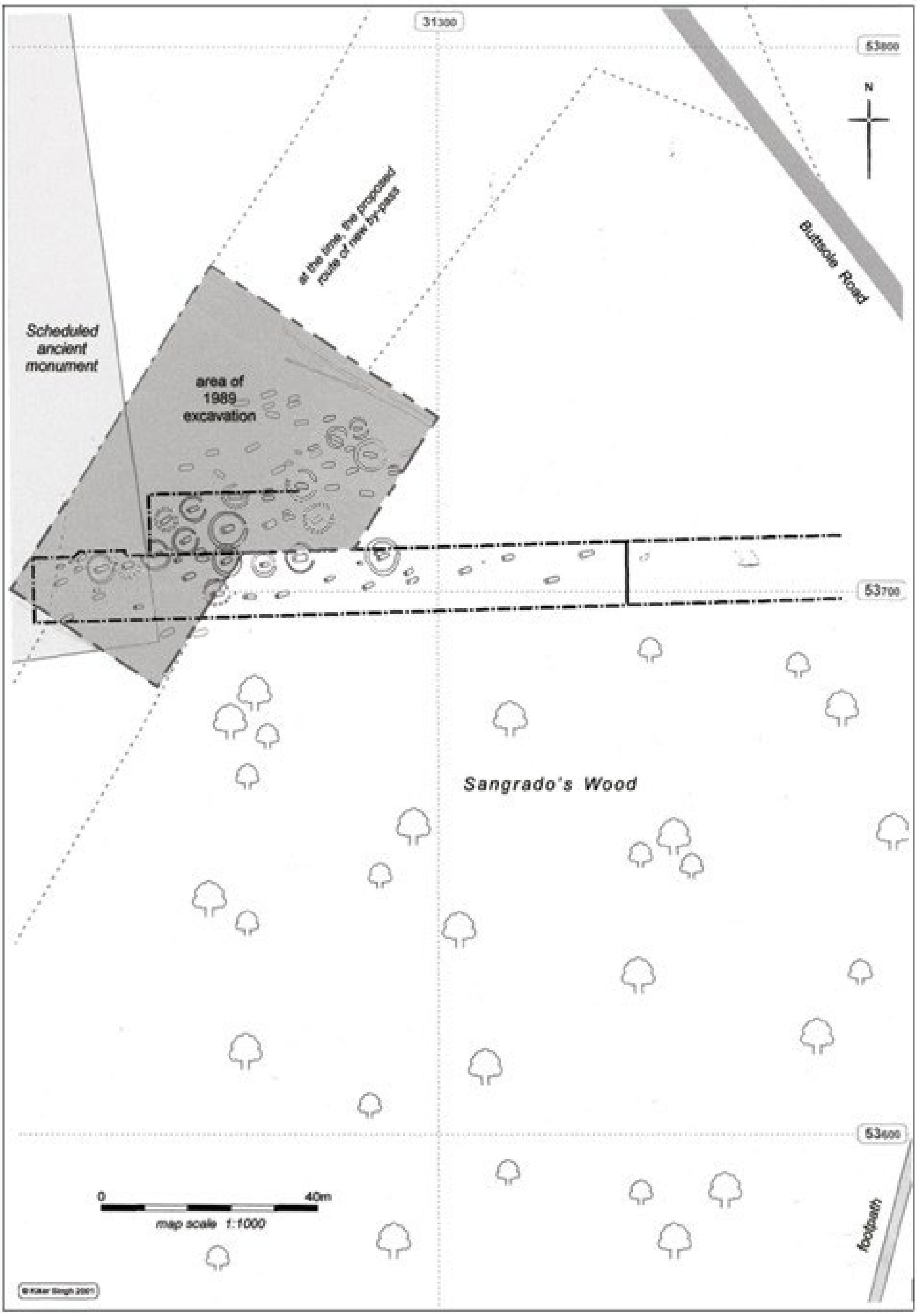

**Fig 24.** Map of the area of the Updown cemetery, showing the inter-relationship of the two excavation seasons: 1976 and 1989 (Welch 2008: 7: Fig 2.).

(mainly based on the recovery of cleats and fittings found within the burial contexts) (Down & Welch 1990: 12; Welch 2008: 10).

Twenty three of the graves were furnished with weaponry, with spearheads being the most numerous, however, some of the graves exhibited evidence of looting, e.g., Grave 18, where only an iron socket remained of what once had likely been a full spear buried with the individual. Comparatively to the other sites discussed in this chapter and used in this study, e.g., Apple Down (Down & Welch 1990), the weaponry uncovered in the furnished graves were fairly meagre in their numbers and intricacies, only a single burial, Grave 14, included a pairing of a spearhead and a shield boss, which otherwise is typical to find in other contemporary cemeteries. This single shield boss were dated to the first half of the seventh century; contemporary counterparts can be found on the European continent in the lower Rhine region and Boulogne. 23 spearheads, with associated fittings and ferrules, were uncovered in the cemetery, these form a very heterogeneous assemblage, belonging to 13 different typologies. However, this diverse range of typologies of spearheads do concur in their dating, as each has been dated to the seventh century (Welch 2008: 28-29). Three graves included Seax blades (Grave 19, 37, and 42). Typical Seax blades uncovered in early medieval cemeteries usually belong to imported Frankish typologies, however, these uncovered at Eastry, are local Kentish imitation blades (Evison's Type 1), dating to the seventh century (Welch 2008: 28).

Beyond weaponry, the artefacts of the furnished graves were less meagre and poor, as several graves were furnished with dress fittings, e.g., brooches, necklets, bracelets, buckles, rings, slot fittings, antler combs, etc, along with tools, e.g., knives, shears, and pottery. These varied artefactual types and their respective typologies appear in large to agree with the dating provided by the weaponry, with a few artefacts being dated to the sixth century, e.g., the buckle uncovered in Grave 12, giving a date of the late sixth to early seventh century (Welch 2008: 35-40). The artefactual evidence of the site was later re-examined by Tim van Tongeren (2022: 93-120), who questioned the possibility of the site stretching further back than the Final Phase period. For example, only 12 out of 78 graves can be considered as unfurnished, and furthermore, only 21 graves were dug beneath barrows, and within ring ditches, in the case of a Final Phase cemetery, these two grave characteristics are typically expected to be the dominant of practices, yet this is not the case at the site of Updown. Further re-examination of the artefactual typologies, suggest that the earliest grave date back to the first half of the sixth century, hence predating the Final Phase period. It is likely that the cemetery was established and used prior to the Final Phase period, and continued in use throughout the Final Phase period, up until at least the later seventh century (Tongeren 2022: 104-112).

#### *7.4.1.1 Updowns's Human Remains*

The human remains uncovered in the cemetery of Updown, were analysed in full by Corinne Duhig and Elizabeth Rega (2008: 50-54), this included both a brief pathological analysis, along with the metrics of the skeletal remains (unpublished). Duhig and Rega's metrics are used regarding the stature analysis of the Updown material in this study.

The majority of the remains were fairly well preserved (grade: 2). Of the 78 graves, 12 individuals were estimated to have been adolescents or younger, 28 as adult males, and 19 as adult females (Duhig & Rega 2008: 50-51). A previous analysis of the stature was included in the osteological report by Duhig and Rega (2008: 52), utilizing the lower limbs regression formulae by Trotter and Gleser (1952 or 1958?); male mean stature: 170.1cm, female mean stature: 159.3cm; average mean error range for male stature: ±3.55cm; average mean error range for female stature: ±2.99cm; note that these average error ranges match those presented by Trotter and Gleser (1952 & 1958) (Duhig & Rega 2008: 52; Welch 2008: 140-143)

Of these 47 sexed adults, eleven individuals (six males and five females), had useable metrics and hence could be considered for stature estimation through the use of the regression formulae in this study.

## *7.5 Chapter Summary: Collecting the Material*

The initial sections of this material chapter outlined the sampling criteria (see Table 1. & 2.) for the material collection of human remains that will be used in this study through the anatomical and regression method, followed by a discussion of the typical challenges faced regarding the sampling of human remains for stature studies in British archaeology, due to the at times poor preservation of human remains in the British Isles. This was followed by extensive site descriptions of 13 (out of 28 sites, see Table 5. for a full list) early medieval sites in Southern Britain which contributed the greater number of human remains for this study, with a total of 512 individuals sampled (males: 327 individuals; females: 185 individuals (see Table 5 through 8. for the full lists of the materials), from 28 sites. Of these 28 sites, the author recorded the metrics of 14 sites, with a total210 individuals, with the remaining sites and their human remains (302 individuals) being recorded by other observers, who provided their recordings to be used in this study. The dating of these sites' human remains ranged from the early fifth to late 11th (post-early medieval) century A.D. (see Fig 25.).

Of the 512 individuals, 69 individuals proved to have been recovered in a complete enough state (see Chapter 9 for a more extensive discussion of this sampling process), and measured in accordance with measurements standards by Pearson (1899), Martin (1928 & 1957), Raxter et al. (2006) and Rosenstock (2019) (see Table 13.), hence could be used with the anatomical method (see Table 6.). These individuals will serve as the base sample (in the hybrid approach), in the following chapters (Chapter 8 through 10) to calculate the regression formulae on, which in turn will be able to estimate the stature of the wider sample of less preserved, or complete individuals.

**Table 5.** List of the number of individuals utilized from each site (MOLAR, i.e., Museum of London). Those recordings from the Museum of London archives do not have a stated observer who performed the recordings.

| SITE (28): | M: | F: | ANALYST |
|---|---|---|---|
| MOUNT PLEASANT | 5 | 4 | Author |
| DROXFORD | 9 | 6 | Author |
| GODALMING | 66 | 29 | Author (anatomical); Betti *et al.* (regression) (TBD) |
| LLANDOUGH | 23 | 17 | Author |
| APPLE DOWN | 25 | 25 | Author |
| BARROW CLUMP | 6 | 6 | Author |
| COLLINGBOURNE DUCIS | 12 | 6 | Author |
| STRATFORD UPON AVON | 53 | 27 | Author |
| 71-77 LEADENHALL STREET | 4 | 16 | Conheeney (2005) |
| ST PETER'S TIP | 24 | 12 | Duhig (unpublished) |
| MELBOURN | 17 | 19 | Duhig (2003) |
| WEYHILL | 46 | - | Clough (2020) |
| UPDOWN, EASTRY | 10 | 3 | Duhig & Rega (2008) |
| BLACKNALL | 8 | 3 | (Museum of London archive) |
| CANTENARY GARDEN | 3 | 1 | Ives (2010) |
| PORTWAY WEST | 1 | 2 | Author |
| PORTWAY EAST, | 1 | - | Author |
| WATCHFIELD | 1 | 3 | Author |
| SHARVARD'S FARM | 2 | 1 | Author |
| BREANMORE | - | 1 | Author |
| ROMSEY ABBEY | 3 | - | Author |
| FIVE MILE LANE | 3 | 3 | Sinnott (TBD) |
| HOLY TRINITY PRIORY | 2 | 1 | (Museum of London archive) |
| LONG ACRE | 1 | - | (Museum of London archive) |
| PEABODY SITE | - | 1 | (Museum of London archive) |
| 1-12 RANGOON STREET | 2 | - | (Museum of London archive) |
| 66-67 BULL WHARF LANE | - | 2 | (Museum of London archive) |
| FLEET VALLEY | 1 | - | (Museum of London archive) |
| POLHILL | 1 | - | Duhig (unpublished) |
| TOTAL: | **327** | **185** | |
| | **Total Number of Individuals:** | **512** | |

**Table 6.** Male and female individuals who proved to have complete enough skeletal remains in accordance with Table 3. and 4., hence could be considered to be used with the anatomical method.. Note that several of the adults have been estimated as generic adult or older, hence affecting the mean age of the sample. In the far left column, the number outside of the parenthesis is the male number of individuals, and in parenthesis is the number of female individuals.

| | ***Males*** | | ***Females*** | |
|---|---|---|---|---|
| **Site number of individuals:** | **Individual (N: 40):** | **Age:** | **Individual (N: 29):** | **Age** |
| ***Stratford Upon Avon: 16(4)*** | SK1151 | Adult | SK1031 | 30-35 |
| | SK2435 | 25-35 | SK2065 | 30-35 |
| | SK1145 | 17-20 | SK2019 | 35-45 |
| | SK2185 | Adult | SK1211 | 40+ |
| | SK2438 | 30-35 | - | - |
| | SK3327 | 30-35 | - | - |
| | SK2378 | Older Adult | - | - |
| | SK2702 | 18-20 | - | - |
| | SK1420 | 50+ | - | - |
| | SK2025 | 20-30 | - | - |
| | SK1102 | Adult | - | - |
| | SK1568 | 45-55 | - | - |
| | SK2040 | Adult | - | - |
| | SK1772 | 50+ | - | - |
| | SK1391 | 25-30 | - | - |
| | SK1652 | 40+ | - | - |
| ***Collingbourne Ducis: 4(1)*** | 11 | 25-35 | 31 | Adult |
| | 27 | 40-50 | - | - |
| | 1104 | 35-45 | - | - |
| | 1293 | 45+ | - | - |
| ***Godalming: 4(3)*** | 3136 | 20-30 | 1042 | 50+ |
| | 3033 | 50+ | 3432 | 45-50 |
| | 1023 | 50+ | 1073 | 20-25 |
| | 1049 | 50+ | - | - |
| ***Droxford 2(0)*** | Grave 19 | 20-25 | - | - |
| | Grave 33 | 40-45 | - | - |
| ***Mount Pleasant:2 (3)*** | Grave 32 | 18 | Grave 14 | 23 |
| | Grave 7 | 24-27 | Grave 23 | 35 |
| | - | - | Grave 35 | 30-35 |
| ***Barrow Clump: 0(3)*** | - | - | 7087 | 33-45 |
| | - | - | 7060 | 45+ |
| | - | - | 7290 | 45+ |
| ***Portway West Andover: 1(0)*** | Area III Grave F1 | Adult | - | - |
| ***Droxford: 1(0)*** | Grave 39 | Older Adult | - | - |
| ***Apple Down: 10(15)*** | GRAVE 1 | 20-30 | GRAVE 3 | 17-25 |
| | GRAVE 12B | 25-35 | GRAVE 4B | 45+ |
| | GRAVE 19 | 33-45 | GRAVE 11 | 25-32 |
| | GRAVE 28 | 50+ | GRAVE 14 | 27-35 |
| | GRAVE 31 | 45+ | GRAVE 17 | Adult |
| | GRAVE 46 | 25-35 | GRAVE 23 | 50+ |
| | GRAVE 54 | 18-19 | GRAVE 50 | 20-25 |
| | GRAVE 71 | 45+ | GRAVE 86 | 40+ |
| | GRAVE 145 | 17-25 | GRAVE 88 | 40+ |
| | GRAVE 152 | 17-25 | GRAVE 87 | 35-40 |
| | - | - | GRAVE 101 | 20-24 |
| | - | - | GRAVE 105 | 40+ |
| | - | - | GRAVE 108 | 18-20 |
| | - | - | GRAVE 143 | 45+ |
| | - | - | GRAVE 157 | 35-45 |
| **Mean Age:** | | **c. 35.1** | | **c. 35.9** |

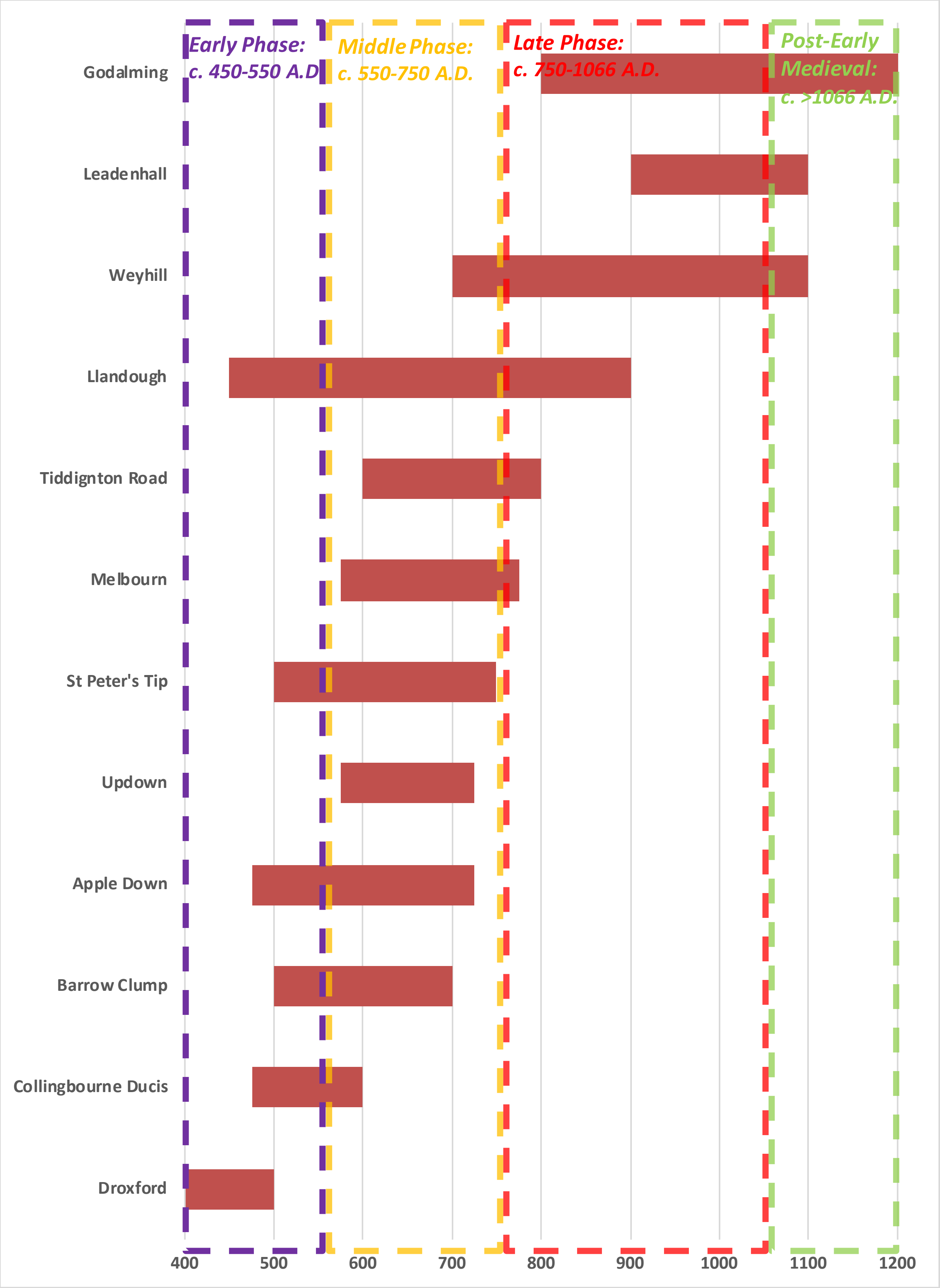

**Fig 25.** Gantt chart outlining the date range of each of the main contributing sites of this study, divided along the arbitrary periodical phase divisions.

**Table 7.** Available bone elements of the male sample used for stature regression estimation, utilizing the newly developed regression formulae. Each elements has either been recorded by the author or other observers. See Table 3. and 4. for a list of bone element acronyms

| | | | MALE | N: 327 | | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE:** | F1 | F2 | T1 | F1 + T1 | F2+T1 | F1+T1+L | F1+T1+L | H1 |
| **ST PETER'S TIP** | 24 | - | 3 | 3 | - | - | - | - |
| **POLHILL** | 1 | - | - | - | - | - | - | - |
| **MELBOURNE** | 16 | - | 16 | 16 | - | - | - | - |
| **UPDOWN** | 9 | - | 3 | 2 | - | - | - | - |
| **FLEET VALLEY** | - | - | 1 | - | - | - | - | - |
| **RANGOON STREET** | 1 | 2 | 1 | 1 | 1 | - | - | - |
| **LONG ACRE** | - | - | 1 | - | - | - | - | - |
| **HOLY TRINITY** | 1 | - | 2 | 1 | 1 | - | - | - |
| **LEADEN HALL** | 1 | 2 | 2 | 1 | 2 | - | - | 1 |
| **CANTENARY GARDEN** | 1 | - | 2 | - | - | - | -- | - |
| **STRATFORD UPON AVON** | 44 | 40 | 45 | 44 | 40 | 16 | 16 | 20 |
| **APPLE DOWN** | 24 | 24 | 21 | 21 | 21 | 10 | 10 | 17 |
| **BARROW CLUMP** | 6 | 6 | 5 | 5 | 5 | - | - | 1 |
| **COLLINGBOURNE DUCIS** | 11 | 10 | 9 | 9 | 9 | 4 | 4 | 8 |
| **MOUNT PLEASANT** | 3 | 4 | 5 | 3 | 4 | 2 | 2 | |
| **DROXFORD** | 9 | 9 | 8 | 8 | 8 | 3 | 3 | 4 |
| **PORTWAY WEST** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **BLACKNALL** | 11 | 11 | 11 | 11 | 11 | - | - | - |
| **GODALMING** | 56 | 4 | 27 | 27 | 4 | 4 | 4 | 27 |
| **LLANDOUGH** | 7 | 9 | 19 | 7 | 9 | - | - | 10 |
| **WATCHFIELD** | - | - | 1 | - | - | - | - | 1 |
| **PORTWAY EAST** | 1 | 1 | - | - | - | - | - | |
| **SHARVARD FARM** | 1 | 1 | 1 | 1 | 1 | - | - | 1 |
| **ROMSEY ABBEY** | 2 | 2 | - | - | - | - | - | 1 |
| **FIVE MILE** | 2 | - | - | - | - | - | - | 1 |
| **WEYHILL** | 40 | 24 | 31 | 31 | 24 | - | - | 25 |
| **TOTAL NUMBER:** | **272** | **150** | **215** | **192** | **141** | **40** | **40** | **118** |

**Table 8.** Available bone elements of the female sample used for stature regression estimation, utilizing the newly developed regression formulae. Each elements has either been recorded by the author or other observers. See Table 3. and 4. for a list of bone element acronyms. Note humerus is excluded here, see Chapter 10 for a discussion of bone the collection of bone elements.

| FEMALE N: 185 | | | | | | | |
|---|---|---|---|---|---|---|---|
| SITE: | F1 | F2 | T1 | F1 + T1 | F2+T1 | F1+T1+L | F1+T1+L |
| ST PETER'S TIP | 12 | - | 2 | 2 | - | - | - |
| MELBOURNE | 9 | - | 5 | 6 | - | - | - |
| UPDOWN | 3 | - | 2 | 2 | - | - | - |
| PEABODY | 1 | 1 | 1 | 1 | 1 | - | - |
| BULL WHARF | 2 | 1 | 2 | 2 | 1 | - | - |
| HOLY TRINITY | 1 | 1 | 1 | 1 | 1 | - | - |
| LEADEN HALL | 12 | 9 | 5 | 5 | 5 | - | - |
| CANTENARY GARDEN | 1 | - | - | - | - | - | - |
| STRATFORD UPON AVON | 24 | 21 | 19 | 19 | 19 | 4 | 4 |
| APPLE DOWN | 23 | 22 | 21 | 21 | 21 | 15 | 15 |
| BARROW CLUMP | 6 | 6 | 3 | 3 | 3 | 3 | 3 |
| COLLINGBOURNE DUCIS | 5 | 5 | 4 | 4 | 4 | 1 | 1 |
| MOUNT PLEASANT | 4 | 3 | 4 | 4 | 3 | 3 | 3 |
| DROXFORD | 4 | 4 | 5 | 3 | 3 | - | - |
| PORTWAY WEST | 2 | 2 | 2 | 2 | 2 | - | - |
| BLACKNALL | 3 | 3 | 3 | - | - | - | - |
| GODALMING | 29 | 3 | 17 | 17 | 3 | 3 | 3 |
| LLANDOUGH | 6 | 6 | 12 | 6 | 6 | - | - |
| WATCHFIELD | 2 | 2 | 2 | 2 | 2 | - | - |
| BREANMORE | 1 | 1 | - | - | - | - | - |
| FIVE MILE | 2 | - | 1 | 1 | - | - | - |
| **TOTAL NUMBER:** | **151** | **88** | **110** | **101** | **74** | **29** | **29** |

# 8. Methodology

This chapter will outline the methodology used by the author when calculating the regression stature formulae. This is achieved, by first regressing the height of each long bone against the living statures achieved with the anatomical method (see chapter 2.5) (Raxter et al. 2008: 149), i.e., establishing the percentile contribution of each long bone, of either sex, towards the full living stature.

The chapter is divided into four sections, beginning with (1) the anatomical method, (2) a detailed breakdown of each formulae and variables related to the regression method, (3) discussing the use of either OLS (Ordinary Least Squares) or RMA (Reduced Major Axis) when calculating regression formulae, and (4) assessing and censoring (if necessary) outliers and anomalies of the base samples, based on leverage and influence factors.

## *8.1 Using the Anatomical Method*

The anatomical method can directly reconstruct the stature of an individual, by tallying up the height of each bone element that contributes to the full stature; from the bregma point of the crania to the heel of the calcaneus. These measurements produce the SKH (Skeletal Height) value, i.e., the stature of the individual with the soft tissue missing. The SKH values are then put through a formula that adds empirical correction factors that incorporate all additions (e.g., missing soft tissue) and subtractions (e.g., bone overlap) to achieve an estimated living stature (Raxter *et al.* 2006: 379). The use of more skeletal elements in the anatomical method, than in the regression method, is both its strength and weakness, as it does not require comparative material. However, the required level of skeletal completeness is relatively rare with archaeological material excavated in the British Isles (as discussed in the previous chapter) (Mays 2016: 647).

Raxter et al. (2006: 378) developed two formulae for the estimation of living stature, one with an age factor [4], and one without [5]. As the stature of an individual starts to deteriorate on average after the age of 30 (Trotter & Gleser 1952: 468), the average loss per year (≥age 30) is estimated to be 0.426cm. The formula [11] with the age factor usually results in an estimate with a slightly lower error range (Raxter *et al.* 2006: 378), hence will be used in favour of the latter in this study.

$$[4]\ \text{LS}\pm4.5\text{cm} = 1.009x_i - (0.0426 * \text{age}) + 12.1$$

$$[5]\ \text{LS}\pm4.5\text{cm} = 0.996x_i + 11.7$$

[4 & 5] Where the $x_i$ variable is the individual's SKH value.

## 8.2 Estimating Missing Skeletal Elements

The greatest limitation faced while using the anatomical method for archaeological populations, is the frequency of missing non-measurable skeletal elements (Auerbach 2011: 67). The preservation level of the human remains can vary significantly depending on a wide range of factors, e.g., the mode of burial, soil pH level, or later exploitation of the burial area, *etc.* (further discussed in Boddington 1987). To allow for a larger material to be utilized for archaeological stature estimation studies, Auerbach (2011) developed formulae for commonly missing skeletal elements (e.g., vertebrae column regions: talus and calcaneus).

Using postcranial measurements to estimate the crania's basion to bregma height (BBH), tends to result in large error ranges. *"In fact, even using regionally constrained samples wherein proportions do not significantly differ, postcranial measurements predict BBH poorly. (Auerbach 2011: 74)."* Hence if the crania is missing, or fragmented, its' BBH height is advisable not to attempt to estimate, rather such individuals should be excluded from the anatomical sample, and rather estimated through the regression method. Better results were achieved with the postcranial skeleton, with exceptions for the second cervical (C2), and first sacral vertebrae height (S1), as large interpopulation variation is exhibited with C2 and S1 (Auerbach 2011: 74).

### 8.2.1 Vertebral column

Missing vertebra elements have been suggested to be possible to estimate through the height of existing adjacent vertebrae (Sciulli *et al.* 1990, 2007). Estimating single missing vertebrae elements gives negligible added errors in relation to the overall stature. However, when combined in the estimation of more than one vertebra, the error ranges could engender considerable error ranges, hence the number of missing elements needs to be considered when these methods are applied.

### 8.2.2 Single Vertebral Element

The estimation of missing vertebrae elements can be achieved through percentile averaging heights of its adjacent vertebrae (superior and inferior). The average height of the missing vertebrae needs to have a height close to ≥50%, of the height of its superior and inferior neighbours, this is referred to as "percentage position". If this percentage position is too low, then the estimated height might greatly overestimate the actual results (Auerbach 2011: 74).

**Table 9.** Auerbach (2011: 76) regression formulae for estimating missing vertebral column length (both sexes).

| | | | | 95%CI | |
|---|---|---|---|---|---|
| **Estimated Section** | **Estimators** | **Regression formula (all measurements in mm)** | **SEE (SEE%)** | **Lower** | **Upper** |
| [6] Cervical | Thoracic ($x$) and Lumbar ($y$) | $0.295x + 0179y + 5.481$ | 4.860 (4.95%) | -2.29 | -0.49 |
| [7] Vertebral Column | Thoracic ($x$) and Lumbar ($y$) | $1.279x + 1.072y + 22.024$ | 12.814 (2.77%) | -0.97 | -0.82 |
| [8] Cervical and Thoracic | Lumbar ($y$) Section | $1.639y + 114.481$ | 18.544 (5.61%) | -1.33 | -1.26 |
| [9] Vertebral Column | Lumbar ($y$) Section | $2.639y + 114.480$ | 18.644 (4.03%) | -1.33 | -1.26 |

An alternative is to calculate the missing vertebral central heights through the percentile central height of the superior or inferior neighbour. The neighbouring vertebras' central height is calculated as a percentage, which in turn can be used to estimate the missing vertebrae elements, e.g., C2 (female), has an average central height of 289.04% of the height of the centrum of C3. This method gave considerably lower error ranges than the previously mentioned method (Auerbach 2011: 75).

A third option is to estimate single missing vertebrae elements through multiple regression formulae, based on present vertebrae elements' height. However, Auerbach (2011: 75) argues that this solution has limited practical use, as it can result in multiple errors.

### *8.2.3 Missing Vertebral Regions*

The previously discussed method applies to individuals with fairly intact vertebral regions. Similar to the estimation of stature through the use of regression formulae, comparable formulae can be applied for the estimation of missing vertebral regions. The cervical and thoracic regions are prone to not be recovered intact for human remains recovered in archaeological contexts. Two methods have been developed for this aim (missing cervical or thoracic): (1) estimating the height of the missing regions, and then adding these results to those regions present; (2) estimating the full vertebral column based on the height of either the thoracic or lumbar (or both) regions present. Both of these methods utilize regression formulae. The latter of these two methods is preferable, as it gives lower SEE and confidence interval values. There is no significant difference between the sexes of the proportions of the vertebral regions, hence the formulae can be used for either of the sexes (Auerbach 2011: 75-76).

The error ranges (SEE and 95%CI) may appear negligible in their difference between the different formulae, however, formula [6] and [8] are the estimates of smaller regions, while [7] and [9] are the entire vertebral region estimated. Auerbach (2011: 76) suggests formula [6] and

[7] when applicable, as preferable to use, as their error ranges are lower than the other two.

### *8.2.4 Estimating Talocalcaneal Height*

The talus and calcaneus are commonly missing elements, only the crania's basion to bregma height, and the vertebral heights are more frequently missing or fragmented beyond useability for metrics. The estimation of the combined height of the two bones (Talocalcaneal (TCH)) is possible through the usage of the maximum length of the femur (FML) combined with the maximum length of the tibia (TML). The talocalcaneal height exhibits significant sexual dimorphism (Auerbach 2011: 76), therefore, separate formulae are necessary for the sexes ([10] & [11]):

$$[10]\ Males\colon 0.100 \times FML - 0.018\ \times TML + 28.775\ (SEE = 3.35; \%SEE = 5.1\%)$$

$$[11]\ Females\colon 0.074 \times FML - 0.004\ \times TML + 27.745\ (SEE = 3.26; \%SEE = 5.47\%)$$

## *8.3 Calculating the Regression Formulae*

Pearson (1899) was the first to introduce statistical regression as a method for mathematically estimating the stature of individuals, based on their skeletal remains. Nonetheless, the iteration of the regression method that is most frequently used is Trotter and Gleser's method (1952, 1958), which utilizes simple linear regression formulae. Simple linear regression is the simplest type of regression, and only uses two variables; with one independent variable ($x$) which dictates the value of the dependent variable ($\hat{y}$) (Zar 2010: 328). When estimating the stature of a dead

**Table 10.** Definitions and symbols used in statistical formulae.

| | |
|---|---|
| $\bar{x}$ | The mean value of the $x$-axis (unless reversed). |
| $\bar{y}$ | The mean value of the $y$-axis (unless reversed). |
| $xi$ | Individual bone element (unless reversed). |
| $y_i$ | The individual anatomical stature result (unless reversed). |
| $\hat{y}_i$ | The estimated stature result achieved with a regression formulae. |
| $S_{xy}$ | The RSS value of the RMA formulae. |
| $S_{yy}^2$ | The RSS value of the OLS formulae. |
| $\beta_1$ | The slope of the best-fit line |
| $\beta_0$ | The $y$ intercept of the best-fit line. |
| $r$ | The correlation coefficient of the RMA formulae. |
| $r^2$ | The coefficient of determination (i.e., range of total variability of the regression formula). |
| SEE | The standard estimated error of the regression formulae |
| 95%CI | The 95% confidence interval with two degrees of freedom, i.e., the error range (±[…]cm). |

individual based on their skeletal remains, the independent variable represents the specific skeletal element (e.g., the femoral height) chosen to be used in the calculation of the stature, and the dependent variable will be the estimated stature. The method aims to calculate regression formulae, for one, or multiple bones, which will allow for the estimate of the stature of an individual, or the mean stature of a group, or whole population, without having the full skeletons preserved. But to be able to calculate such formulae, it is not only necessary to have the skeletal measurements, but that of the actual living stature from a large enough sample which can represent the mean stature of the group, or population (Radu & Kelemen 2015: 333). Having such mean stature values for archaeological populations can be rare, or difficult to establish, hence the formulae developed by Trotter and Gleser (1952, 1958) have seen wide use within archaeology.

### *8.3.1 Defining the formulae*

Linear regression formulae are determined through the best-fit line between the two chosen variables (stature and chosen bone element). This is possible to do with a scatterplot diagram, where the correlation between the $y$ and $x$-axis is plotted out. The best-fit line would describe the mean of the functional relationship that exists between the two variables (Zar 2010: 331), as such, the line is used to calculate the formulae for the estimates.

$$[3]\ \hat{y}_i = \beta_1 x_i + \beta_0$$

Where $\hat{y}_i$ is the dependent value (estimated stature). $\beta_1$ is the slope of the central tendency line, $\beta_0$ is the $y$-intercept, where the line cuts the $y$-axis, and $x_i$ is the independent value (the height of the chosen skeletal element) that dictates $\hat{y}_i$ value.

The variables of a simple linear regression formula can be calculated with two different methods: Ordinary Least Squares (OLS), or through RMA (Reduced Major Axis).

OLS formulae ([12] & [13]):

$$[12]\ OLS\ \beta_1 = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$$

Formula [12], can be described as the change in $y$ (vertical rise) divided by the change in $x$ (horizontal run), or can also be described as the change in $y$ (vertical rise) divided by the change in $x$ (horizontal run). The $\bar{x}$ variable is the mean height of the chosen skeletal element. The $y_i$ variable is the living stature (for a single individual) previously established through the use of

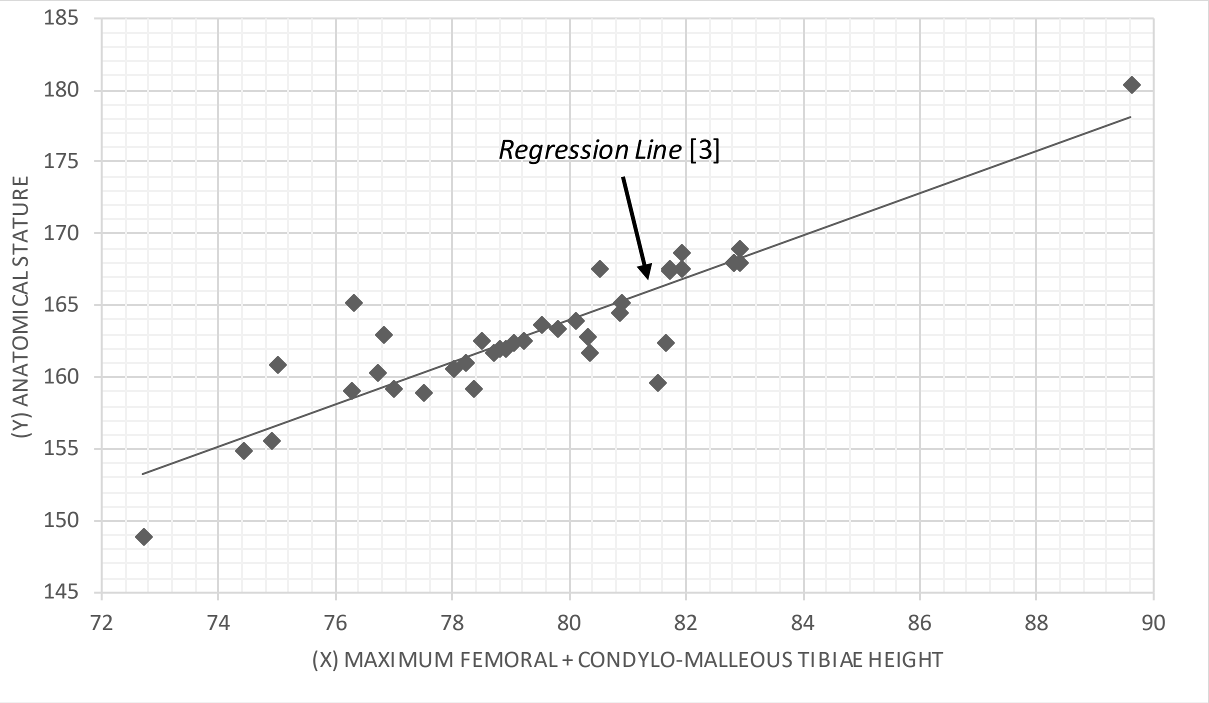

**Fig. 26.** An example of an OLS regression line [3] calculated through formulae [12 & 13] on an anatomical sample population. Here the $x$ variable is the maximum length of the femur combined with the condylo-malleous length of tibia. Whilst the $y$ variable is the estimated stature previously achieved through the anatomical method**.** All measurements are in cm.

the anatomical method (the base sample), with the $\bar{y}$ variable being the mean living stature.

The $\beta_0$, or $y$ intercept can then be calculated with this formula [13]:

$$[13]\ (OLS\ or\ RMA)\ \beta_0 = \bar{y} - (OLS\ or\ RMA)\ \beta_1\bar{x}$$

The RMA $\beta_1$ formulae [14] (Harper 2016: 5):

$$[14]\ RMA\,\beta_1 = \left(\frac{\sum(y_i - \bar{y})^2}{\sum(x_i - \bar{x})^2}\right)^{0.5}$$

The RMA $\beta_0$, the $y$-intercept, is calculated through the same formulae [13], as the OLS $\beta_0$ (Harper 2016: 5). Which of OLS and RMA is the more appropriate for stature regression use, is further discussed below.

By calculating the $\beta_1$ and $\beta_0$ variables, it is possible to establish the regression of the contributing height factor of each long bone to the full living stature of the base sample, whose stature was previously calculated through the anatomical method, due to the greater level of completeness of their remains, as was outlined by Raxter et al. (2008: 149). With these two variables established, the baseline for the regression formula is achieved [3] (see Fig 26.). For modern scholars, these formulae can be simplified and automated, e.g., through the use of Microsoft Excel or graph calculators.

The coefficient of determination $(r^2)$ value [15]:

$$[15]\ r^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

The $r^2$ value is the range of the total variability of outcome for a regression formula. The closer the value is to 1.00 (100%), the higher precision can be expected from the regression formula. The $r^2$ value is useful when comparing different models (combined with the Residual Sum of Squares values; see below), but it only signifies the variability of the sample population on which the regression formula was based and calculated (Vittinghoff *et al.* 2012: 42). Caution is still necessary when using a $r^2$ value to determine the accuracy of a formula for a population beyond the sample. Similar to the $\beta_1$[12 & 14] and the $\beta_0$ [13] values, the $r^2$ value can also be automated and simplified through the use of Microsoft Excel or graph calculators.

### *8.3.2 Calculating the Error Ranges*

A regression stature estimation formula is only as accurate as its error range. This has many times been ignored or negated in the past (e.g., Mellink & Angel 1970: 254), or even outright calculated wrong (e.g., Trotter & Gleser 1952, 1958; Trotter 1970) due to a lack of understanding of the underlying statistical methodology and formulae (Jeong & Jantz 2016: 82).

To be able to determine the accuracy of a linear regression formula, the error range or the 95%CI (95% Confidence Interval) value needs to be determined first. With the 95%CI value, it will be possible to estimate the error ranges for the calculations performed with the regression formula. The lower the confidence value is, the higher the accuracy of the calculation and the estimates will be (Zar 2010: 356-357, 376). However, before determining the 95%CI value, the Standard Estimated Error (SEE) value for each individual of the different groups needs to be determined. If the regression line (i.e., the $\beta_1$ and $\beta_0$ values; also referred to as best fit line) have been fitted through the OLS formulae [12 & 13], then the error range can be calculated as:

$$[16]\ S_{yy}^2 = \frac{\sum(\hat{y}_i - y_i)^2}{N}$$

[16]: The $S_{yy}^2$ is the mean OLS RSS (Residual Sum of Squares) OLS value. *N* is the number of individuals from the sample group that was used to calculate the formulae. RSS (sometimes referred to as MSE (Mean Squared Errors) or SSR (Sum of Squared Residuals)) is the interpretation of the distribution of residual errors that cannot be accounted for by the developed regression model, i.e., squared error ranges for the sample population. Errors in either the *x* or *y*

variables reduces the precision of the best-fit line, which in turn, lowers the correlation between the *x* and the *y*-axis, increasing the amount of residuals. The greater the RSS value is, the greater the range of the SEE value will be, which will affect the 95%CI (the final error range, see below). Hence when developing a OLS regression formula, the RSS value is where the initial focus shall lie, as the accuracy of the whole formula is reliant on it.

$$[17]OLS\,SEE = \sqrt{S_{yy}^2 \left(1 + \frac{1}{N} + \frac{(x_i - \bar{x})^2}{x_\sigma^2 (N-1)}\right)}$$

[17]: The $x_\sigma^2(N-1)$ variable is the corrected sum of squares of the measured skeletal elements, with $x_\sigma^2$ being the squared standard deviation (SD [18]) of *x*, i.e., squared SD of the measured skeletal elements (Vercellotti *et al.* 2009: 141).

SD [18] is the dispersion of data in a normal distribution, i.e., the SD value is indicative of how accurate the mean value is representative of a sample data (Lee et al. 2015: 220), or, the greater SD value, the greater the uncertainty of the results.

$$[18]SD = \sqrt{\frac{\Sigma\left(\bar{y}(\bar{x}) - y_i(x_i)\right)^2}{N-1}}$$

If the $\beta_1$ and $\beta_0$ values have been calculated through the RMA formulae [13 & 14], then the error range formulae should be calculated as:

$$[19]\; S_{xy} = \frac{\Sigma(\hat{x}_i - \bar{x})(\hat{y}_i - \bar{y})}{N-1}$$

[19]: The $Sxy$ is the covariance of the *x* and *y* variables.

$$[20]\; r = \frac{S_{xy}}{S_x * S_y}$$

[20]: *r* is the correlation coefficient, with $S_x$ being the SD value of the *x* variable, and $S_y$ is the SD value of the *y* variable.

$$[21]\; S_{xx} = \sum x^2 - \frac{(\sum x)^2}{N}$$

[21] $S_{xx}$ is the corrected sum for the squares of the measured skeletal elements.

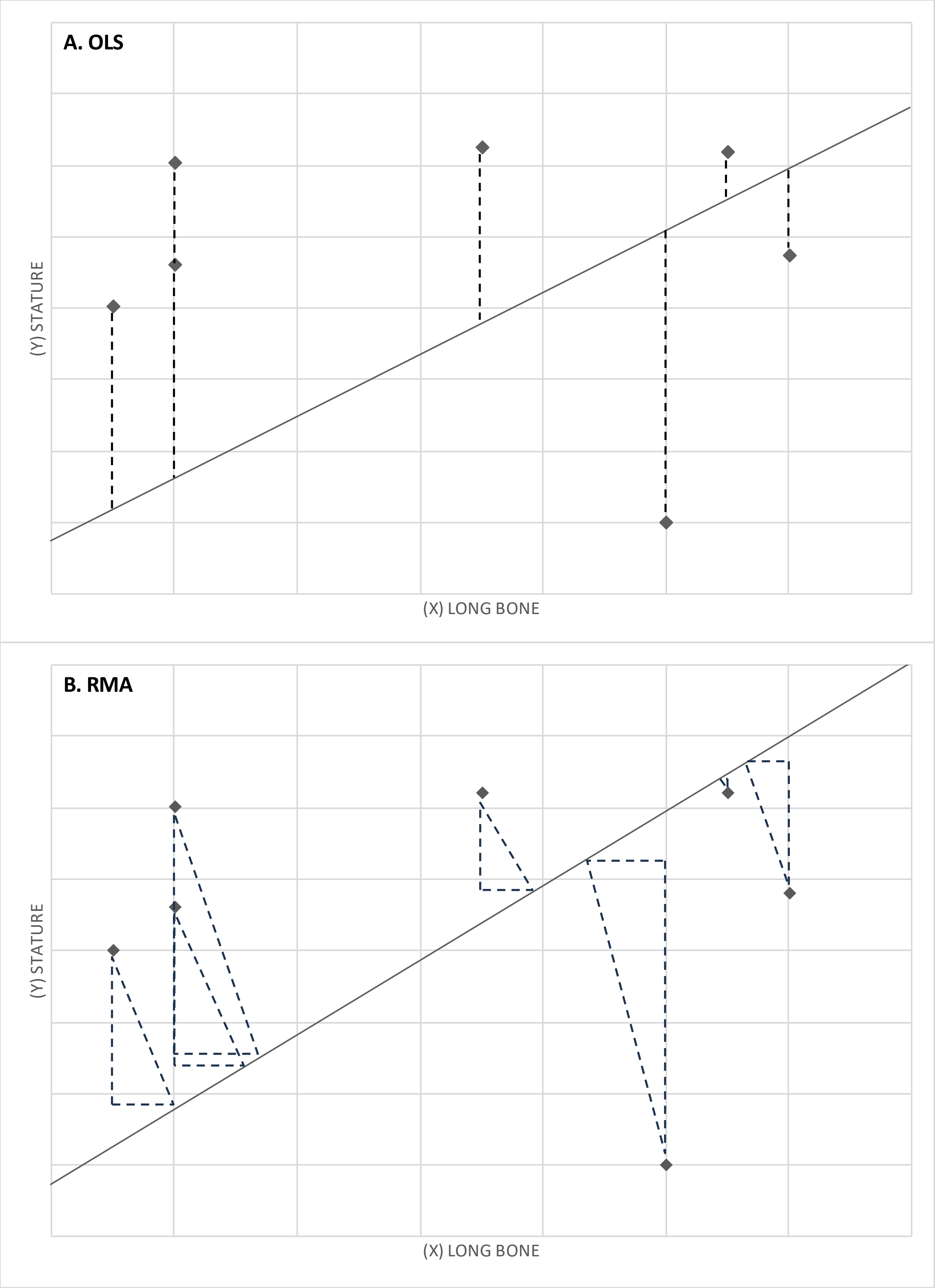

**Fig 27.** Using a hypothetical sample (both A and B use one and the same sample): (A) line fitting and plotting out of deviation using ordinary least squares (OLS) regression, and (B) line fitting and plotting out of deviation using reduced major axis (RMA) regression (note the steeper slope of the line). Both of the approaches fit slopes of the regression line by attempting to minimize the RSS value, here illustrated by the dashed lines. However, the two approaches differ in their calculation of residuals; OLS (A) uses vertical residuals, whereas RMA (B) uses diagonal residuals (Kilmer & Rodriguez 2017: 5).

With all of the above variable, the RMA SEE value can be calculated for the whole sample, which unlike OLS, cannot be calculated on an individual basis [22]:

$$[22]\,\text{RMA}\,SEE = \sqrt{S_{\text{y}}\left(\frac{(1-\text{r})}{N}\left(2+\bar{x}^{2}\frac{(1+\text{r})}{S_{\text{xx}}}\right)\right)^{0.5}}$$

The RMA covariance [19] calculates the sum of the product of $x$ and $y$ like the area of a rectangle (the $x$-axis multiplied by the $y$-axis, i.e., the variance residuals in relation to the regression line). While OLS calculates the squared vertical distance between (sum of vertical deviation [16]) $\hat{y}_i$ and the best-fit line $y_i$ (Smith 2009: 477). The higher the OLS RSS value is [16], or the greater the area of the triangle of variability is for RMA [19], the higher the error range will be.

### *8.3.1 T-test*

To estimate the final error range for the stature estimate, the 95%CI needs to be established with the t-value [23]. The t-value is a critical value used in a t-test (Student Test). The function of a t-test is to test the hypothesis with regards to the values of a population. A t-test can also be explained as a statistical technique used to measure whether the differences between two samples are statistically significant (Mishra et al. 2019: 408). In the case of a stature estimate achieved through a regression formula, the result is compared to the original sample used to base the formula on, in this study, that would be the anatomical sample.

The hypothetical SEE [17 & 22] values are tested, to see if the values fall within the 95%CI, and is accurate enough to be deemed as a reliable result to be used in the study. Meaning, that the 95%CI is the ± error range of the estimate. The variable $\text{t}_{0.05\text{N}-2}$, is the two-sided t-value at the 5% level (0.05, i.e., the academic standard for statistical significance), with two degrees of freedom: the sample size is subtracted by two (N - 2) (Vercellotti et al. 2009: 141). The t-value can easily be found in any t-table (Table 11.) and is determined by the sample size and degrees of freedom.

$$[23]\ 95\%CI = t_{0.05N-2} * SEE$$

## *8.4 OLS or RMA Determined through the use of Logarithms*

It is common in stature studies, to arbitrarily chose either OLS or RMA, or both, yet rarely ever is it discussed which is a better fit for the material. OLS is based on the knowledge of the inherent presence of errors in the sampling data used for the Y-axis, which is a given in stature estimation formulae, especially when basing the Y-axis on values achieved with the anatomical method

**Table 11.** Two sided T-test (Student test) table. Note: 0.05 (highlighted in orange) equals to 95% confidence interval; (N) is the number of individual (N-2 for two degrees of freedom, e.g., a sample of 30 individuals should use the 0.05 t-value corresponding to N=28, i.e., 2.05)

| | ***Two-sided α*** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***.50*** | ***.20*** | ***.10*** | ***.05*** | ***.02*** | ***.01*** | ***.005*** | ***.002*** | ***.001*** | ***.0005*** | ***.0002*** | ***.0001*** |
| **(N)** | | | | | | | | | | | | |
| **1** | 1.00 | 3.08 | 6.31 | 12.71 | 31.82 | 63.66 | 127.32 | 318.31 | 636.62 | 1273.24 | 3183.10 | 6366.20 |
| **2** | .82 | 1.89 | 2.92 | 4.30 | 6.96 | 9.22 | 14.09 | 22.33 | 31.60 | 44.70 | 70.70 | 99.99 |
| **3** | .76 | 1.64 | 2.35 | 3.18 | 4.54 | 5.84 | 7.45 | 10.21 | 12.92 | 16.33 | 22.20 | 28.00 |
| **4** | .74 | 1.53 | 2.13 | 2.78 | 3.75 | 4.60 | 5.60 | 7.17 | 8.61 | 10.31 | 13.03 | 15.54 |
| **5** | .73 | 1.48 | 2.02 | 2.57 | 3.37 | 4.03 | 4.77 | 5.89 | 6.87 | 7.98 | 9.68 | 11.18 |
| **6** | .72 | 1.44 | 1.94 | 2.45 | 3.14 | 3.71 | 4.32 | 5.21 | 5.96 | 6.79 | 8.02 | 9.08 |
| **7** | .71 | 1.42 | 1.90 | 2.37 | 3.00 | 3.50 | 4.03 | 4.79 | 5.41 | 6.08 | 7.06 | 7.88 |
| **8** | .71 | 1.40 | 1.86 | 2.31 | 2.90 | 3.36 | 3.83 | 4.50 | 5.04 | 5.62 | 6.44 | 7.12 |
| **9** | .70 | 1.38 | 1.83 | 2.26 | 2.82 | 3.25 | 3.69 | 4.30 | 4.78 | 5.29 | 6.01 | 6.59 |
| **10** | .70 | 1.37 | 1.81 | 2.23 | 2.76 | 3.17 | 3.58 | 4.14 | 4.59 | 5.05 | 5.69 | 6.21 |
| **11** | .70 | 1.36 | 1.80 | 2.20 | 2.72 | 3.11 | 3.50 | 4.03 | 4.44 | 4.86 | 5.45 | 5.92 |
| **12** | .70 | 1.36 | 1.78 | 2.18 | 2.68 | 3.06 | 3.43 | 3.93 | 4.32 | 4.72 | 5.26 | 5.69 |
| **13** | .69 | 1.35 | 1.77 | 2.16 | 2.65 | 3.01 | 3.37 | 3.85 | 4.22 | 4.60 | 5.11 | 5.51 |
| **14** | .69 | 1.35 | 1.76 | 2.15 | 2.63 | 2.98 | 3.33 | 3.79 | 4.14 | 4.50 | 4.99 | 5.36 |
| **15** | .69 | 1.34 | 1.75 | 2.13 | 2.60 | 2.95 | 3.29 | 3.73 | 4.07 | 4.42 | 4.88 | 5.24 |
| **16** | .69 | 1.34 | 1.75 | 2.12 | 2.58 | 2.92 | 3.25 | 3.69 | 4.02 | 4.35 | 4.79 | 5.13 |
| **17** | .69 | 1.33 | 1.74 | 2.11 | 2.57 | 2.90 | 3.22 | 3.65 | 3.97 | 4.29 | 4.71 | 5.04 |
| **18** | .69 | 1.33 | 1.73 | 2.10 | 2.55 | 2.88 | 3.20 | 3.61 | 3.92 | 4.23 | 4.65 | 4.97 |
| **19** | .69 | 1.33 | 1.73 | 2.09 | 2.54 | 2.86 | 3.17 | 3.58 | 3.88 | 4.19 | 4.59 | 4.90 |
| **20** | .69 | 1.33 | 1.73 | 2.09 | 2.53 | 2.85 | 3.15 | 3.55 | 3.85 | 4.15 | 4.54 | 4.84 |
| **21** | .69 | 1.32 | 1.72 | 2.08 | 2.52 | 2.83 | 3.14 | 3.53 | 3.82 | 4.11 | 4.49 | 4.78 |
| **22** | .69 | 1.32 | 1.72 | 2.07 | 2.51 | 2.82 | 3.12 | 3.51 | 3.79 | 4.08 | 4.45 | 4.74 |
| **23** | .68 | 1.32 | 1.71 | 2.07 | 2.50 | 2.81 | 3.10 | 3.49 | 3.77 | 4.05 | 4.42 | 4.69 |
| **24** | .68 | 1.32 | 1.71 | 2.06 | 2.49 | 2.80 | 3.09 | 3.47 | 3.75 | 4.02 | 4.38 | 4.65 |
| **25** | .68 | 1.32 | 1.71 | 2.06 | 2.49 | 2.79 | 3.08 | 3.45 | 3.73 | 4.00 | 4.35 | 4.62 |
| **26** | .68 | 1.32 | 1.71 | 2.06 | 2.48 | 2.78 | 3.07 | 3.44 | 3.71 | 3.97 | 4.32 | 4.59 |
| **27** | .68 | 1.31 | 1.70 | 2.05 | 2.47 | 2.77 | 3.06 | 3.42 | 3.69 | 3.95 | 4.30 | 4.56 |
| **28** | .68 | 1.31 | 1.70 | 2.05 | 2.47 | 2.76 | 3.05 | 3.41 | 3.67 | 3.94 | 4.28 | 4.53 |
| **29** | .68 | 1.31 | 1.70 | 2.05 | 2.46 | 2.76 | 3.04 | 3.40 | 3.66 | 3.92 | 4.25 | 4.51 |
| **30** | .68 | 1.31 | 1.70 | 2.04 | 2.46 | 2.75 | 3.03 | 3.39 | 3.65 | 3.90 | 4.23 | 4.48 |
| **35** | .68 | 1.31 | 1.69 | 2.03 | 2.44 | 2.72 | 3.00 | 3.34 | 3.59 | 3.84 | 4.15 | 4.39 |
| **40** | .68 | 1.30 | 1.68 | 2.02 | 2.42 | 2.70 | 2.97 | 3.31 | 3.55 | 3.79 | 4.09 | 4.32 |
| **45** | .68 | 1.30 | 1.68 | 2.01 | 2.41 | 2.69 | 2.95 | 3.28 | 3.52 | 3.75 | 4.05 | 4.27 |
| **50** | .68 | 1.30 | 1.68 | 2.01 | 2.40 | 2.68 | 2.94 | 3.26 | 3.50 | 3.72 | 4.01 | 4.23 |
| **55** | .68 | 1.30 | 1.67 | 2.00 | 2.40 | 2.67 | 2.93 | 3.25 | 3.48 | 3.70 | 3.99 | 4.20 |
| **60** | .68 | 1.30 | 1.67 | 2.00 | 2.39 | 2.66 | 2.91 | 3.23 | 3.46 | 3.68 | 3.96 | 4.17 |
| **65** | .68 | 1.29 | 1.67 | 2.00 | 2.39 | 2.65 | 2.91 | 3.22 | 3.45 | 3.66 | 3.94 | 4.15 |
| **70** | .68 | 1.29 | 1.67 | 1.99 | 2.38 | 2.65 | 2.90 | 3.21 | 3.44 | 3.65 | 3.93 | 4.13 |
| **75** | .68 | 1.29 | 1.67 | 1.99 | 2.38 | 2.64 | 2.89 | 3.20 | 3.43 | 3.64 | 3.91 | 4.11 |
| **80** | .68 | 1.29 | 1.66 | 1.99 | 2.37 | 2.64 | 2.89 | 3.20 | 3.42 | 3.63 | 3.90 | 4.10 |
| **85** | .68 | 1.29 | 1.66 | 1.99 | 2.37 | 2.64 | 2.88 | 3.19 | 3.41 | 3.62 | 3.89 | 4.08 |
| **90** | .68 | 1.29 | 1.66 | 1.99 | 2.37 | 2.63 | 2.88 | 3.18 | 3.40 | 3.61 | 3.88 | 4.07 |
| **95** | .68 | 1.29 | 1.66 | 1.99 | 2.37 | 2.63 | 2.87 | 3.18 | 3.40 | 3.60 | 3.87 | 4.06 |
| **100** | .68 | 1.29 | 1.66 | 1.98 | 2.36 | 2.63 | 2.87 | 3.17 | 3.39 | 3.60 | 3.86 | 4.05 |

(see chapter 2.5). RMA assumes errors within the *x*-axis, which is far less prevalent, as the inter-observer errors (this refers to the measurements not measured by the author in this study; see material section) of bone measurements are negligible compared to estimated stature values. Furthermore, RMA assumes that the relation between the *x* and *y* values is symmetrical (i.e., isometric), whilst OLS assumes the opposite (allometric). With regards to stature estimation, as previously discussed in regards to secular allometric trends (Jantz & Jantz 1999), OLS is better suited than RMA, for the relation between bone length and stature is not symmetrical, rather allometric, hence cannot be reversed, as the $\hat{x}_i$ values are used to predict the $\hat{y}_i$(see a further summary checklist in Table 12.).

The assumption of isometry, or limited allometry, in regards to the relation between stature and long bone length, tend to cause the fitting of the regression line through RMA formulae to overestimate the correlation between the two variables. This results in the fitting of a steeper regression line (see Fig 27.), hence are at risk of not accounting for the true allometric scaling of the sample, i.e., the full variation may not be accounted for by the final calculated formula. This is not an issue using OLS, as the factor of allometric scaling of traits (i.e., long bone height's relation to the full stature), as the errors are measured through vertical deviations (see Fig 27), rather than diagonal deviations (Kilmer & Rodriguez 2017: 8-11).

Allometry refers to the seize related changes of morphological traits (Klingenberg 2016:

**Table 12.** OLS and RMA checklists (Smith 2009: 482).

**Indications for OLS:**

1. X ‘‘causes’’ Y
2. X in some noncausal manner restricts, limits, or determines Y.
3. X is being used to predict values of Y (Smith 1994; Woodhouse 2006).
4. The purpose of the regression is to understand the range of values Y can take at a given value of X.
5. Change in Y is a response by correlated evolution to selection on X (Lande, 1979, 1985).
6. The question is interpreted as asking if subjects with different values of X have different expected values of Y (Warton et al. 2006).
7. Residuals will be evaluated as data. A subcategory of this would be the ‘‘recognition of individual outliers’’ (Martin 1989).

**Indications for RMA:**

1. It seems arbitrary which variable is on the X-axis and which variable is on the Y-axis.
2. The objective is to define some mutual, codependent, biological ‘‘law’’ underlying the interaction between X and Y (Sprent, 1966).
3. The slope of the line will be used to interpret the pattern of change in ‘‘shape’’ (i.e., proportions) with change in size. The question is whether X and Y maintain an isometric relationship, or whether Y exhibits positive or negative allometry (Warton et al. 2006).

113), i.e., the correlation of body size (stature) in relation to shape and other bodily characteristics (e.g., the height of each bone element) in a being (Shingleton 2010: 1). Allometry is a well-known and widely researched concept within evolutionary biology over the last century (e.g., Snell 1892; Huxley 1924, 1932; Cock 1966; Gould 1966; Calder 1984; Schmidt-Nielsen 1984), yet its consideration within archaeologically related stature studies have commonly been missing. Humans, similar to any other biologically long-term evolved creatures, are not exempt from allometric consideration (Wilson et al. 2010: 684-685), hence this key factor is of important consideration when formulating stature regression formulae, by either choosing OLS or RMA.

Any biological element or section of the body can easily be determined as isometric or allometric, by calculating the allometric coefficient ($log_{10}\ \beta_1$). This can be done through the formula [24]:

$$[24]\ log_{10}\,\beta_1 = \frac{\sum(log_{10}x_i - log_{10}\bar{x})(log_{10}y_i - log_{10}\bar{y})}{\sum(log_{10}x_i - log_{10}\bar{x})^2}$$

Note the similarity to formula [12]. However, here, the variables have been reversed, the $y$ variable is the selected bone element, and the $x$ variable is the anatomical stature. Each variable is put through a logarithm of ten ($log_{10}$), i.e., inverse exponential, or phrased reversely, as an exponential value: ten raised to what base number (*b*) will result in $x$ or $y$:

*Scaling factor of x*(*y*)

$$log_{10}x(y) = 10^{b} \swarrow$$

$$= x(y) \leftarrow$$

*Stature achieved in adulthood* (*x*); *or final height of bone element* (*y*)

Historically, the base values were determined by using natural logarithms together with numerical logarithmic tables (e.g., Jones 1893; Cajori 1913). However, the simplest and most efficient mode to calculate the base value of $log_{10}x(y)$ is to use the log function of a graph calculator or Microsoft Excel, where the value of 10 raised to *b* equals $x$ or $y$, e.g., the $log_{10}x$ (anatomical stature) and $log_{10}y$ (femoral bicondylar height). This can also be explained as: $log_{10}x_i$ is the scaling factor of $x$ (*vis-à-vis* $log_{10}y_i$), and the value of ten raised to the value of *b* is representative of the $x$ value scales in relation to the $y$ value, with the $x_i$ being the final results, i.e., the stature achieved in adulthood, whilst $y_i$ is the final height achieved for each bone element. Hence using $log_{10}x_i$ (the anatomical stature) in correlation to $log_{10}y_i$ (bone element), plotted out in a scatter plot diagram (i.e., a log-log scale diagram when utilizing logarithms for both axes; see Fig 30.), the scaling rate of each bone element in accordance to the full stature can be traced, as $log_{10}\ \beta_1$ is the calculated slope of the best-fit line of the logarithmic sample, similar to when formulating the $\beta_1$ variable [12] of a stature regression formula.

If $log_{10}$ $\beta_1$ is near one, its isometric (equal) in its scaling rate to the being as a whole, e.g., the human heart has a $log_{10}$ $\beta_1$ value of 0.98, meaning that the heart's scaling is nearly perfectly isometric in relation to the full size of the stature and body mass of the human body, hence less variation in the bodily proportion in relation to the size of the heart can be expected. Through $log_{10}$ $\beta_1$, it is possible to quantify the to what degree each bodily trait is allometric or isometric, in proportion to the full stature achieved in adulthood (around the age of 18), (Trotter & Gleser 1952: 469-471; Shingleton 2010: 2-3). If however, the $log_{10}$ $\beta_1$ value is lesser than one (i.e., $<1$), then its scaling factor is negatively allometric, e.g., the brain volume and skull size in relation to the full stature and body mass is negatively allometric, due to its less than one $log_{10}$ $\beta_1$ value (c. 0.78, i.e., $<1$), or *vice versa,* if the value is greater than one (i.e., $>1$), then its positively allometric. If the logarithmic results are either positive or negative, then it would suggest a greater size variation in the specific characteristic, that cannot fully be accounted for in through linear regression, hence the use of RMA would be a poor fit for the regression formulae calculation, as the *x* and *y* variables are then not reversible (see Table 12.).

## *8.5 Identifying outliers through Studentized Residuals*

A common issue that is encountered when establishing the baseline for regression formulae, using the base anatomical sample, is the presence of outliers. These outliers can either represent individuals who are significantly shorter or taller than the average of the sample, or more commonly, individuals whose body ratios do not match the wider trends of the sample population (e.g., though not solely, individuals with high RSS values comparatively to the average of the sample). The presence of outliers or anomalies can exert a disproportionate influence on the wider analysis of a whole sample population, for the population mean is not a robust value, and is not resistant towards dilution, hence may provide a poor reflection of the full population sample. A slight departure from the normal stature trend may inflate the standard error range, resulting in inaccurate hypothesis testing (Wilcox 2005: 1; Reifman & Keyton 2010: 1636-1637), or a diametrically opposed results than if these values were removed (i.e., censored) (Cook 2011: 301). This is due to the formation of a regression line being heavily reliant on the mean value of the sample population, which in turn if diluted through outliers, will result in a less accurate regression formula with higher error ranges, hence less likely to fit the population that it was developed for. These issues and anomalies can be summarized as:

1. Significantly short or tall individuals compared to the mean values of the sample, whose stature cannot be accounted for by the stature formulae, without ahigh RSS values. These

anomalies can be the result of a myriad of different factors, e.g., trauma, dwarfism, lack of growth hormone (short stature outside of the range of the sample population), or excessive growth hormone (as juxtaposed to the issue of the former), or sever rickets *et cetera*.

2. Individuals whose estimated stature falls within the normative stature range, yet who may have body ratios that do not match the normal curve (e.g., the tibia's percentile contribution to the full stature). Larger deviations in the body ratios, can, e.g., suggest that the individual is of foreign origin (foreigner originating from a population with a marked difference in body ratio, caused by either genetic predisposition or secular trends) than the majority of the sample population. This is a reoccurring issue that is especially prevalent in studies that attempt to develop generalized stature formulae for wide samples of geographically, periodical, and genetically unrelated populations (e.g., Sjøvold 1990; Ruff et al. 2012; Ruff 2018).

Samples that include individuals exhibiting the issues outlined in (1.), or (2.), may benefit from censoring, i.e., removal of the outlying values, as this could reduce the resulting error ranges of the regression formulae (Kilmer & Rodriguez 2017: 11). Yet before considering censoring, these outliers needs to first be identified. To identify outliers, the most efficient method is the *studentized residuals* approach; this method assess the normal distribution curve of the sample's dependent variable (i.e., $y$ variable), which has a significant bearing on the calculation of the estimated coefficients (e.g., $\beta_0$ [13] and $\beta_1$[12 & 14]), hence affects the reliability of the linear regression formulae calculations.

The studentized residuals ($t_i$) of an individual's data points can be determined through this simple formula [25]:

$$[25] t_i = t_{0.05N-2} * \frac{e_i}{S_e}$$

The $e_i$ variable is the residual value of the $y$ variable [26]:

$$[26]\ e_i = y_i - \hat{y}_i$$

The $S_e$ variable is the sample's standard deviation of $e_i$.

The resulting value of formula [25] can be summarized as: the $t_i$variable represents the vertical (i.e., $y$ variable) deviation from the normative trends of the sample. Vertical deviations from the normative trends of a sample can cause the regression line to be shifted, causing the

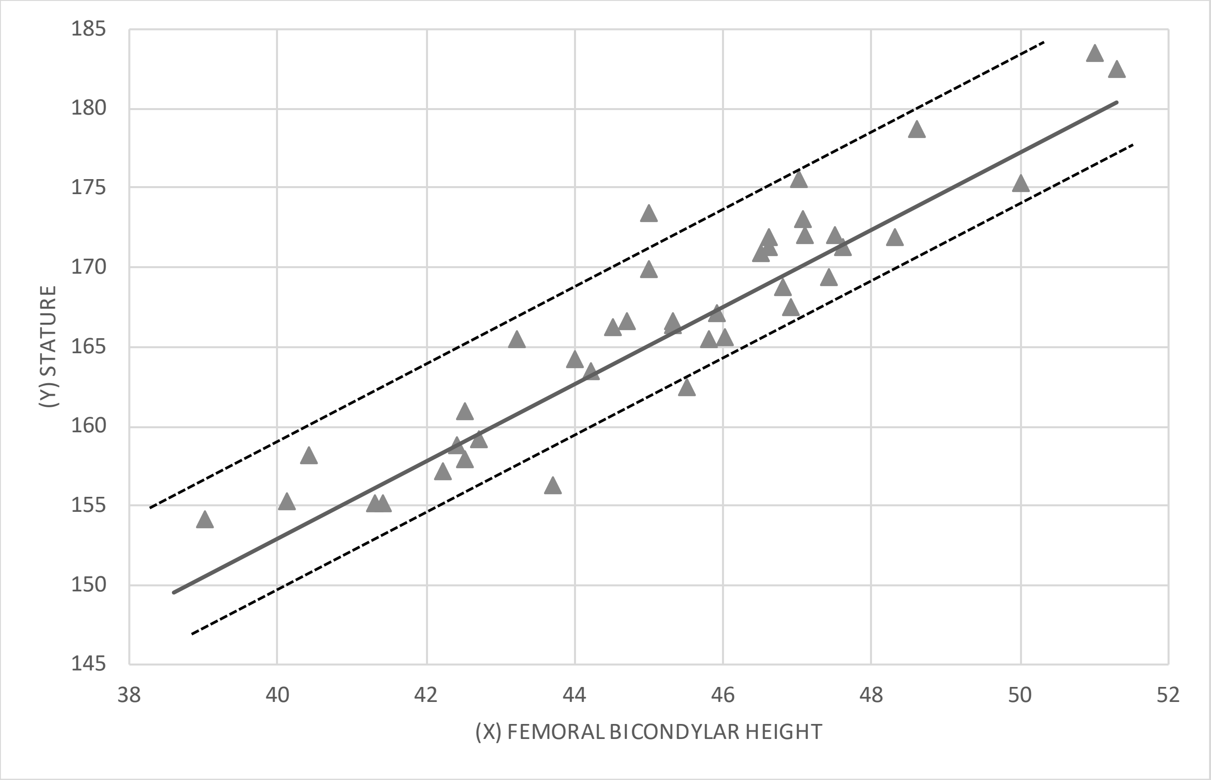

**Fig 28.** An example of a scatter plot diagram, plotting out the relation of the femoral bicondylar height (*x*) to the anatomical stature (*y*). By using formula [25], the value of the outliers has been calculated, the striped lines represents the cut off points (i.e., ≥3) from the normative distribution of the sample, whilst the solid line is the calculated regression line.

line to be steeper or shallower, hence may cause less representative estimated coefficient variables (i.e., $\beta_0$ [13] and $\beta_1$[12 & 14]). If an individual's $t_i$ value is equal to or greater than three (i.e., ≥3), then it is considered as an outlier, hence may be considered for removal. Those individuals who is determined as outliers, tend to also exhibit high RSS values, hence is a poor fit for the wider sample. The percentile, or the number of how many individuals are necessary to censor, always need to be assessed on a case by case basis, and it is determined by how well does each individual's $y$ variables fit within the normal distribution of the specific sample (e.g., Fig 28.).

## *8.6 Chapter Summary: Codifying the Methodological Stature Estimation Approach*

A key focus of this study, and this chapter, has been on codifying and assembling a comprehensive approach regarding each step of stature estimation, ranging from the sampling of the anatomical base sample, to how to empirically calculate new stature regression formulae on said base samples. This chapter has outlined each of these key steps and aspects that should be considered in the process of using either the anatomical or regression stature methods. Furthermore, the issue of identifying anomalies or outliers is addressed through studentized residuals, to limit the possibility of dilution of the accuracy of the produced regression stature formulae, due to the presence of ill-fitting sample outliers.

The discussion of this methodological chapter can be summarized in these four points:

- Outlining the usage of the anatomical method to establish the base sample, which then will serve as the foundation to calculate the regression formulae on.
- Analysing OLS (Ordinary Least Squares) or RMA (Reduced Major Axis) for stature regression calculation, as to determine which is more suitable.
- Calculating stature regression formulae, through OLS or RMA, for each of the skeletal elements, determining the estimated coefficients, along with the error ranges, which hence can be utilized for the less complete individuals.
- Through the calculation of studentized residuals, the possible sample outliers are established, hence determining the possible outliers for censoring, to increase the accuracy of the regression formulae calculated on the base anatomical samples.

Each of these steps will be further returned to and illustrated in practice in the following results and discussion chapters.

# 9. Results

The following chapter will summarize the results achieved with the methodology outlined in the previous chapter. The results will be summed up and presented in five sections:

1. The sampling and usage of the anatomical method to establish the base sample, which will serve as the foundation to calculate the regression formulae.
2. With the results of the anatomical method, which is better suited: OLS (Ordinary Least Squares) or RMA (Reduced Major Axis) for stature regression calculation can be investigated and determined conclusively using logarithms.
3. Based on the results of the previous step, OLS, or RMA, will be used to calculate stature (unmodified) regression formulae, for each of the skeletal elements, of either of the sexes, along with the error ranges.
4. Further modifications of the base samples determined on the results of studentized residuals analysis, to increase the accuracy of the achieved stature formulae.
5. With the base sample modified, and the stature regression formulae calculated, the wider early medieval population whose remains are less complete, can have their stature estimated along with the error ranges determined.

## *9.1 Sampling of the Complete Individuals*

As discussed in previous chapters regarding aDNA, a large data set is required to avoid erroneous conclusions caused by a selective smaller data set (Stone 2008: 467), this applies equally to the study of stature estimation, and it is a paramount consideration when formulating the regression formulae (Ramsier et al. 2021: 523). Hence the question that arises is: what is a large enough data set for such a query? An assertion that is easy to make, yet a larger sample is not always a better fit, as the required number of individuals in the formulation of the regression formulae is dependent on the degree of homogeneity or heterogeneity within the stature ratios of the population. A greater degree of heterogeneity will require a larger base sample, whilst a homogenous sample will require a smaller sample, as the body ratios will be more clearly defined in the latter. Hence no hypothetical number can be stated ahead of running sample tests, e.g., by calculating the population means RSS value for the base sample estimated with the anatomical method, which lies as the basis to calculate the error range on (further discussed below). Yet even the minimal number of complete skeletons, of either sex, required to reliably regress the long bone length against the estimated living stature achieved with the anatomical method, is difficult to achieve (Mays et al. 2016: 647), especially in Britain (see Fig 7.). The solution to this issue is not to supplement one sample, with that of a unrelated contemporary population, to bolster the sample numbers, e.g., the study of Ruff et al. (2012), as this will dilute the sample. Nor is the solution to apply the formulae calculated on a noncontemporary sample, from an earlier or later period, whose body genetic predisposition or secular trends are unknown to be a match e.g., Trotter and Geleser's (1952 & 1958) formulae, as this will only achieve tentative results. In short, it is most important to ensure the validity of the baseline data set, rather than to artificially bolster its number with poorly suited data.

From the 28 different sites included in this study, 512 individuals were sampled (males: 327 individuals; females: 185 individuals (see material chapter for a full list)), based on the criteria outlined in the material chapter (Table 1 & 2). Both left and right limbs were measured when available per individual, with the mean metric of the two sides being used, rather than favouring one side over the other. Of these 512 individuals, 69 individuals had all (or the majority of (further discussed below) of their necessary elements which contribute to the full SKH (Skeletal Height) measured in accordance with the collective standards by Pearson (1899), Martin (1928 & 1957), Raxter et al. (2006) and Rosenstock (2019) (see Table 13.).

As with the wider sample of 512 individuals, preservation was uneven between the sexes, with males (40 individuals) predominating over females (29 individuals) (see Table 15. and Table 16.). As was previously discussed, skeletal preservation tends to be worse in older females,

**Table 13.** Measurement standards and acronyms for each long bone (Pearson 1899; Martin 1928; Raxter et al. 2006; Siegmund 2010; Rosenstock 2019).

| Long Bone | Description | Abbreviation |
|---|---|---|
| **Femur** | - Caput-condyle-length (maximum length) | F1 |
| | - Bicondylar length, physiological length | F2 |
| **Tibia** | - Condylo-malleolar length, lateral condylo-malleolar length | T1 |
| **Humeri** | - Maximum length | H1 |
| **Femur + Tibia** | - Caput-condyle-length (maximum length) combined with condylo-malleolar length, lateral condylo-malleolar length | F1+T1 |
| | - Bicondylar length, physiological length combined with condylo-malleolar length, lateral condylo-malleolar length | F2+T1 |
| **Femur+ Tibia+ Lumbar** | - Caput-condyle-length (maximum length) combined with condylo-malleolar length, lateral condylo-malleolar length and the combined length of the five lumbars. | F1+T1+L |
| | - Bicondylar length, physiological length combined with condylo-malleolar length, lateral condylo-malleolar length and the combined length of the five lumbars. | F2+T1+L |

than in older males, especially the vertebral column (e.g., Boddington 1987; Anderson 2003; Solomons 2013), hence the larger male sample used with the anatomical method in this study is not surprising. Several individuals' remains almost fulfilled the criteria, yet were lacking, e.g., in the preservation of the vertebrae column. This was rectified through the use of the formulae established by Auerbach (2011), which allowed for the estimate of the cervical and thoracic regions when missing (as outlined in the methodology chapter). An important example in this study which highlights the value of Auerbach's (2011) formulae in stature estimation research, is the Stratford-Upon-Avon population, where only a single male individual (SK1145) of the sample of 20 fairly complete individuals had a completely preserved vertebrae column, with the remainder only having their lumbar and sacral sections preserved. This allowed for the missing vertebrae sections to be estimated through Auerbach's (2011: 76) formula [9] ($y$ being the height of the Lumbar section).

$$[9]\ 2.639y + 114.480$$

In the case of the Stratford-Upon-Avon example, this formula allowed for the expansion of the sample population of useable individuals for the anatomical method by another 19 individuals.

## *9.2 The Anatomical Method's Results*

The 69 individuals as shown in Table 15. (females) and Table 16. (males) had their living stature (i.e., LS) reconstructed with the anatomical method's formula [4] (Raxter et al. 2006), which includes the age factor (i.e., 0.0426∗*age*).

$$[4]\ \mathrm{LS}\pm4.5\mathrm{cm}=1.009x_i-(0.0426*\mathrm{age})+12.1$$

Whenever the individual's precise age has not been possible to establish, e.g., when generic age categories, such as "adult" is stated (six instances: two females and four males), then the age factor (0.0426∗age), is multiplied with zero. As Raxter et al. (2006: 378) suggested, formula [4] with the age factor tend to produce lower error ranges, even when the age is multiplied with zero, compared to the formula [5] without the age factor. In those instances when the individuals' age is estimated as "older adult" (two male instances), according to Simmonds et al. (2013), the age categorization is considered as: age ≥45, at the time of death, hence these individuals' age has been calculated as 45. When an age range is used, e.g., age 40-50, then it is calculated as the mean age, i.e., 45, and age categories such as 45+, similar to the category of older adults, is calculated as 45. This was done to ensure that all individuals are calculated with the same formula, and none with formula [5], as not to invite errors induced by summing up results

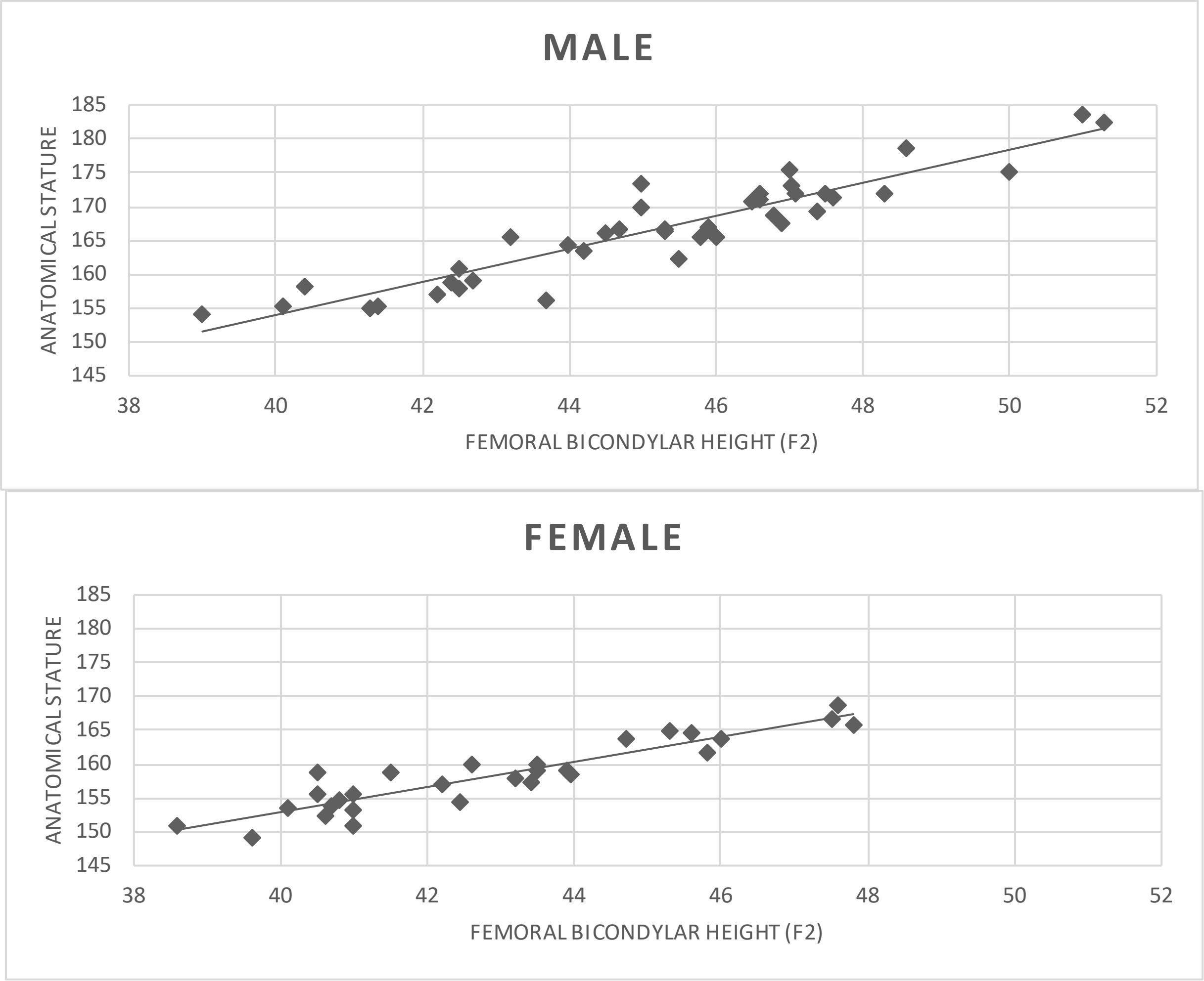

**Fig 29.** Example of a single bone elements' contribution towards the full stature of the individual (in cm), for both sexes, established through the results of the anatomical method, see Table 15. and 16. In these illustrated examples, the bicondylar femoral height (x) is plotted out in relation to the full anatomically estimated stature (y).

achieved with different formulae, with different degrees of accuracy. Any precision lost due to the occasional generalized application of the age factor should be negligible to the overall stature results. Taking the aforementioned caveats with the age estimates of the sample populations, the mean age of the female sample at the time of death was 35.9 years, whilst the male average was 35.1 years, hence no significant disparity between the sexes.

Illustrating the formulae in practice, using the three above-mentioned formulae, applied for the male individual SK1151, from the site of Stratford-Upon-Avon, who had an SKH value of 141.8cm, and a generic age of "adult", hence the age factor is calculated as zero (note: the anatomical method's 95%CI, unlike the regression formulae developed through OLS, is not calculated on an individual basis, but rather for the whole sample population):

*SKH ($x_i$) and age factor values of male individual SK1151*

$$\begin{cases} x_i = 141.8\text{cm} \\ age\ factor = 0 \text{ (generic adult age estimate)} \end{cases}$$

$$\text{Stature [4]: } 1.009*141.8-(0.0426*0) + 12.1 \approx 155.2 \pm 4.5\text{cm}$$

The mean stature of the 69 fairly complete individuals put through formula [4] were: 159cm for the female sample (SD: 5.1); 167cm for males (SD: 7.4). The larger SD value of the male sample is caused by a greater disparity between the mean value of the sample, and the individuals on the extreme tails of the sample, i.e., those of significantly greater or lesser stature than that of the average population sample.

This disparity between the sexes in regards to the extremes and greater SD value for males correlates to the expected secular stature trends (i.e., long-term changes in body ratios) *"*[…] *male secular change is stronger than female secular change* […] *(Jantz & Jantz 1999: 65)"*, hence these early medieval stature results follow the wider trends (further discussed below in regard to the regression formulation, and in the following discussion chapter). These differences in the secular trends can be illustrated by plotting out the contribution of the height of a single bone element to the full stature of an individual, e.g., the femoral bicondylar height's

**Table 14.** The mean measurements of each bone element of the 69 individuals used with the anatomical method, along with standard deviation (SD), percentile contribution towards the full skeletal height (SKH%), and stature estimate (ST%). Note: no percentile contribution towards the full SKH or stature is provided for the F1 element, as the anatomical method only utilizes the F2 measurements. All measurements are in cm.

| | | **Male** | **N: 40** | | | **Female** | **N: 29** | |
|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SD** | **SKH%** | **ST%** | **Mean** | **SD** | **SKH%** | **ST%** |
| **Cranial Height:** | 13.9 | 0.7 | 9.1% | 8.3% | 13.6 | 0.7 | 9.3% | 8.5% |
| **Vertebral Column:** | 50.5 | 3.0 | 32.9% | 30.2% | 48.2 | 1.9 | 33.0% | 30.3% |
| **Maximum Femoral Height (F1):** | 45.2 | 2.9 | - | - | 42.9 | 2.5 | - | - |
| **Femoral Bicondylar Height (F2):** | 45.6 | 2.9 | 29.7% | 27.3% | 43.3 | 2.5 | 29.6% | 27.2% |
| **Condyle-Malleolus Height of Tibia (T1):** | 37.1 | 2.6 | 24.2% | 22.2% | 34.9 | 2.0 | 23.9% | 22.0% |
| **Articulated Foot Height:** | 6.8 | 0.4 | 4.4% | 4.1% | 6.2 | 0.3 | 4.2% | 3.9% |
| **Skeletal Height (SKH):** | 153.5 | 7.4 | - | 92.1% | 145.4 | 5.1 | - | 91.4% |
| **Stature Estimation:** | 167.0 | 7.5 | - | - | 159 | 5.1 | - | - |

**Table 15.** Female stature results achieved through the anatomical method (Est A Stature). Note that several of the adults have been estimated as generic adult or older, hence affecting the mean age of the sample. All measurements in are in cm.

| | ***Females*** | | | |
|---|---|---|---|---|
| **Site (number of individuals):** | **Individual (N: 29):** | **Age:** | **SKH** | **Est A Stature** |
| ***Stratford Upon Avon (4)*** | SK1031 | 30-35 | 141.6 | 154.9 |
| | SK2065 | 30-35 | 153.2 | 166.6 |
| | SK2019 | 35-45 | 140.5 | 153.4 |
| | SK1211 | 40+ | 155.7 | 168.8 |
| ***Collingbourne Ducis (1)*** | 31 | Adult | 147.9 | 161.3 |
| ***Godalming (3)*** | 1042 | 50+ | 146.3 | 158.9 |
| | 3432 | 45-50 | 151.1 | 163.8 |
| | 1073 | 20-25 | 145.1 | 158.5 |
| ***Mount Pleasant (3)*** | Grave 14 | 23 | 135.8 | 149.1 |
| | Grave 23 | 35 | 141.4 | 154.6 |
| | Grave 35 | 30-35 | 145.6 | 158.9 |
| ***Barrow Clump (3)*** | 7087 | 33-45 | 138.1 | 151.1 |
| | 7060 | 45+ | 153.2 | 166.0 |
| | 7290 | 45+ | 148.9 | 161.7 |
| ***Apple Down (15)*** | GRAVE 3 | 17-25 | 140.4 | 153.8 |
| | GRAVE 4B | 45+ | 142.9 | 155.6 |
| | GRAVE 11 | 25-32 | 138.9 | 152.3 |
| | GRAVE 14 | 27-35 | 150.4 | 163.8 |
| | GRAVE 17 | Adult | 144.6 | 158.0 |
| | GRAVE 23 | 50+ | 147.3 | 159.9 |
| | GRAVE 50 | 20-25 | 144.0 | 157.4 |
| | GRAVE 86 | 40+ | 145.0 | 158.0 |
| | GRAVE 88 | 40+ | 151.7 | 164.7 |
| | GRAVE 87 | 35-40 | 146.9 | 160.0 |
| | GRAVE 101 | 20-24 | 151.6 | 165.1 |
| | GRAVE 105 | 40+ | 140.6 | 153.5 |
| | GRAVE 108 | 18-20 | 145.8 | 159.2 |
| | GRAVE 143 | 45+ | 138.3 | 151.0 |
| | GRAVE 157 | 35-45 | 144.0 | 157.0 |
| **Mean:** | | **35.9** | **145.4** | **159±4.5cm** |
| **SD:** | | | **5.1** | **5.1** |

**Table 16.** Male stature results achieved through the anatomical method (Est A Stature). Note that several of the adults have been estimated as generic adult or older, hence affecting the mean age of the sample. All measurements are in cm.

| | ***Males*** | | | |
|---|---|---|---|---|
| **Site (number of individuals):** | **Individual (N: 40):** | **Age:** | **SKH** | **Est A Stature** |
| ***Stratford Upon Avon (16)*** | SK1151 | Adult | 141.8 | 155.2 |
| | SK2435 | 25-35 | 145.8 | 159.2 |
| | SK1145 | 17-20 | 162.1 | 175.7 |
| | SK2185 | Adult | 141.9 | 155.3 |
| | SK2438 | 30-35 | 158.6 | 172.0 |
| | SK3327 | 30-35 | 157.9 | 171.3 |
| | SK2378 | Older Adult | 165.8 | 178.8 |
| | SK2702 | 18-20 | 156.0 | 169.5 |
| | SK1420 | 50+ | 153.8 | 166.4 |
| | SK2025 | 20-30 | 143.8 | 157.2 |
| | SK1102 | Adult | 143.0 | 156.4 |
| | SK1568 | 45-55 | 141.7 | 154.2 |
| | SK2040 | Adult | 152.2 | 165.7 |
| | SK1772 | 50+ | 151.7 | 164.3 |
| | SK1391 | 25-30 | 160.0 | 173.5 |
| | SK1652 | 40+ | 150.5 | 163.5 |
| ***Collingbourne Ducis (4)*** | 11 | 25-35 | 157.5 | 171.0 |
| | 27 | 40-50 | 153.8 | 166.7 |
| | 1104 | 35-45 | 153.2 | 166.7 |
| | 1293 | 45+ | 149.9 | 162.5 |
| ***Godalming (4)*** | 3136 | 20-30 | 148.4 | 161.0 |
| | 3033 | 50+ | 152.9 | 165.5 |
| | 1023 | 50+ | 156.4 | 169.9 |
| | 1049 | 50+ | 160.1 | 173.1 |
| ***Droxford (2)*** | Grave 19 | 20-25 | 153.7 | 167.2 |
| | Grave 33 | 40-45 | 152.8 | 166.3 |
| ***Mount Pleasant (2)*** | Grave 32 | 18 | 145.5 | 158.9 |
| | Grave 7 | 24-27 | 142.6 | 155.3 |
| ***Portway West Andover (1)*** | Area III Grave F1 | Adult | 145.3 | 158.3 |
| ***Droxford (1)*** | Grave 39 | Older Adult | 159.2 | 172.1 |
| ***Apple Down (10)*** | GRAVE 1 | 20-30 | 158.4 | 171.9 |
| | GRAVE 12B | 25-35 | 168.9 | 182.5 |
| | GRAVE 19 | 33-45 | 145.0 | 158.0 |
| | GRAVE 28 | 50+ | 158.7 | 171.4 |
| | GRAVE 31 | 45+ | 170.6 | 183.6 |
| | GRAVE 46 | 25-35 | 155.3 | 168.8 |
| | GRAVE 54 | 18-19 | 154.1 | 167.6 |
| | GRAVE 71 | 45+ | 152.7 | 165.5 |
| | GRAVE 145 | 17-25 | 158.6 | 172.1 |
| | GRAVE 152 | 17-25 | 161.8 | 175.3 |
| **Mean:** | | **35.1** | **153.5** | **167±4.5cm** |
| **SD:** | | | **7.4** | **7.5** |

contributing factor to the full stature (see Fig. 28). As illustrated in the scatter plot diagrams above (Fig 29.), the greater variability of the male sample, in relation to the regression line, is unlikely an artefact of the greater size of the male sample, but rather follows the wider secular stature trends, which persists even in modern populations. Table 14. illustrates that except for the cranial height (i.e., basion to bregma height) the SD value for each bone element is less for the female sample, i.e., the body ratios of the female sample is less heterogenous than the male sample. The results presented in Fig 29., and Table 14., point towards the more homogenous trends of female stature, hence these are easier to trace through biostatistics (see next chapter).

## *9.3 Calculating the Regression Formulae*

The mean stature of the 69 complete individuals put through formula [4], with the mean estimated stature of 158.5cm (SD: 5.1) for females, and the mean estimated stature of 167.0cm (SD: 7.5) for males, serve as the established baseline to calculate the regression formulae on. The larger SD value of the males, compared to the females, is a necessary factor to consider when formulating the regression formulae that can be used for the wider sample of the lesser well-preserved population (further addressed below).

### *9.3.1 OLS or RMA; Allometric or Isometric*

Before proceeding with the calculation of the regression formulae, it is necessary to establish whether OLS (Ordinary Least Squares) (originally introduced by Pearson 1899) or RMA (Reduced Major Axis) (i.e., squared error ranges for the sample population) (e.g., Sjøvold 1990; Ruff et al. 2012; Rosenstock et al. 2019), is appropriate to use when calculating the $\beta_1$ variable in formula [3], through formula [12] and [14].

$$[3]\ \hat{y}_i = \beta_1 x_i + \beta_0$$

$$[12]\ \text{OLS}\,\beta_1 = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\Sigma(x_i - \bar{x})^2}$$

$$[14]\ \text{RMA}\,\beta_1 = \left(\frac{\Sigma(y_i - \bar{y})^2}{\Sigma(x_i - \bar{x})^2}\right)^{0.5}$$

OLS or RMA are crucial to establish (i.e., the $x$ and $y$ variables, including the mean), as the $\beta_1$ variable, is the basis for the second variable of formula [3], i.e., $\beta_0$, which is calculated through the formula [13].

$$[13]\ \beta_0 = \bar{y} - (\text{OLS or RMA})\ \beta_1 \bar{x}$$

With the accompanying error range formulae of OLS: mean RSS ($S_{yy}^2$) [19], SEE [17] and 95%CI ($\mathrm{t}_{0.05\mathrm{N}-2}$) [23] formulae, or the error range formulae of RMA: the covariance of the *x* and *y* variables ($S_{xy}$) [19], *r* correlation coefficient [20], the corrected sum for the squares for the *x* variable ($S_{x\mathrm{x}}$) [21], SEE [22] and 95%CI [23]. OLS error range formulation:

$$[16]\, S_{yy}^2 = \frac{\sum(\hat{y}_i - \mathrm{y}_i)^2}{N}$$

$$[17\ \&\ 23]\, OLS\ 95\%CI\ = \mathrm{t}_{0.05\mathrm{N}-2} \sqrt{S_{yy}^2 \left(1 + \frac{1}{N} + \frac{(x_i - \bar{x})^2}{x_\sigma^2 (N-1)}\right)}$$

RMA error range formulation:

$$[19]\, S_{xy} = \frac{\sum(\hat{x}_i - \bar{x})(\hat{y}_i - \bar{y})}{N-1}$$

$$[20]\, r = \frac{S_{xy}}{S_x *\ S_y}$$

$$[21]\, S_{x\mathrm{x}} = \sum \mathrm{x}^2 - \frac{(\sum \mathrm{x})^2}{N}$$

$$[22\ \&\ 23]\ \mathrm{RMA}\ 95\%CI\ = \mathrm{t}_{0.05\mathrm{N}-2} \sqrt{S_\mathrm{y} \left(\frac{(1-\mathrm{r})}{N}\left(2 + \bar{x}^2 \frac{(1+\mathrm{r})}{S_\mathrm{xx}}\right)\right)^{0.5}}$$

Which of the two approaches serves as a better fit, can be determined through the checklist introduced by Smith (2009: 482), regarding indications that suggest either the better fit of OLS or RMA for regression line fitting [3] of a sample population (see. Table 7.). Question number one and three on the checklist for *Indications for RMA*, are the most important key aspects when discerning between the two:

> **1.** It seems arbitrary which variable is on the X-axis and which variable is on the Y-axis (Smith 2009: 482).
>
> **3.** The slope of the line will be used to interpret the pattern of change in ‘‘shape’’ (i.e., proportions) with change in size. The question is whether X and Y maintain an isometric relationship, or whether Y exhibits positive or negative allometry (Warton et al. 2006; Smith 2009: 482).

The importance of these two questions, compared to the other eight, is that it summarize the issue of both OLS and RMA application, i.e., either isometric (RMA: *x* can predict *y*, and when reversed, $y$ can predict $x$), or, allometric (OLS; $x$ can predict $y$, but not the reverse). For example, the value of 10 raised to $b$ equals $x$ or $y$, e.g., the $log_{10}x$ (anatomical stature) and $log_{10}y$ (femoral bicondylar height) of male individual 3136 is shown below:

$$log_{10}166.7(x_i) \approx 2.221$$

$$log_{10}45.3(y_i) \approx 1.656$$

Or inversed:

$$10^{2.221} \approx 166.7(x_i)$$

$$10^{1.656} \approx 45.3(y_i)$$

The example below illustrates the calculation of the $log_{10}\ \beta_1$ for the femoral bicondylar height of the male base sample, using randomly selected male individual 3136:

*log₁₀* F2 ($y_i$) and LST ($x_i$) values of male individual 3136

$$\begin{cases} log_{10}y_i = 1.656 \\ log_{10}x_i = 2.221 \end{cases}$$

*log₁₀* F2 ($\bar{y}$) and LST ($\bar{x}$) mean values of male base sample

$$\begin{cases} log_{10}\bar{y} = 1.654 \\ log_{10}\bar{x} = 2.221 \end{cases}$$

$$[24]\ log_{10}\ \beta_1 : \frac{\sum(2.221 - 2.221)(1.656 - 1.654)}{\sum(2.221 - 2.221)^2} \approx 1.3$$

The result shown above, and the $log_{10}\ \beta_1$ results of each element of either of the sexes as shown in Table 17. (see Fig 19. for a scatter plot diagram of the results of the above calculation of F2 $log_{10}\ \beta_1$). These results (i.e., ≥1.0) exhibits the allometric nature of the samples' long bone scaling factor in relation to the full stature achieved in adulthood, hence solving Smith's (2009: 482) question three in regards to RMA in the negative. Each element, except for the humeri, exhibits positive allometric trends, whilst the male humeri $log_{10}\ \beta_1$ value of: 0.89 suggests a negative allometric trend. The humeri $log_{10}\ \beta_1$ value was not possible to calculate for the

**Table 17.** The $log_{10}y$ (bone element) and $log_{10}B1$ results for either of the sexes. The $log_{10}x$ (anatomical stature) for the males is 2.221, whilst 2.199 for the female sample.

| | **Male** | **N:40** | **Female** | **N:29** |
|---|---|---|---|---|
| **Element:** | *log₁₀y* | *log₁₀B1* | *log₁₀y* | *log₁₀B1* |
| **F1** | 1.66 | 1.33 | 1.64 | 1.69 |
| **F2** | 1.65 | 1.31 | 1.63 | 1.67 |
| **T1** | 1.57 | 1.41 | 1.54 | 1.56 |
| **H1** | 1.52 | 0.89 | - | - |

female sample due to the low number of available humeri for recording. The conclusion which can be drawn from the results of formula [24], is that none of the long bones can be considered as isometrically aligned with the samples' full stature. These results are in accordance to Jantz and Jantz (1999: 58-65) previous findings.

### *9.3.2 Calculating Linear Regression on the Unmodified Sample Populations*

With the body ratios of the sample population, of either of the sexes, established through the anatomical method, and with the RMA formulae ruled out, in favour of the OLS formulae, the unmodified sample population's accuracy can be ascertained, to determine if further modification of the sample population, i.e., censoring through studentized residuals analysis to increase the accuracy of the regression formulae if necessary (discussed in later sections).

Below, male individual 3136 from Godalming, and the length of their F2 element is further utilized as an example with formula [12]; as indicated by the summation sign (i.e., $\sum$), this process is repeated for the whole male and female sample whilst formulating the regression formulae.

F2 ($x_i$) and LST ($y_i$) values of male individual 3136 $\begin{cases} y_i = 166.7 \\ x_i = 45.3 \end{cases}$

F2 ($\bar{x}$) and LST ($\bar{y}$) mean values of male base sample $\begin{cases} \bar{y} = 167.0 \\ \bar{x} = 45.2 \end{cases}$

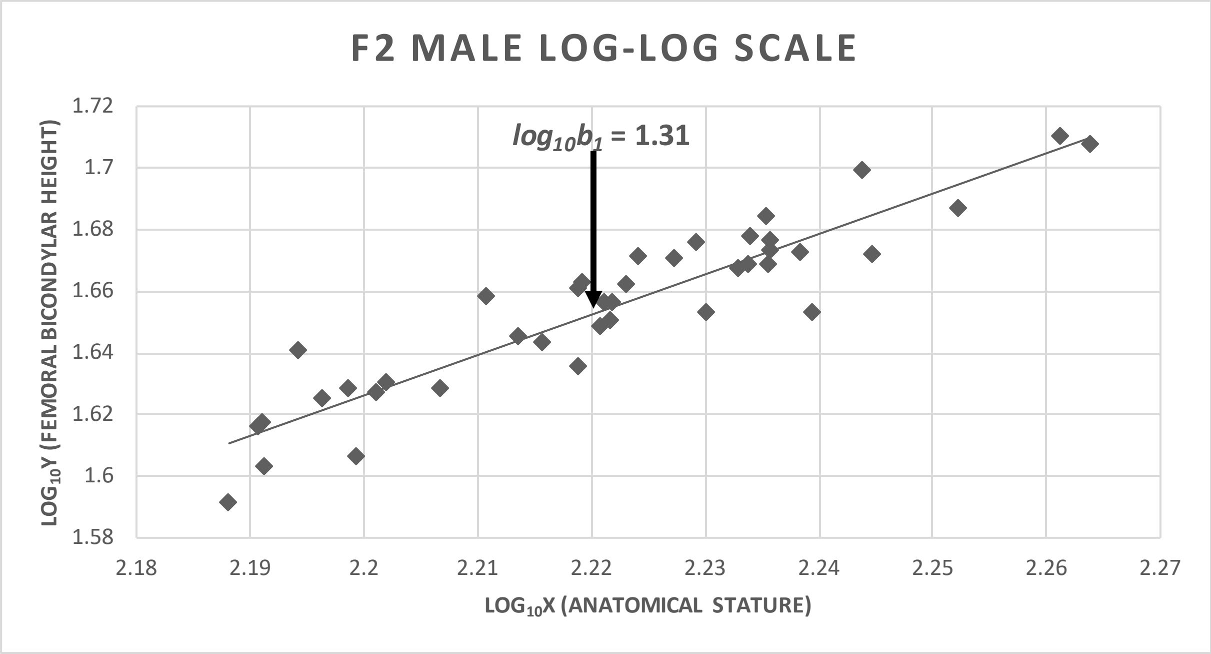

**Fig 30.** Illustrating the male F2 element's $\log_{10}$ values of both the $x$ (anatomical stature) and $y$ (F2 height) variables plotted out in a scatter plot diagram, i.e., a log-log scale diagram.

$$\beta_1\,(individual\,3136\;example);\;\frac{\sum(45.3-45.2)(166.7\;-167)}{\sum(45.3\;-45.2)^2}=2.4429$$

$$\beta_0\colon 167-2.4429*45.2=56.58092$$

Through the use of formulae [12] and [13], applied on the results achieved with the anatomical method, the two variables (i.e., $\beta_1$ and $\beta_0$) have been calculated for the unmodified sample of the femoral bicondylar height, hence a complete stature regression formula is achieved, e.g.:

$$(individual\,3136\;example)\colon 2.4429*44(x_i)+56.58092\approx 164.1(\,\hat{y}_i)$$

It should be noted, that Microsoft Excel and graph calculators can be used to simplify and increase the efficiency of OLS regression formulae calculation [12 & 13] as outlined above. With the regression formulae calculated for each bone element, the wider accuracy of each formulae is now possible to investigate through the use of the OLS RSS ($S_{yy}^2$) formula [16], where the original anatomical stature is compared to the estimated stature calculated through the regression formula (see Fig 30):

$$S_{yy}^2\,(individual\,3136\;example)\colon \frac{\sum(164.07-166.7)^2}{40}\approx 7.56$$

The $S_{yy}^2$, or RSS value, of 7.56, hence serves as the base to calculate the SEE value [20], followed by the 95%CI [23] value. With the continued example of male individual 3136 below:

**Table 18.** The combined results of the mean estimated stature, calculated on the unmodified samples of either sexes; also included are standard deviation, calculated mean RSS, 95%CI (final error range), and $r^2$ (result variability) value of said results. Note: only 28 humeri samples were used in the male calculation, whilst no female humeri formula is included here, as only nine samples were possible to record (see Table 19.), hence too few to use as a base to calculate regression formulae on (further discussed in the following chapter). See Table 13. For bone abbreviations. All measurements are in cm.

| | | **Male** | **N: 40** | | | | **Female** | **N: 29** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Formulae** | **Mean Stature** | **SD** | **Mean RSS** | 95%CI | $r^2$ | **Mean Stature** | **SD** | **Mean RSS** | 95%CI | $r^2$ |
| **F1:** | 166.7 | 2.9 | 8.1 | 5.9 | 0.85 | 158.3 | 2.5 | 3.06 | 3.71 | 0.88 |
| **F2:** | 166.7 | 3.0 | 7.6 | 5.7 | 0.86 | 158.3 | 2.54 | 3.86 | 4.16 | 0.85 |
| **T1:** | 166.7 | 2.5 | 8.9 | 6.2 | 0.84 | 158.0 | 1.99 | 5.72 | 5.15 | 0.78 |
| **F1+T1** | 166.7 | 5.3 | 7.0 | 5.4 | 0.87 | 158.3 | 4.41 | 2.88 | 3.59 | 0.88 |
| **F2+T1** | 166.7 | 5.4 | 7.2 | 5.6 | 0.87 | 158.3 | 4.41 | 3.22 | 3.80 | 0.87 |
| **H1** | 168.1 | 3.0 | 7.8 | 5.9 | 0.86 | - | - | - | - | - |
| **F1+T1+L** | 166.6 | 7.47 | 4.49 | 4.10 | 0.92 | 158.3 | 4.96 | 1.67 | 2.74 | 0.93 |
| **F2+T1+L** | 166.6 | 7.52 | 3.79 | 4.42 | 0.94 | 158.3 | 4.94 | 1.84 | 2.87 | 0.93 |

$$95\%CI\ [17\,\&\,23\ combined](individual\ 3136\ example): 2.03\ \sqrt{7.56\left(1+\frac{1}{40}+\frac{(45.3-45.2)^2}{8.16(40-1)}\right)} \approx 5.8$$

Final stature estimate for individual 3136: 164.1±5.8cm

The mean 95CI% for the wider male sample using this formula is c. ±5.72cm, which is a fairly large error range (i.e., a range of 11.44cm).

With the coefficient variable calculated with the formula (i.e., range of total variability of the regression formula) [15]:

$$[15]\ r^2 = 1 - \frac{\Sigma(y_i - \hat{y}_i)^2}{\Sigma(y_i - \bar{y})^2}$$

$$\text{Coefficient variable } (r^2) \text{ of male F2 sample (individual 3136 example)}: 1 - \frac{\Sigma(166.7 - 164.07)^2}{\Sigma(166.7 - 167)^2} \approx 0.86$$

As illustrated by the pooled mean stature and error range results (see Table 18.), the unmodified male sample population, in its unmodified state, is ill-fitted to base regression formulae for. Hence the necessitates further considerations of modification, to increase the accuracy of the formulae, by lowering the RSS and 95%CI values. Meaning, that the male sample population warrants the consideration application of further analysis and modification through censoring of outlying data points (see the following chapter).

Comparatively, the female sample population proved to be far more homogenous, hence proved a good fit for the calculation of regression formulae, for each of the different bone elements, with the tibiae (T1) being an exception (95%CI ±5.15cm; see Table 18.).

Of the 40 male individuals of the anatomical base sample, only twenty eight males had their humeri recorded, and only nine humeri were recorded for the female base sample. This can in large part be attributed to the fact that upper limbs recovery rate is less than that of the lower

**Table 19.** The number of available elements of: humeri, fibulae, ulnae and radii of the anatomical base sample (not including the wider sample used with the regression method), measured for this study by the author. "N" referring to the number of individuals with one or more elements recovered, "Pairs" referring to those individuals who had both right and left side recovered in a complete state.

| | Male | | Female | |
|---|---|---|---|---|
| **Element** | **N** | **Pairs** | **N** | **Pairs** |
| **Humeri** | 28 | 3 | 9 | 4 |
| **Fibulae** | 2 | - | - | - |
| **Ulnae** | 8 | - | 2 | 1 |
| **Radii** | 14 | 1 | 2 | - |

limbs, due to the higher concentration of cortical bones in the femur and tibia (Rattanachet 2022: 1). The low number of measured humeri for the female sample were not feasible to consider for regression formulae calculation. In regards to the male samples' humeri, 12 individuals less than the other bone elements (40 individuals) could be used for the formulae calculation. The $r^2$ value of 0.86, suggests a fairly good fitting of the regression line. Yet due to the low number of elements, less modification of the humeri sample is possible to increase the accuracy by lowering the RSS and 95%CI value (see below). The greater correlation between the lower limbs, and the full stature, compared to the upper limbs correlation, should be considered when using the humeri to calculate stature formulae (Wilson et al. 2010: 688; Rattanachet 2022: 4). The elements of fibulae, ulnae, and radii, suffered from similar poor recovery rates (see Table 19.), or even less, hence could not be considered for further analysis.

## 9.4 Final Unmodified Stature Regression Formulae

With all of the considerations regarding the sample variables, and the calculation of the stature regression formulae of either sexes addressed above (Table 18. & 19), the final unmodified stature formulae for each element, of either of the sexes, can be formulated. The $x_i$ variable in each of the formulae below is the chosen bone element used for the stature estimation, e.g., in formula [27 & 28] $x_i$ is the height of the humeri.

### 9.4.1 Male Stature Regression Formulae

Humeri maximum height (H1) [27 & 28]:

$$[27]\ \hat{y}_i = 4.2586x_i + 26.573$$

$$[28]\ 95\%\text{CI}\ (\hat{y}_i \pm [\ldots]\text{cm}) = \overset{\textit{T value}}{2.06}\sqrt{7.821\left(1.04 + \frac{(x_i - 33.3)^2}{69.6261}\right)}$$

Here, the SEE and the 95%CI, i.e., t test (student test), have been combined. To calculate only the SEE value for this element, or any of the following, the same formula(s) can be used but with the t-value removed.

Maximum femoral height (F1) [29 & 30]:

$$[29]\ \hat{y}_i = 2.3691x_i + 58.632$$

$$[30]\ 95\%\text{CI}\ (\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{8.091\left(1.025 + \frac{(x_i - 45.6)^2}{334.5334}\right)}$$

Femoral bicondylar height (F2) [31 & 32]:

$$[31]\ \hat{y}_i = 2.4429x_i + 56.267$$

$$[32]\ 95\%\text{CI }(\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{7.561\left(1.025 + \frac{(x_i - 45.2)^2}{318.1844}\right)}$$

Tibia condylo-malleolar height (T1) [33 & 34]:

$$[33]\ \hat{y}_i = 2.6738x_i + 67.435$$

$$[34]\ 95\%\text{CI }(\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{8.882\left(1.037 + \frac{(x_i - 37.1)^2}{258.202}\right)}$$

Maximum femoral height (F1), plus tibia condylo-malleolar height (T1) [35 & 36]:

$$[35]\ \hat{y}_i = 1.3178x_i + 56/874$$

$$[36]\ 95\%\text{CI }(\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{5.9802\left(1.0285 + \frac{(x_i - 83.0)^2}{219.4302}\right)}$$

Maximum bicondylar height (F2), plus tibia condylo-malleolar height (T1) [37 & 38]:

$$[37]\ \hat{y}_i = 1.3399x_i + 55.58$$

$$[38]\ 95\%\text{CI }(\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{5.0\left(1.0285 + \frac{(x_i - 82.6)^2}{1060.16964}\right)}$$

Maximum femoral height (F1), plus tibia condylo-malleolar height (T1), plus lumbar (L) [39 & 40]:

$$[40]\ \hat{y}_i = 1.2349x_i + 48.153$$

$$[41]\ 95\%\text{CI }(\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{3.7904\left(1.027 + \frac{(x_i - 95.9)^2}{1333.8731}\right)}$$

Femoral bicondylar height (F2), plus tibia condylo-malleolar height (T1), plus lumbar (L) [41 & 42]:

$$[41]\ \hat{y}_i = 1.2178x_i + 49.277$$

$$[42]\ 95\%\text{CI }(\hat{y}_i \pm [\ldots]\text{cm}) = 2.03\sqrt{4.4939\left(1.027 + \frac{(x_i - 96.3)^2}{1316.308}\right)}$$

### *9.4.2 Female Stature Regression Formulae*

Maximum femoral height (F1) [43 & 44]:

$$[43]\ \hat{y}_i = 1.9006x_i + 76.018$$

$$[44]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.05\sqrt{3.056\left(1.0345 + \frac{(x_i - 43.3)^2}{173.187}\right)}$$

Femoral bicondylar height (F2) [45 & 46]:

$$[45]\ \hat{y}_i = 1.8561x_i + 78.668$$

$$[46]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.05\sqrt{3.859\left(1.0345 + \frac{(x_i - 42.9)^2}{175.079}\right)}$$

Tibia condylo-malleolar height (T1) [47 & 48]:

$$[47]\ \hat{y}_i = 2.385x_i + 75.056$$

$$[48]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.05\sqrt{4.183\left(1.037 + \frac{(x_i - 35.0)^2}{104.583}\right)}$$

Maximum femoral height (F1), plus tibia condylo-malleolar height (T1) [49 & 50]:

$$[49]\ \hat{y}_i = 1.1267x_i + 70.017$$

$$[50]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.06\sqrt{2.248\left(1.036 + \frac{(x_i - 78.4)^2}{511.365}\right)}$$

Maximum bicondylar height (F2), plus tibia condylo-malleolar height (T1) [51 & 52]:

$$[51]\ \hat{y}_i = 1.1318x_i + 70.032$$

$$[52]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.06\sqrt{2.299\left(1.036 + \frac{(x_i - 78.0)^2}{505.757}\right)}$$

Maximum femoral height (F1), plus tibia condylo-malleolar height (T1), plus lumbar (L) [53 & 54]:

$$[53]\ \hat{y}_i = 1.0814x_i + 60.033$$

$$[54]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.06\sqrt{1.665\left(1.035 + \frac{(x_i - 90.9)^2}{589.278}\right)}$$

Femoral bicondylar height (F2), plus tibia condylo-malleolar height (T1), plus lumbar (L) [55 & 56]:

$$[55]\ \hat{y}_i = 1.081x_i + 60.46$$

$$[56]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.06\sqrt{1.835\left(1.035 + \frac{(x_i - 90.5)^2}{558.467}\right)}$$

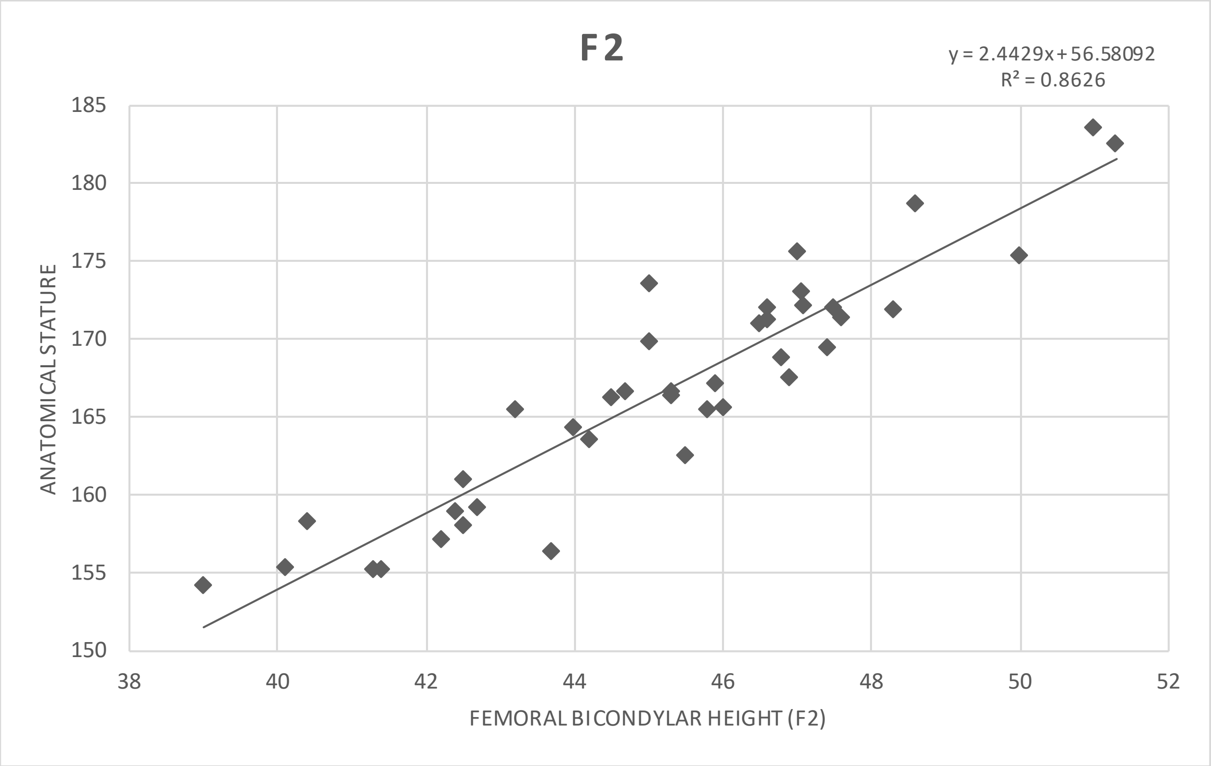

**Fig 31.** Example of scatter plot diagram, plotting out the relationship between femoral bicondylar length (F2) to the full estimated stature, based on the unmodified male anatomical sample. All measurements are in cm.

### *9.4.2 Censoring the Samples' Outliers*

If the total variance of the results of the developed stature regression formulae is large across the data points, i.e., a high 95%CI value (e.g., Ruff et al. (2012) male femoral formulae's 95%CI: ±6.35cm, further discussed in the next chapter), then it is necessary to consider corrections for biases induced in the slope of the regression lines. These biases commonly stem from the inclusion of individuals who are poor representatives of the average values of specific skeletal element within a population (Kilmer & Rodriguez 2017: 11). Biases of such nature, were especially present in the male base sample, as is evident in the limited accuracy of the unmodified male stature results. This was less apparent in the female sample, due to the greater natural tendency towards homogeneity in female populations, as previously discussed by Jantz and Jantz (1999) and Wolanski and Kasprzak (1976), with the female tibiae being an exception.

As discussed in the previous chapter, an individual can only be determined as a suitable candidate to be used as a part of the sample population, for each bone element, by first formulating regression formulae on the unmodified sample.

The results of the unmodified sample determining the variability through the analysis of studentized residuals [25 & 26].

**Table 20.** The studentized residuals [25] results of the male sample's femoral bicondylar element (F2). Greater allowance have been given to the number of decimals included here, as to illustrate the range of the fit of each individual. The four individuals marked in dark grey are the outliers of the sample.

| *Males* | | | | |
|---|---|---|---|---|
| **Site (number of individuals):** | **Individual (N: 40):** | **Age:** | $t_i$ | $S^2_{yy}$ |
| ***Stratford Upon Avon (16)*** | SK1151 | Adult | -1.445 | 3.931 |
| | SK2435 | 25-35 | -0.996 | 1.867 |
| | SK1145 | 17-20 | 3.335 | 20.936 |
| | SK2185 | Adult | -1.549 | 4.519 |
| | SK2438 | 30-35 | 1.395 | 3.666 |
| | SK3327 | 30-35 | 0.881 | 1.460 |
| | SK2378 | Older Adult | 2.742 | 14.147 |
| | SK2702 | 18-20 | -1.864 | 6.535 |
| | SK1420 | 50+ | -0.363 | 0.248 |
| | SK2025 | 20-30 | -1.577 | 4.679 |
| | SK1102 | Adult | -4.836 | 44.019 |
| | SK1568 | 45-55 | 1.956 | 7.199 |
| | SK2040 | Adult | -2.165 | 8.824 |
| | SK1772 | 50+ | 0.407 | 0.312 |
| | SK1391 | 25-30 | 5.352 | 53.912 |
| | SK1652 | 40+ | -0.5209 | 0.511 |
| ***Collingbourne Ducis (4)*** | 11 | 25-35 | 0.842 | 1.335 |
| | 27 | 40-50 | 0.862 | 1.393 |
| | 1104 | 35-45 | -0.183 | 0.0632 |
| | 1293 | 45+ | -3.588 | 24.225 |
| ***Godalming (4)*** | 3136 | 20-30 | 0.651 | 0.798 |
| | 3033 | 50+ | -1.915 | 6.904 |
| | 1023 | 50+ | 2.704 | 13.764 |
| | 1049 | 50+ | 1.387 | 3.621 |
| ***Droxford (2)*** | Grave 19 | 20-25 | -0.884 | 1.471 |
| | Grave 33 | 40-45 | 0.947 | 1.688 |
| ***Mount Pleasant (2)*** | Grave 32 | 18 | -0.682 | 0.877 |
| | Grave 7 | 24-27 | 0.814 | 1.248 |
| ***Portway West Andover (1)*** | Area III Grave F1 | Adult | 2.421 | 11.032 |
| ***Droxford (1)*** | Grave 39 | Older Adult | -0.154 | 0.045 |
| ***Apple Down (10)*** | GRAVE 1 | 20-30 | -1.701 | 5.445 |
| | GRAVE 12B | 25-35 | 0.679 | 0.869 |
| | GRAVE 19 | 33-45 | -1.508 | 4.279 |
| | GRAVE 28 | 50+ | -0.855 | 1.375 |
| | GRAVE 31 | 45+ | 1.998 | 7.515 |
| | GRAVE 46 | 25-35 | -1.309 | 3.229 |
| | GRAVE 54 | 18-19 | -2.371 | 10.576 |
| | GRAVE 71 | 45+ | 2.723 | 13.950 |
| | GRAVE 145 | 17-25 | 0.583 | 0.639 |
| | GRAVE 152 | 17-25 | -2.227 | 9.338 |
| **Mean:** | | **35.1** | -0.0004 | **7.561** |

**Table 21.** The combined results of the mean estimated stature, calculated on the now modified samples of either sexes; also included are standard deviation (SD), calculated mean RSS, 95%CI (final error range), and $r^2$ (result variability) value of said results. See Table 13. For bone abbreviations. All measurements are in cm.

| | **Male** | | | | | **Female** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Formulae** | **Mean Stature** | **SD** | **Mean RSS** | 95%CI | $r^2$ | **Mean Stature** | **SD** | **Mean RSS** | 95%CI | $r^2$ |
| **F1:** | 166.9 | 3.0 | 5.9 | 5.1 | 0.88 | 158.6 | 2.6 | 2.0 | 3.0 | 0.98 |
| **F2:** | 166.7 | 3.0 | 4.4 | 4.4 | 0.92 | 158.3 | 2.5 | 3.0 | 3.7 | 0.88 |
| **T1:** | 165.8 | 2.6 | 5.1 | 4.7 | 0.89 | 158.2 | 1.9 | 3.7 | 4.1 | 0.85 |
| **F1+T1** | 169.1 | 5.8 | 3.1 | 3.6 | 0.96 | - | - | - | - | - |
| **F2+T1** | 168,9 | 5.9 | 3.9 | 4.1 | 0.94 | - | - | - | - | - |

$$[25] t_i = t_{0.05N-2} * \frac{e_i}{S_e}$$

$$[26]\, e_i = y_i - \hat{y}_i$$

This process will elucidate those individuals whose body ratios far lay outside the normative variation (see Table 20..)., hence skewing the regression line, producing less reliable constant coefficients.

Whence the samples have been modified, each can be compared to the unmodified samples, to determine if the unmodified samples achieved an great enough reduction of the RSS value, which in turn will achieve lower SEE and 95%CI values, hence justifying the reduction in sample size through censoring. This greater accuracy is achieved through a decreased variability and better stature trend representation of the base sample. Using formulae [25 & 26], for each bone element, for each of the sexes, the outliers (see Table 21.) were identified and removed.

Putting studentized residuals into practice, an example from this study's anatomical sample, using the male femoral bicondylar length (F2) sample, through formulae [25 & 26], the first outlying male individual: SK1145, of the Stratford Upon Avon sample:

$$[26]\, e_i\colon 175.7 - 171.1 = 4.576$$

$$[25] t_i\colon 2{,}03 * \frac{4{,}576}{2{,}785} \approx 3.335$$

As seen in the result of formula [25] above, this individual's $t_i$ value exceeds the recommended cut off point (≥3) for outliers when using studentized residuals. As seen in Table 20., the male F2 sample had four outliers, and furthermore, as seen in the Table 20., these outlier $t_i$ values tended to match the individuals who exhibited high RSS values.

This process was repeated for the F1, F2 and T1 elements, of either of the sexes. It was only necessary perform the identification of outliers and modification of the F1+T1, F2+T1 for the male sample, as the unmodified female sample already produced reliable results using the combined elements, as seen in Table 18. The male humerus sample proved too small for modification, hence any reduction in the sample size of the sample detrimental for the accuracy.

## 9.5 Final Modified Stature Regression Formulae

Similar to the previously discussed considerations regarding the unmodified sample variables, the calculation of the stature regression formulae of either sexes, based on the unmodified samples addressed above (Table 18.), the final modified stature formulae for each element, of either of the sexes, can be calculated, as seen below. Again, similar to previous unmodified formulae section, the $x_i$ variable represent the chosen bone element used for the stature estimation.

### 9.5.1 Male Stature Regression Formulae

Maximum femoral height (F1) [57 & 58]:

$$[57]\ \hat{y}_i = 2.2355x_i + 59.871$$

$$[58]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.03\sqrt{5.994\left(1.027 + \frac{(x_i - 45.7)^2}{328.4}\right)}$$

Femoral bicondylar height (F2) [59 & 60]:

$$[59]\ \hat{y}_i = 2.3941x_i + 58.461$$

$$[60]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.03\sqrt{4.406\left(1.025 + \frac{(x_i - 45.2)^2}{312.6}\right)}$$

Tibia condylo-malleolar height (T1) [61 & 62]:

$$[61]\ \hat{y}_i = 2.5809x_i + 70.91$$

$$[62]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.03\sqrt{5.094\left(1.027 + \frac{(x_i - 37.0)^2}{240.2}\right)}$$

Maximum femoral height (F1), plus tibia condylo-malleolar height (T1) [63 & 64]:

$$[63]\ \hat{y}_i = 1.4055 + 50.777$$

$$[64]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.03\sqrt{3.873\left(1.025 + \frac{(x_i - 84.1)^2}{1274}\right)}$$

Maximum bicondylar height (F2), plus tibia condylo-malleolar height (T1) [65 & 66]:

$$[65]\ \hat{y}_i = 1.4359x_i + 49.03$$

$$[66]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.03\sqrt{3.018\left(1.027 + \frac{(x_i - 83.6)^2}{1167}\right)}$$

### *9.5.2 Female Stature Regression Formulae*

Maximum femoral height (F1) [67 & 68]:

$$[67]\ \hat{y}_i = 1.9224x_i + 74.949$$

$$[68]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.05\sqrt{1.973\left(1.0384 + \frac{(x_i - 43.5)^2}{259.1}\right)}$$

Femoral bicondylar height (F2) [69 & 70]:

$$[69]\ \hat{y}_i = 1.9286x_i + 75.368$$

$$[70]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.06\sqrt{3.017\left(1.0357 + \frac{(x_i - 43.0)^2}{246.9}\right)}$$

Tibia condylo-malleolar height (T1) [71 & 72]:

$$[71]\ \hat{y}_i = 2.3458x_i + 76.289$$

$$[72]\ 95\%\mathrm{CI}\ (\hat{y}_i \pm [\ldots]\mathrm{cm}) = 2.06\sqrt{3.749\left(1.0384 + \frac{(x_i - 34.9)^2}{89.6}\right)}$$

### *9.5.3 Chapter Summary and Final Results: Applying the Modified Regression Formulae on the Wider Sample*

With each bone elements' regression formula calculated, along with the 95%CI, the stature of the wider sample of 512 individuals (185 females and 327 males, see Table 18, 19 & 22.) can now be estimated, using the modified formulae when possible (formula: [57] through [72]), and supplementing with unmodified formulae (formula: [56] through [56]), in those instances when it was deemed not necessary (e.g., F1+T1, F2+T1 in regards to the female sample, or F1+T1+L, F2+T1+L for either sex), or possible (H1), to censor the sample. As seen in Table 7. and 8., each bone element is not spread equally in number across each site and sexes, e.g., the number of male individuals estimated with the maximum femoral height formula (N:265) [27 & 28],

**Table 22.** Summary of the stature results achieved with each formulae, for either of the sexes (see Table 23. through 28. for a more detailed breakdown), when applied to the wider sample of the less complete individuals. The mean stature when pooling the stature results together is included in the bottom row. The total number on the final row (Inv) is the final number of individuals, rather than the number of elements. All measurements are in cm.

| | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| **Formulae** | **N:** | **Mean Stature** | **SD** | **95%CI** | **N:** | **Mean Stature** | **SD** | **95%CI** |
| **F1:** | 271 | 168.0 | 5.6 | 5.1 | 153 | 158.5 | 5.8 | 3.0 |
| **F2:** | 153 | 167.6 | 5.5 | 4.4 | 91 | 160.1 | 5.1 | 3.7 |
| **T1:** | 204 | 166.7 | 7.9 | 4.7 | 113 | 159.6 | 6.0 | 4.1 |
| **F1+T1:** | 164 | 170.2 | 7.1 | 4.3 | 86 | 158.8 | 5.6 | 3.6 |
| **F2+T1:** | 112 | 168.9 | 6.5 | 4.1 | 61 | 159.2 | 5.3 | 3.8 |
| **H1:** | 118 | 167.0 | 6.9 | 5.7 | - | - | - | - |
| **Total/Mean** | 327(Inv) | 168.1 | - | - | 185(Inv) | 159.2 | - | - |

and those estimated with humeri maximum height formula (N:118) [25 & 26] (see Table 23. – 25 . (males); Table 26. – 28. (females)). This section's resulting formulae can be summarized as:

- The lower limb bones (in the case of the males), is preferable to use, due to their greater corelation with the full stature achieved in adulthood. Previous studies have reached similar conclusions regarding the lower limb bones better predictor factor (Vercellottie 2009; Sládek et al. 2015; Albanese 2016; Ruff 2018; Koukli et al. 2023).
- The femoral formulae performed better, for both sexes, than the formulae calculated for the tibiae (T1). The femoral bicondylar height (F2), due to its greater contributing factor towards stature (the anatomically correct position of the bone when following the sagittal line), proved superior to the formulae developed using the femoral maximum height (F1).
- Multivariate formulae, i.e., equations using two or more bones (e.g., F1+T1), provide incrementally greater accuracy, hence when possible, should be considered as the preferrable choice.

When pooling the estimated stature results achieved with the different formulae, the average stature for the male sample of 327 individuals is: 168.1cm, and 159.2cm for the female sample of 185 individuals (Table 22. for the results achieved on an element by element basis; for a sites by sites basis see Table 23. through 28; with illustrative boxplots in Fig 34 through 37.). These results presented here will be further addressed in the following chapter, and discussed in relation to the previous evidence presented in earlier chapters.

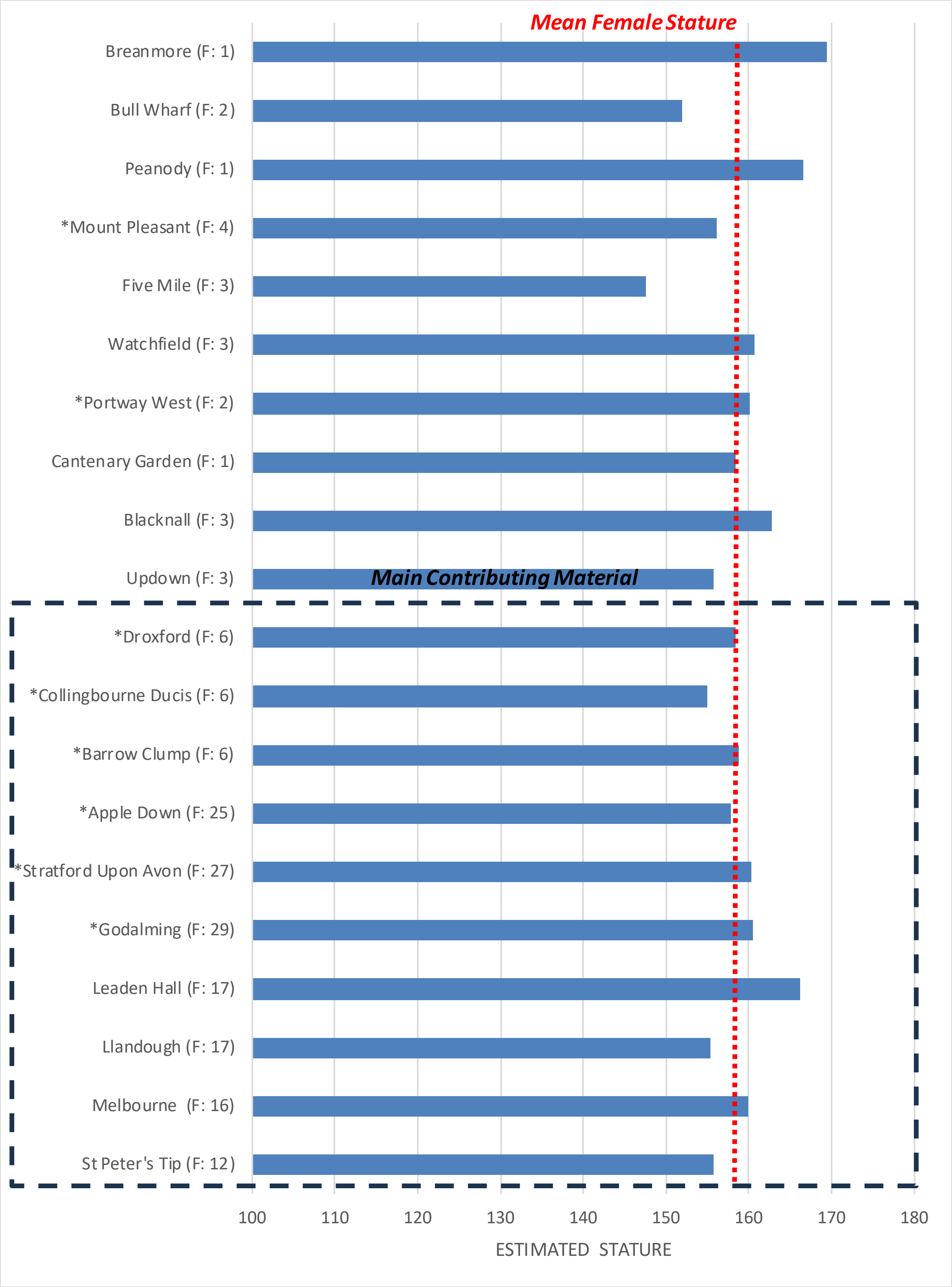

**Fig 32.** The pooled mean female stature, i.e., the mean estimated stature of each formulae pooled (F = number of females), site names with "*" contributed towards the anatomical base sample. All measurements are in cm.

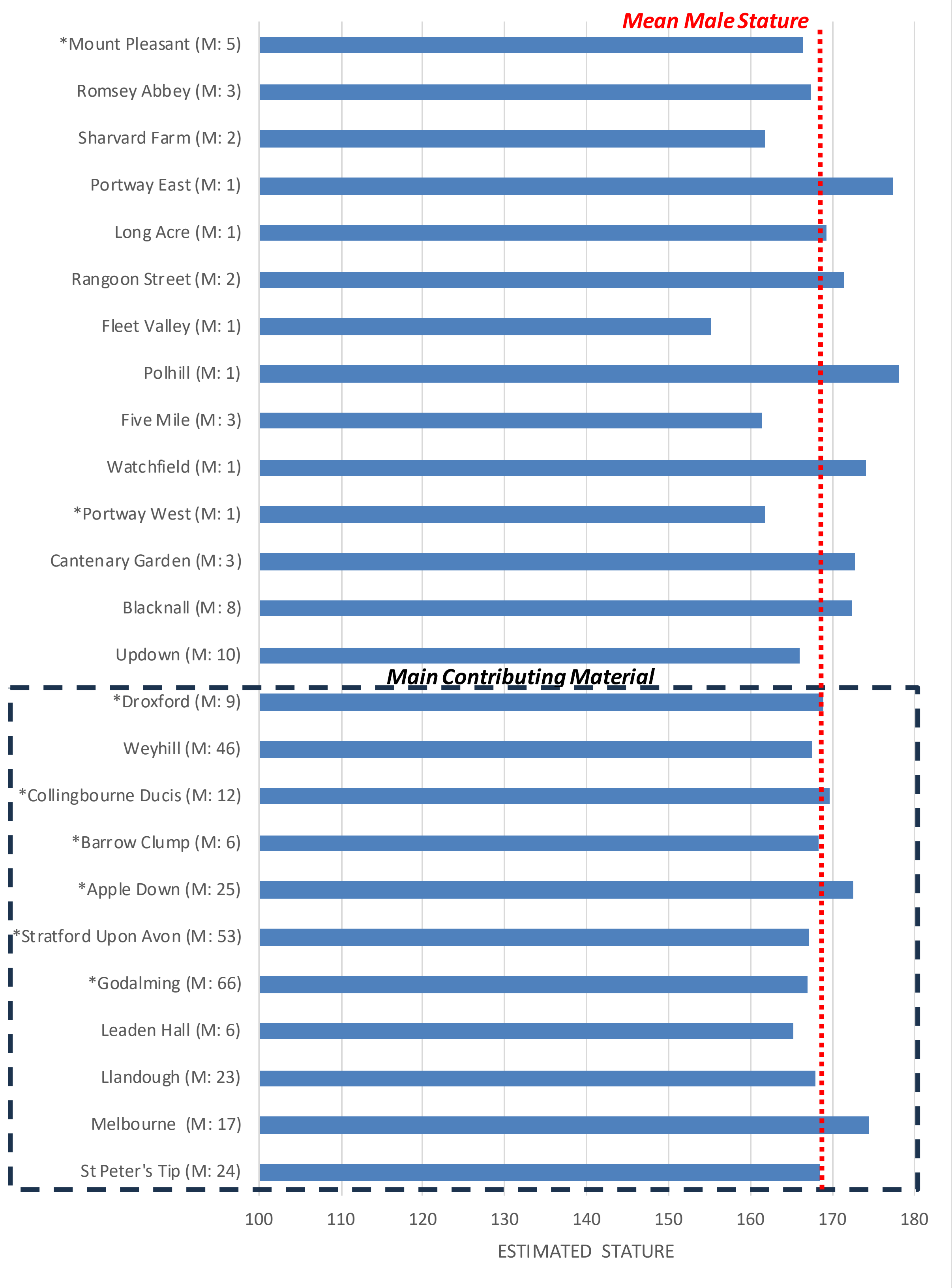

**Fig 33.** The pooled mean male stature, i.e., the mean estimated stature of each formulae pooled (M = number of males), site names with "*" contributed towards the anatomical base sample. All measurements are in cm.

**Table 23.** Male stature estimation results utilizing the F1 (N: 265) and F2 (N:147) height, achieved formulae presented in pervious chapter. All measurements are in cm.

| | MALE F1 | | | | MALE F2 | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE:** | **N** | **LST** | **SEE** | **95%CI** | **N** | **LST** | **SEE** | **95%CI** |
| **ST PETER'S TIP** | 24 | 168.6 | 2.3 | 4.7 | - | - | - | - |
| **POLHILL** | 1 | 178.1 | 2.4 | 4.9 | - | - | - | - |
| **MELBOURNE** | 16 | 174.5 | 2.4 | 4.8 | - | - | - | - |
| **UPDOWN** | 5 | 167.0 | 2.3 | 4.7 | - | - | - | - |
| **FLEET VALLEY** | - | - | - | - | - | - | - | - |
| **RANGOON STREET** | 1 | 170.3 | 2.3 | 4.7 | 2 | 170. | 2.1 | 4.2 |
| **LONG ACRE** | - | - | - | - | - | - | - | - |
| **HOLY TRINITY** | 1 | 158.7 | 2.3 | 4.7 | - | - | - | - |
| **LEADEN HALL** | 1 | 169.6 | 2.3 | 4.7 | 2 | 166.8 | 2.1 | 4.2 |
| **CANTENARY GARDEN** | 1 | 167.7 | 2.3 | 4.7 | - | - | - | - |
| **STRATFORD UPON AVON** | 44 | 167.6 | 2.3 | 4.7 | 40 | 166.4 | 2.1 | 4.2 |
| **APPLE DOWN** | 24 | 171.7 | 2.4 | 4.8 | 24 | 171.4 | 2.1 | 4.2 |
| **BARROW CLUMP** | 6 | 167.8 | 2.3 | 4.7 | 6 | 168.1 | 2.1 | 4.2 |
| **COLLINGBOURNE DUCIS** | 11 | 168.2 | 2.3 | 4.7 | 10 | 169.1 | 2.1 | 4.2 |
| **MOUNT PLEASANT** | 3 | 166.4 | 2.3 | 4.7 | 4 | 165.9 | 2.1 | 4.2 |
| **DROXFORD** | 9 | 168.8 | 2.3 | 4.7 | 9 | 168.6 | 2.1 | 4.2 |
| **PORTWAY WEST** | 1 | 160.5 | 2.3 | 4.7 | 1 | 160.7 | 2.1 | 4.2 |
| **BLACKNALL** | 8 | 168.4 | 2.3 | 4.7 | 8 | 168.4 | 2.1 | 4.2 |
| **GODALMING** | 56 | 170.3 | 2.3 | 4.8 | 4 | 165.9 | 2.1 | 4.2 |
| **LLANDOUGH** | 7 | 168.9 | 2.3 | 4.7 | 9 | 168.1 | 2.1 | 4.2 |
| **WATCHFIELD** | - | - | - | - | - | - | - | - |
| **PORTWAY EAST** | 1 | 177.5 | 2.4 | 4.9 | 1 | 177.2 | 2.1 | 4.3 |
| **SHARVARD FARM** | 1 | 162.4 | 2.3 | 4.7 | 1 | 161.8 | 2.1 | 4.2 |
| **ROMSEY ABBEY** | 2 | 162.2 | 2.3 | 4.7 | 2 | 166.3 | 2.1 | 4.2 |
| **FIVE MILE** | 2 | 161.7 | 2.3 | 4.7 | - | - | - | - |
| **WEYHILL** | 40 | 167.3 | 2.3 | 4.7 | 24 | 167.8 | 2.1 | 4.2 |
| | | **168.01** | **2.3** | **4.7** | | **167.6** | **2.1** | **4.2** |

**Table 24.** Male stature estimation results, utilizing the T1 (N: 204) and H1 (N: 118) height, achieved formulae presented in pervious chapter. All measurements are in cm.

| | MALE T1 | | | | MALE H1 | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE:** | **N** | **LST** | **SEE** | **95%CI** | **N** | **LST** | **SEE** | **95%CI** |
| **ST PETER'S TIP** | 3 | 166.8 | 2.3 | 4.6 | - | - | - | - |
| **POLHILL** | - | - | - | - | - | - | - | - |
| **MELBOURNE** | 16 | 172.9 | 2.3 | 4.7 | - | - | - | - |
| **UPDOWN** | 3 | 165.5 | 2.3 | 4.6 | - | - | - | - |
| **FLEET VALLEY** | 1 | 155.2 | 2.4 | 4.8 | - | - | - | - |
| **RANGOON STREET** | 1 | 171.3 | 2.3 | 4.6 | - | - | - | - |
| **LONG ACRE** | 1 | 169.3 | 2.3 | 4.6 | - | - | - | - |
| **HOLY TRINITY** | 2 | 161.8 | 2.3 | 4.6 | - | - | - | - |
| **LEADEN HALL** | 2 | 171.3 | 2.3 | 4.6 | 1 | 175.5 | 2.8 | 5.7 |
| **CANTENARY GARDEN** | 2 | 177.6 | 2.3 | 4.8 | - | - | - | - |
| **STRATFORD UPON AVON** | 45 | 165.5 | 2.3 | 4.6 | 20 | 168.3 | 2.8 | 5.7 |
| **APPLE DOWN** | 21 | 171.3 | 2.3 | 4.6 | 17 | 172.3 | 2.8 | 5.7 |
| **BARROW CLUMP** | 5 | 166.3 | 2.3 | 4.6 | 1 | 172.0 | 2.7 | 5.6 |
| **COLLINGBOURNE DUCIS** | 9 | 170.0 | 2.3 | 4.6 | 8 | 170.8 | 2.8 | 5.7 |
| **MOUNT PLEASANT** | 5 | 165.7 | 2.3 | 4.6 | - | - | - | - |
| **DROXFORD** | 8 | 166.5 | 2.3 | 4.6 | 4 | 172.8 | 2.7 | 5.6 |
| **PORTWAY WEST** | 1 | 159.9 | 2.3 | 4.6 | 1 | 162.1 | 2.8 | 5.7 |
| **BLACKNALL** | - | - | - | - | - | - | - | - |
| **GODALMING** | 27 | 165.2 | 2.3 | 4.6 | 27 | 168.4 | 2.7 | 5.6 |
| **LLANDOUGH** | 19 | 163.7 | 2.3 | 4.6 | 10 | 169.1 | 2.8 | 5.8 |
| **WATCHFIELD** | 1 | 169.3 | 2.3 | 4.6 | 1 | 178.8 | 2.8 | 5.8 |
| **PORTWAY EAST** | - | - | - | - | | - | - | - |
| **SHARVARD FARM** | 1 | 158.0 | 2.3 | 4.7 | 1 | 169.0 | 2.7 | 5.6 |
| **ROMSEY ABBEY** | - | - | - | - | 1 | 173.6 | 2.7 | 5.6 |
| **FIVE MILE** | - | - | - | - | 1 | 160.9 | 2.8 | 5.7 |
| **WEYHILL** | 31 | 167.2 | 2.3 | 4.6 | 25 | 166.1 | 2.8 | 5.7 |
| | | **166.7** | **2.3** | **4.6** | | **169.9** | **2.8** | **5.7** |

**Table 25.** Male stature estimation results, utilizing the F1+T1 (158) and F2+T1 (106) height, achieved formulae presented in pervious chapter. All measurements are in cm.

| | **MALE F1+T1** | | | | **MALE F2+T1** | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE:** | **N** | **LST** | **SEE** | **95%CI** | **N** | **LST** | **SEE** | **95%CI** |
| **ST PETER'S TIP** | 3 | 170.3 | 2.1 | 4.3 | - | - | - | - |
| **POLHILL** | - | - | - | - | - | - | - | - |
| **MELBOURNE** | 15 | 176.0 | 2.2 | 4.4 | - | - | - | - |
| **UPDOWN** | 2 | 165.7 | 2.1 | 4.3 | - | - | - | - |
| **FLEET VALLEY** | - | - | - | - | - | - | - | - |
| **RANGOON STREET** | 1 | 172.3 | 2.1 | 4.3 | 1 | 172.8 | 2.0 | 4.1 |
| **LONG ACRE** | - | - | - | - | - | - | - | - |
| **HOLY TRINITY** | 1 | 157.0 | 2.2 | 4.4 | - | - | - | - |
| **LEADEN HALL** | 1 | 174.0 | 2.1 | 4.3 | 2 | 170.4 | 2.0 | 4.1 |
| **CANTENARY GARDEN** | - | - | - | - | - | - | - | - |
| **STRATFORD UPON AVON** | 37 | 167.5 | 2.1 | 4.3 | 34 | 167.1 | 2.0 | 4.1 |
| **APPLE DOWN** | 21 | 173.9 | 2.1 | 4.3 | 21 | 174.0 | 2.0 | 4.1 |
| **BARROW CLUMP** | 5 | 167.6 | 2.1 | 4.3 | 5 | 167.9 | 2.0 | 4.1 |
| **COLLINGBOURNE DUCIS** | 8 | 169.5 | 2.1 | 4.3 | 7 | 169.7 | 2.0 | 4.1 |
| **MOUNT PLEASANT** | 3 | 167.1 | 2.1 | 4.3 | 4 | 166.6 | 2.0 | 4.1 |
| **DROXFORD** | 8 | 168.3 | 2.1 | 4.3 | 8 | 168.4 | 2.0 | 4.1 |
| **PORTWAY WEST** | 1 | 167.4 | 2.1 | 4.3 | 1 | 159.7 | 2.1 | 4.2 |
| **BLACKNALL** | 8 | 180 | 2.2 | 4.4 | - | - | - | - |
| **GODALMING** | 27 | 168.6 | 2.1 | 4.3 | 4 | 163.5 | 2.0 | 4.1 |
| **LLANDOUGH** | 5 | 169.2 | 2.1 | 4.3 | 7 | 168.1 | 2.0 | 4.1 |
| **WATCHFIELD** | - | - | - | - | - | - | - | - |
| **PORTWAY EAST** | - | - | - | - | - | - | - | - |
| **SHARVARD FARM** | 1 | 159.6 | 2.1 | 4.4 | 1 | 159.3 | 2.1 | 4.2 |
| **ROMSEY ABBEY** | - | - | - | - | - | - | - | - |
| **FIVE MILE** | - | - | - | - | - | - | - | - |
| **WEYHILL** | 25 | 168.3 | 2.1 | 4.3 | 17 | 168.8 | 2.0 | 4.1 |
| | | **170.2** | **2.1** | **4.3** | | **168.9** | **2.0** | **4.1** |

**Table 26.** Female stature estimation results, utilizing the F1 (N: 153) and F2 (N: 91) height, achieved formulae presented in pervious chapter. All measurements are in cm.

| | FEMALE F1 | | | | FEMALE F2 | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE:** | N | LST | SEE | 95%CI | N | LST | SEE | 95%CI |
| **ST PETER'S TIP** | 12 | 158.0 | 1.8 | 3.7 | - | - | - | - |
| **MELBOURNE** | 9 | 160.0 | 1.8 | 3.7 | - | - | - | - |
| **UPDOWN** | 3 | 153.9 | 1.8 | 3.7 | - | - | - | - |
| **PEABODY** | 1 | 165.5 | 1.8 | 3.8 | 1 | 166.1 | 1.6 | 3.3 |
| **BULL WHARF** | 2 | 149.8 | 1.9 | 3.9 | 1 | 153.1 | 1.6 | 3.3 |
| **HOLY TRINITY** | 1 | 169.9 | 2.0 | 4.0 | 1 | 169.8 | 1.7 | 3.5 |
| **LEADEN HALL** | 12 | 161.7 | 1.8 | 3.8 | 9 | 162.4 | 1.6 | 3.2 |
| **CANTENARY GARDEN** | 1 | 158.3 | 1.8 | 3.7 | - | - | - | - |
| **STRATFORD UPON AVON** | 24 | 159.4 | 1.8 | 3.8 | 21 | 160.6 | 1.6 | 3.3 |
| **APPLE DOWN** | 23 | 157.4 | 1.8 | 3.7 | 22 | 157.3 | 1.6 | 3.2 |
| **BARROW CLUMP** | 6 | 157.7 | 1.8 | 3.8 | 6 | 157.8 | 1.6 | 3.3 |
| **COLLINGBOURNE DUCIS** | 5 | 154.0 | 1.8 | 3.8 | 5 | 153.5 | 1.6 | 3.3 |
| **MOUNT PLEASANT** | 4 | 160.0 | 1.8 | 3.7 | 3 | 157.1 | 1.6 | 3.2 |
| **DROXFORD** | 4 | 158.6 | 1.8 | 3.7 | 4 | 158.1 | 1.6 | 3.2 |
| **PORTWAY WEST** | 2 | 160.5 | 1.8 | 3.7 | 2 | 160.0 | 1.6 | 3.3 |
| **BLACKNALL** | 3 | 155.5 | 1.8 | 3.7 | 3 | 157.0 | 1.6 | 3.2 |
| **GODALMING** | 29 | 161.9 | 1.8 | 3.7 | 3 | 159.9 | 1.6 | 3.2 |
| **LLANDOUGH** | 6 | 157.0 | 1.8 | 3.8 | 6 | 158.4 | 1.6 | 3.3 |
| **WATCHFIELD** | 2 | 160.1 | 1.8 | 3.7 | 2 | 162.7 | 1.6 | 3.2 |
| **BREANMORE** | 1 | 170.0 | 2.0 | 4.0 | 1 | 168.8 | 1.7 | 3.4 |
| **FIVE MILE** | 2 | 143.4 | 2.1 | 4.3 | - | - | - | - |
| | | **158.5** | **1.8** | **3.8** | | **160.2** | **1.6** | **3.3** |

**Table 27.** Female stature estimation results, utilizing the T1 (N: 113) and F+T1 (N: 86) height, achieved formulae presented in pervious chapter. All measurements are in cm.

| | FEMALE T1 | | | | FEMALE F1+T1 | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE:** | N | LST | SEE | 95%CI | N | LST | SEE | 95%CI |
| **ST PETER'S TIP** | 2 | 155.1 | 2.0 | 4.1 | 2 | 154.2 | 1.5 | 3.1 |
| **MELBOURNE** | 5 | 158.7 | 2.0 | 4.1 | 6 | 160.8 | 1.5 | 3.1 |
| **UPDOWN** | 2 | 157.5 | 2.0 | 4.1 | 2 | 156.0 | 1.5 | 3.0 |
| **PEABODY** | 1 | 167.2 | 2.1 | 4.3 | 1 | 166.7 | 1.6 | 3.2 |
| **BULL WHARF** | 2 | 149.6 | 2.1 | 4.4 | 2 | 154.9 | 1.5 | 3.2 |
| **HOLY TRINITY** | 1 | 168.8 | 2.1 | 4.4 | 1 | 169.9 | 1.5 | 3.1 |
| **LEADEN HALL** | 5 | 160.2 | 2.1 | 4.1 | 3 | 163.0 | 1.5 | 3.1 |
| **CANTENARY GARDEN** | - | - | - | - | - | - | - | - |
| **STRATFORD UPON AVON** | 19 | 161.1 | 2.0 | 4.2 | 16 | 160.2 | 1.5 | 3.1 |
| **APPLE DOWN** | 21 | 158.6 | 2.0 | 4.1 | 19 | 157.8 | 1.5 | 3.1 |
| **BARROW CLUMP** | 3 | 159.0 | 2.0 | 4.2 | 3 | 159.5 | 1.5 | 3.1 |
| **COLLINGBOURNE DUCIS** | 4 | 157.1 | 2.0 | 4.1 | 3 | 155.2 | 1.5 | 3.1 |
| **MOUNT PLEASANT** | 4 | 155.4 | 2.0 | 4.1 | 4 | 155.4 | 1.5 | 3.1 |
| **DROXFORD** | 5 | 158.4 | 2.0 | 4.1 | 3 | 158.7 | 1.5 | 3.1 |
| **PORTWAY WEST** | 2 | 160.2 | 2.0 | 4.1 | 2 | 160.3 | 1.5 | 3.1 |
| **BLACKNALL** | 3 | 176.0 | 2.4 | 5.0 | - | - | - | - |
| **GODALMING** | 17 | 160.1 | 2.0 | 4.1 | 16 | 161.0 | 1.5 | 3.1 |
| **LLANDOUGH** | 12 | 155.9 | 2.0 | 4.1 | 1 | 147.8 | 1.5 | 3.1 |
| **WATCHFIELD** | 2 | 158.8 | 2.0 | 4.1 | 1 | 162.3 | 1.5 | 3.0 |
| **BREANMORE** | - | - | - | - | - | - | - | - |
| **FIVE MILE** | 1 | 154.0 | 2.0 | 4.1 | 1 | 145.5 | 1.5 | 3.1 |
| | | **159.6** | **2.0** | **4.2** | | **158.8** | **1.5** | **3.1** |

**Table 28.** Female stature estimation results, utilizing the F2+T1 (N: 61) height, achieved formulae presented in pervious chapter. All measurements are in cm.

**FEMALE F2+T1**

| SITE: | N | LST | SEE | 95%CI |
|---|---|---|---|---|
| **ST PETER'S TIP** | - | - | - | - |
| **MELBOURNE** | - | - | - | - |
| **UPDOWN** | - | - | - | - |
| **PEABODY** | 1 | 167.0 | 1.5 | 3.2 |
| **BULL WHARF** | 1 | 152.7 | 1.5 | 3.1 |
| **HOLY TRINITY** | 1 | 170.0 | 1.6 | 3.3 |
| **LEADEN HALL** | 5 | 166.2 | 1.6 | 3.2 |
| **CANTENARY GARDEN** | - | - | - | - |
| **STRATFORD UPON AVON** | 15 | 159.9 | 1.5 | 3.1 |
| **APPLE DOWN** | 18 | 157.7 | 1.5 | 3.0 |
| **BARROW CLUMP** | 3 | 159.8 | 1.5 | 3.1 |
| **COLLINGBOURNE DUCIS** | 3 | 154.8 | 1.5 | 3.1 |
| **MOUNT PLEASANT** | 3 | 156.9 | 1.5 | 3.0 |
| **DROXFORD** | 3 | 158.5 | 1.5 | 3.0 |
| **PORTWAY WEST** | 2 | 160.1 | 1.5 | 3.1 |
| **BLACKNALL** | - | - | - | - |
| **GODALMING** | 3 | 159.2 | 1.5 | 3.0 |
| **LLANDOUGH** | 3 | 157.3 | 1.5 | 3.0 |
| **WATCHFIELD** | 1 | 159 | 1.5 | 3.1 |
| **BREANMORE** | - | - | - | - |
| **FIVE MILE** | - | - | - | - |
|  |  | **159.2** | **1.5** | **3.1** |

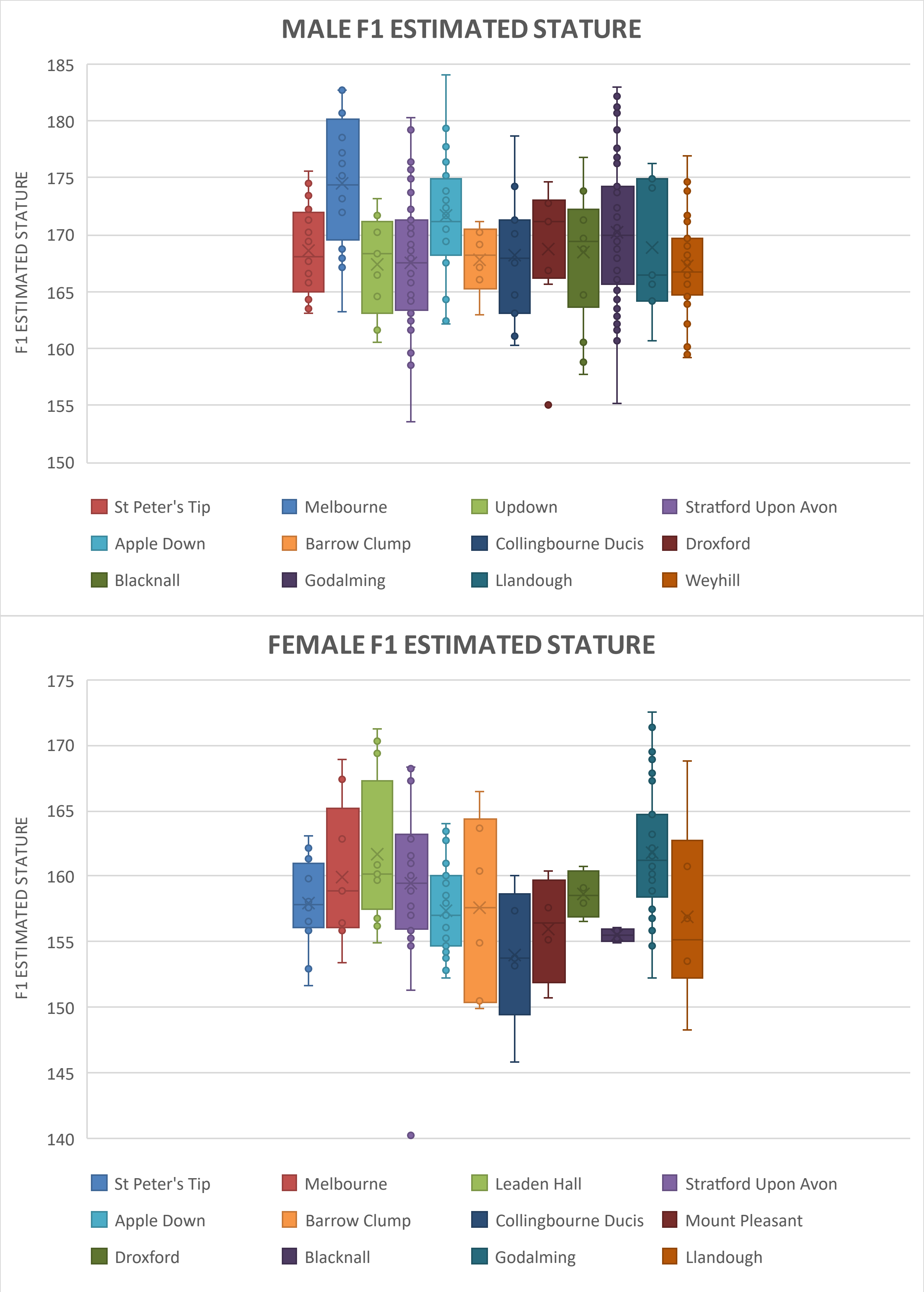

**Fig 34.** Box plot chart illustrating the range of stature estimates achieved with the F1 formulae between the different sites.

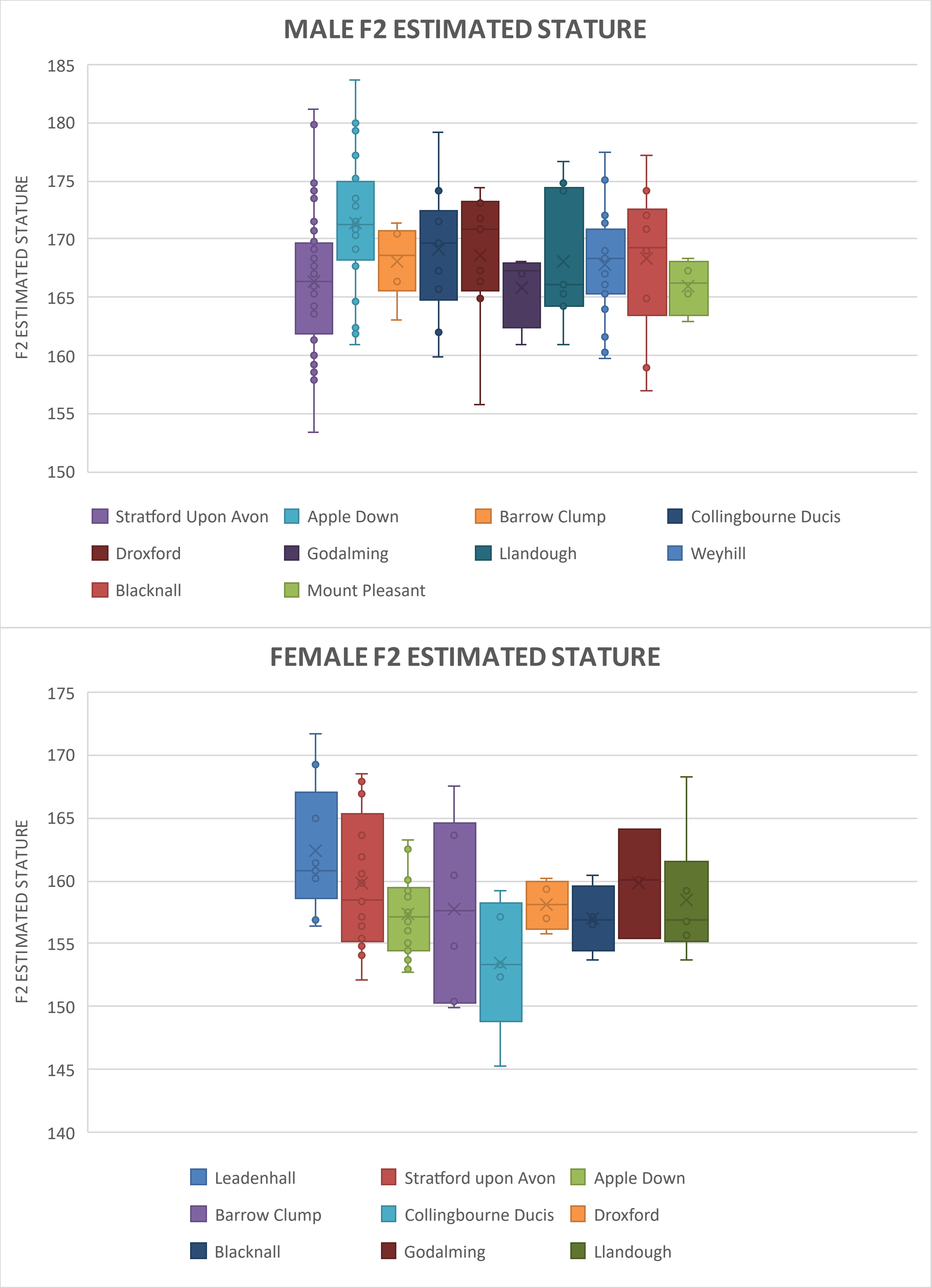

**Fig 35.** Box plot chart illustrating the range of stature estimates achieved with the F2 formulae between the different sites.

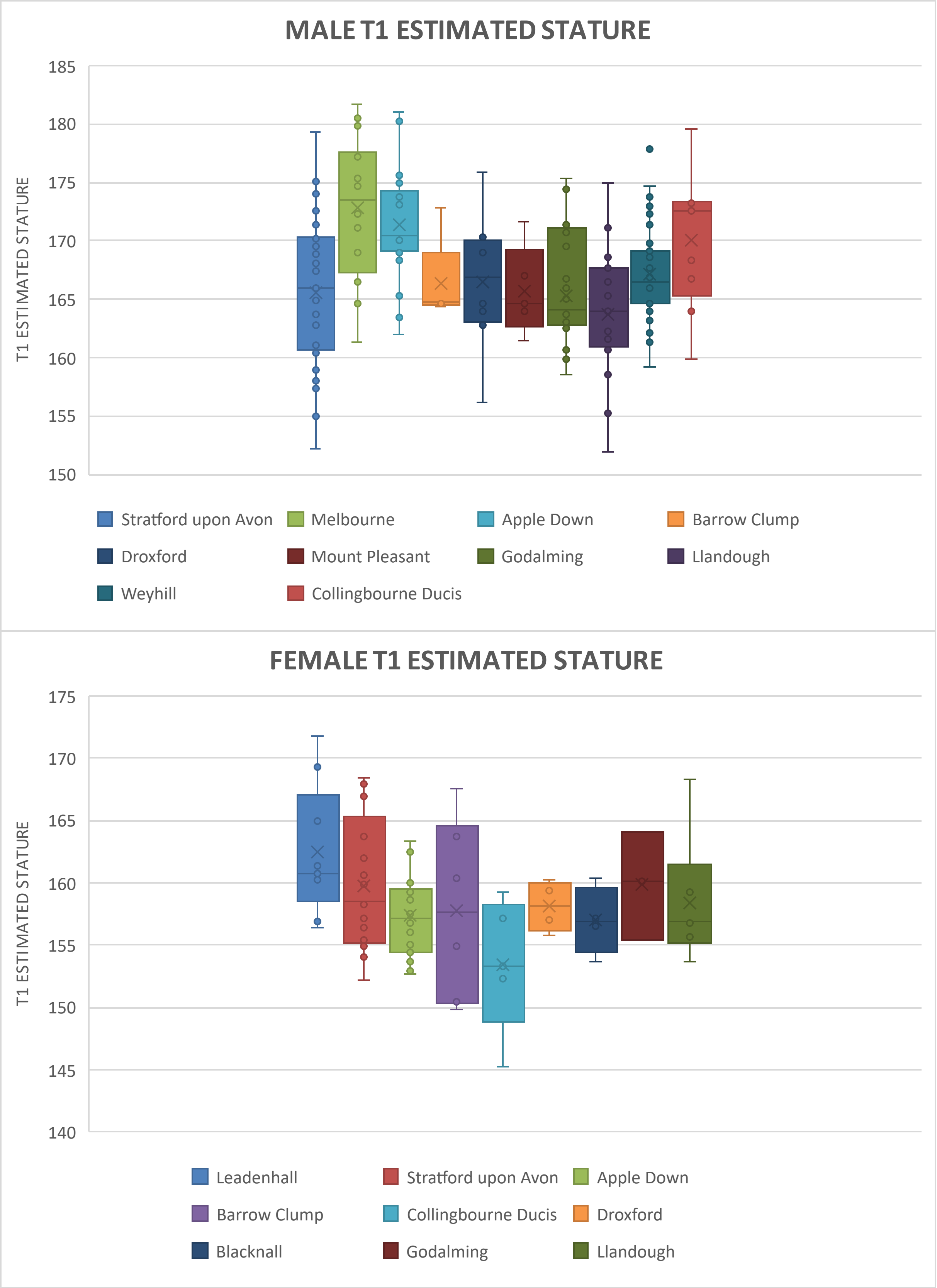

**Fig 36.** Box plot chart illustrating the range of stature estimates achieved with the T1 formulae between the different sites.

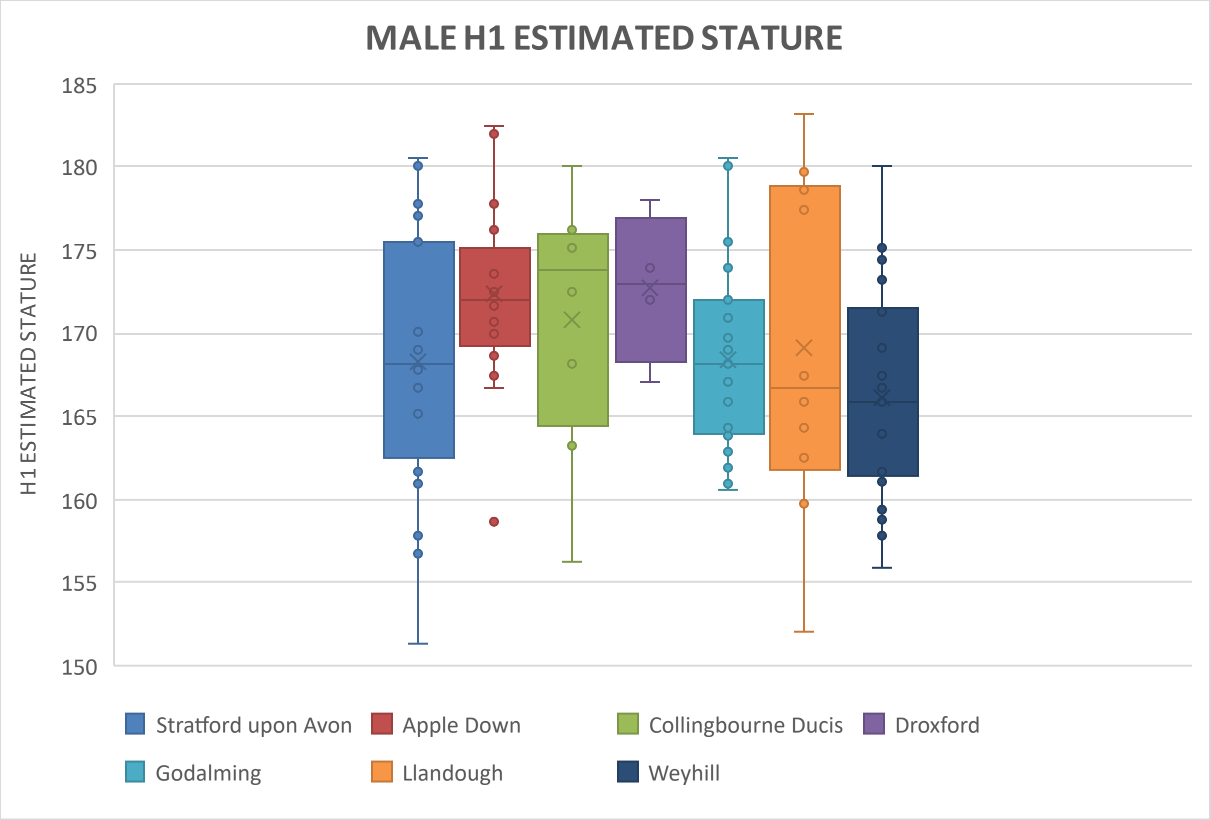

**Fig 37.** Box plot chart illustrating the range of stature estimates achieved with the H1 (male) formulae between the different sites.

# 10. Discussion

The aims of this study have been threefold: **1.** To develop new accurate regression formulae for the British early medieval populations utilizing a temporal base sample, this was achieved, by utilizing the remains of 69 early medieval individuals (40 males and 29 females), by regressing their long bone length against their estimated living stature achieved with the anatomical method. These new stature regression formulae were applied for the wider sample of 512 individuals (185 females and 327 males). **2.** to further the analysis and discussion of the health of the British early medieval populations, through the use of the stature formulae and results achieved in the previous chapters, and compare it to further data, e.g., in relation to nutritional intake and pathology. This will be addressed in this following sections, harkening back to the data presented in chapter five. **3.** to address the dichotomy of previous methodological approaches to stature estimation, both in regards to early medieval Britain and further afield. This has been discussed in the methodology and the results chapters, and will be further discussed in this following sections.

## *10.1 Discussing the Methodological Application*

### *10.1.1 The Issue of RMA or OLS*

A common issue within archaeological stature studies, is that the line fitting of stature samples are interchangeably calculated through RMA (Reduced Major Axis) or OLS (Ordinary Least Squares). This has been considered an arbitrary issue. The confusion surrounding its arbitrary nature, likely stems from Sjøvold's (1990: 435) influential study, in which he cites the very limited study by May and Speitling (1975) (only a single male individual was utilized in this study) as being conclusive evidence of the isometric relationship between the long bone scaling factor in relation to the full stature within population. Since Sjøvold's study, the issues and choice in favour of either RMA or OLS has been relegated to mere comparisons between error ranges produced through either approaches (e.g., Maijanen & Niskanen 2009). In regards to the issue, Mays (2016: 648) stated: *"*[…] *there is currently no consensus over the issue, with some researchers using OLS* […] *others favouring RMA* […]. *",* equally echoed by Rosenstock et al. (2019: 5662): "*Whether OLS and RMA are preferable for stature estimation is yet an unsettled issue* […]." Yet a more common practice it is to exclude the consideration between OLS or RMA completely from the results, treating it as a *vis-à-vis* (interchangeable) factor. This lack of empiricism in the presentation of the formulation of regression formulae does not address the issue over which is a better fit for stature regression formulae calculation. Rather, the arbitrary discussion of the issue with the common argument that is has no greater bearing on the results, nor for that matter, that there is a solution, beyond slight differences in the error ranges produced by either, has stagnated the development.

Past studies have measured the applicability of the two through SD (Standard Deviation) and 95%CI (95% Confidence Interval, i.e., by putting the SEE (Standard Estimated Error) value through a t-test) values: “*In general* [...] *RMA performed better on current assessment criteria than did OLS equations (Mays 2016: 651)”*. Yet such assumptions are based on flawed inferences, and may result in stature estimates which cannot be accounted for by the 95%CI value. As question three for indications of RMA from Smith’s (2009: 482) study comparing OLS and RMA applicability phrased the issue as: *“1. It seems arbitrary which variable is on the X-axis and which variable is on the Y-axis* […] *3. The question is whether X and Y maintain an isometric relationship* [indicative of RMA]*, or whether Y* [or X] *exhibits positive or negative allometry* [indicative of OLS]*.”* RMA regression does not take into account the covariance between traits when estimating the slope of the regression line, hence does not describe functional scaling, i.e., how bone elements scale in relation to the stature achieved in adulthood within a population. Hence the RMA approach is a poor approach for an allometric sample (Kilmer & Rodriguez 2017: 8). Unlike OLS, which assumes skeletal trait covariance between the *x* (independent variable, i.e., long bone height) and *y* (dependent variable, i.e., estimated stature).,

Below, male individual 3136 from Godalming, is used as an example, with the regular RMA stature regression formulation, where *x* is the femoral bicondylar height, and *y* is the estimated stature.

F2 ($x_i$) and LST ($y_i$) values of male individual 3136 $\begin{cases} y_i = 166.7 \\ x_i = 45.3 \end{cases}$

F2 ($\bar{x}$) and LST ($\bar{y}$) mean values of male base sample $\begin{cases} \bar{y} = 167.0 \\ \bar{x} = 45.2 \end{cases}$

$$[8]\ \text{RMA}\ \beta_1: \left(\frac{\sum(166.7-167)^2}{\sum(45.3-45.2)^2}\right)^{0.5} \approx 2.631$$

$$[7]\ \beta_0: 167 - 2.631 * 45.2 \approx 48.078$$

$$[5]\ \hat{y}_i: 2.631 * 45.3 + 48.078 \approx 167.3$$

$$[19]\ S_{xy}: \frac{\sum(45.3-45.2)(166.7-167)}{40-1} \approx 19.93$$

$$[20]\ r\colon \frac{19.93}{2.856 \ast\ 7.512} = \approx 0.929$$

$$[21]\ S_{xx}\colon \textstyle\sum 45.3^2 - \dfrac{(\sum 45.3)^2}{40} \approx 317.55$$

$$[22\ \&\ 24]\text{RMA } SEE\colon 2.03\ \sqrt{7.512\left(\frac{(1-0.929)}{40}\left(2+45.22^2\frac{(1+0.929)}{317.55}\right)\right)^{0.5}} \approx 2.2$$

Final stature estimate for individual 3136: 167.3±2.2cm

$$[9]\ r^2\colon 1-\frac{\sum(166.7-167.26)^2}{\sum(166.7-167)^2} \approx 0.86$$

A further example, where the variables of male individual 3136 are reversed (*x*=anatomical stature, *y*=estimated femoral bicondylar height):

$$[8]\ \text{RMA } \beta_1\colon \left(\frac{\sum(45.3-45.2)^2}{\sum(166.7-167)^2}\right)^{0.5} \approx 0.379$$

$$[7]\ \ \beta_0\colon 45.2-0.379 \ast 167 \approx -18.252$$

$$[5]\ \hat{y}_i\colon 0.379 \ast 166.7-18.252\ \approx 44.9$$

$$[19]\ S_{xy}\colon \frac{\sum(166.7-167)(45.3-45.2)}{40-1} \approx 19.9$$

$$[20]\ r\colon\ \frac{19.93}{7.512 \ast 2.856} = \approx 0.929$$

$$[21]\ S_{xx}\colon \textstyle\sum 166.7^2 - \dfrac{(\sum 166.7)^2}{40} \approx 2201.55$$

$$[22\ \&\ 24]\text{RMA } SEE\colon 2.03\ \sqrt{2.856\left(\frac{(1-0.929)}{40}\left(2+167^2\frac{(1+0.929)}{2201.55}\right)\right)^{0.5}} \approx 1.60$$

Final femoral bicondylar height estimate for individual 3136: 44.9±1.6cm

$$[9]\ r^2 = 1-\frac{\sum(45.22-44.92)^2}{\sum(45.22-45.30)^2} \approx 0.86$$

The two examples above illustrate why RMA at a cursory glance may be considered the superior choice for fitting regression lines, compared to OLS, as the error range of the first example where the femoral bicondylar height is used to estimate the stature is only ±2.2cm (a range of 4.4cm), which is far lower than the stature error range of the same bone element achieved with OLS of

±5.7cm (a range of 11.4 cm, i.e., more than double the range; using the unmodified sample as illustrated in the previous chapter). However, this is only a rudimentary test, which does not consider all the necessary variables. Important to note, the above example does not address Smith's (2009: 482) third question regarding the issue of if the relation between stature and long bone height is either isometric or allometric. Hence merely comparing the error ranges between the two formulae is tentative and indeed arbitrary.

Allometry, or size related changes of morphology, which is non-parallel to the development of the full stature reached in adulthood, has long been a key concept in Zoology and Morphometrics (i.e., quantitative analysis of form, e.g., size and shape), regarding the study of biological evolution and morphometrics of different species evolutionary biology over the last century (e.g., Snell 1892; Huxley 1924, 1932; Jolicoeur & Mosimann 1960; Jolicoeur 1963; Cock 1966; Gould 1966; Sneath & Sokal 1973; Oxnard 1974; Pimentel 1979; Calder 1984; Schmidt-Nielsen 1984; Bookstein 1986; Rohlf 1990; Marcus et al. 1993; Klingenberg 2010, 2016; Mitteroecker et al. 2013). Yet allometry regarding the relation between long bone development to the full stature achieved in adulthood, of human beings, has remained a peripheral issue within physical anthropology. The percentile contribution of long bone height to stature has been a known allometric factor and was quantified by Jants and Jantz (1999), who concluded that the lower limbs were positively allometric, whilst the humeri is negatively allometric. This can be further proven on an individual basis of a population sample, for either of the sexes, and for each of the long bone elements (see Table 17.), using logarithms, as was illustrated with formulae [24].

$$[24]\ log_{10}\,\beta_1 = \frac{\sum(log_{10}x_i - log_{10}\bar{x})(log_{10}y_i - log_{10}\bar{y})}{\sum(log_{10}x_i - log_{10}\bar{x})^2}$$

The $log_{10}\,\beta_1$ [24] results, for each of the long bone elements, of either of the sexes, as shown in Table 17., concurred with the previous results of Jantz and Jantz (1999), with each long bone exhibiting allometric growth trends, with each positive exhibiting positive allometry. With adult stature achieved by the age of 18 in females (possible incremental increase up until the age of 21) and 20 for males (Coly et al. 2006: 2415), with Trotter and Gleser (1958: 101) suggesting a slightly longer growth period, which may continue up until the age of 23 for either of the sexes. The only exception was the humeri, which exhibited a negative allometric trend, in concurrence to the results of Jantz and Jantz (1999: 58-60); this was not possible to calculate for the female sample due to the low number of measured humeri of the base sample. This addresses Smith's (2009: 482) question one and the first half of question three, in the negative,

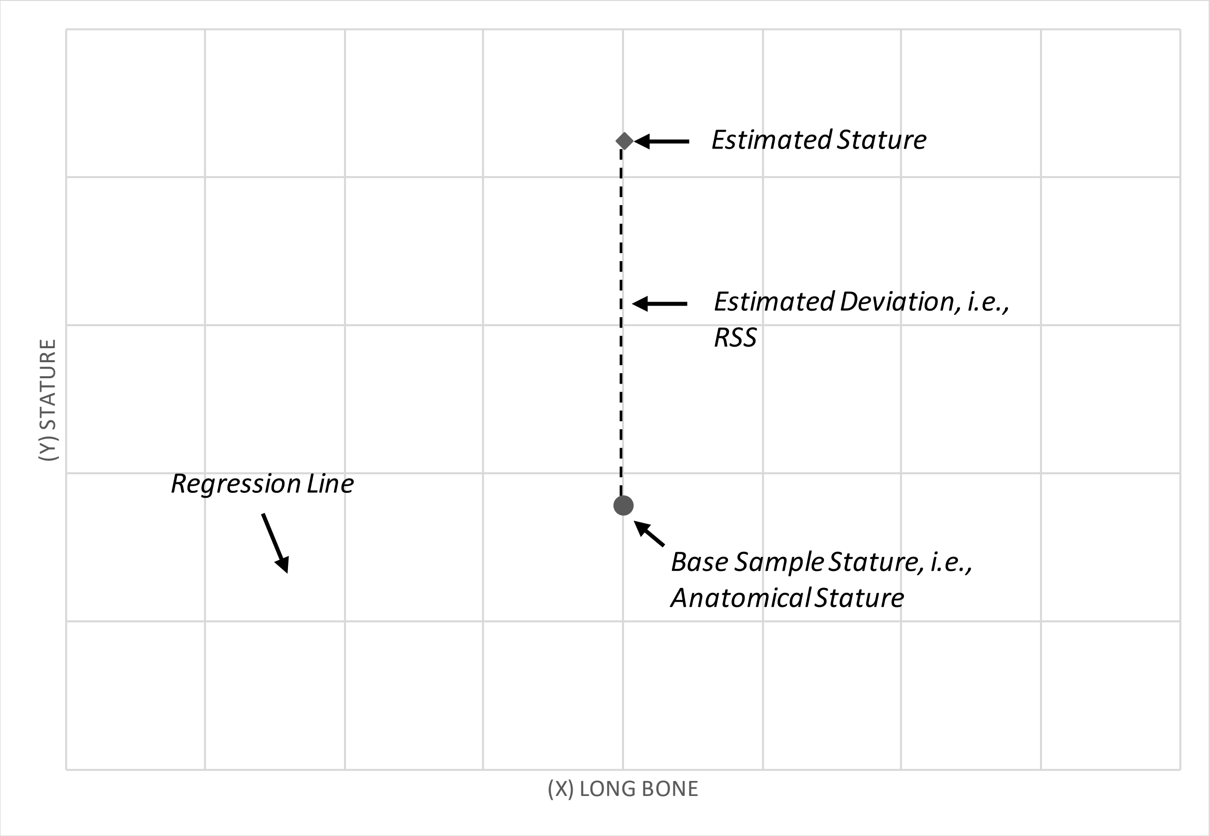

**Fig 38.** Using a hypothetical sample, calculated through OLS, illustrating the calculation of the OLS vertical residuals, i.e., the RSS value.

as the *x* and *y* variables does not maintain an isometric relationship, which would allow for an arbitrary reversal of the *x* and *y* variables, as was illustrated in the example above. The second half of Smith's (2009: 482) question three is answered in the positive, as each of the long bone exhibits positive or negative allometry in relation to the full stature reached in adulthood. Hence Sjøvold (1990) (citing May and Speitling's (1975) earlier study) previous assertion of long bones' isometric factor in relation to the full stature achieved in adulthood within a population, is contradicted by the above discussion.

One of the perceived strengths of the RMA approach is that the *x* variable is assumed to include errors in proportion to its standard deviation (McArdle 1988: 2329–2339; 2003: 1363–1366), i.e., measurement errors of the *x* variable. This could be considered as a strength, if the possibility of inter-observer errors may have been a factor in the materials recordings. However, each individual of the base sample (unlike the wider sample) used in this study with the anatomical method to formulate the regression formulae on, was recorded by the author. Hence any possible errors induced by the recording methods (though unlikely) would be consistent throughout the whole sample. Kilmer & Rodriguez (2017: 7), concluded that measurement errors in biostatistical studies, in general, accounted for an average error factor of 0.05 (i.e., ≤5%) of the total variance. Suggesting a merely small bias introduced through (possible) measurement errors in the *x* variable, hence if present, is a negligible error factor.

> If X has 5% measurement error, then on average, OLS slopes will be attenuated [reduced] by approximately 5% […] This contrasts with the behaviour of RMA regression, where proportionately more error in Y overestimates the slope and proportionately more error in X attenuates the slope (Kilmer & Rodriguez 2017: 10).

Furthermore, to a certain degree, these possible errors in the *x* variable are accounted for by the more generous OLS error ranges estimated through the 95%CI formulae [17 & 23] and its two degrees of freedom (N-2). Hence the conclusion that may be drawn from the above discussion, is that RMA cannot be considered a good fit when formulating stature regression formulae, as unlike OLS, it does not account for allometric scaling, neither negative nor positive (see Table 17.), i.e., the uneven scaling factor between different segments of the body in relation to the full stature. "*When it comes to describing allometric relationships, RMA regression is the wrong fix to a small problem* [i.e., the perceived errors in the x variable] *(Kilmer and Rodriguez 2017: 11).*"

If the base sample which the regression formulae is measured by one observer, following the measurements standards outlined in the methodology section, then OLS is the superior approach. RMA should only be considered when there is a large prevalence, or suspected prevalence, of errors in the *x* variables, which may be an artefact of interobserver errors, e.g., the numeral observers of the measurement recordings used by Trotter and Gleser (1958) in their second stature study. In this rare case, it could have warranted the use of RMA in favour of OLS.

### *10.1.2 The Issue of Trotter and Gleser's Formulae and Secular Stature Trends*

Beyond the question of RMA or OLS, the function, calculation and usage of stature regression formulae has long been a contentious issue, as far back as its inception in the late 19th century (Galton 1889, 1890; Pearson 1892; 1896, 1899; 1897, 1899; Yule 1895, 1896, 1897a, 1897b. Until this day, many of these issues have commonly been left unacknowledged. However, Pearson was aware of the limitation of his method, e.g., his comments regarding the application of his formulae three decades after its initial publication in Stevenson's (1929) study of early 20th century Chinese populations' stature.

> [Footnote by Pearson:] Before applying our French reconstruction formulae to a second race, it would certainly be wise, where it is possible, to test whether the above index [mean body ratio values] is approximately the same for the two races (Stevenson 1929: 311).

Yet such cautions relating to interpopulation secular stature trends have in large been unheeded, as the Trotter & Gleser (1952, 1958) formulae have been applied without reservation for myriads of different unrelated archaeological populations without challenge, including the early medieval period (as illustrated in the material section).

When applying Trotter and Gleser's formulae on an archaeological population, which are either geographically or temporally (or both) unrelated to the North American 20th century base material, nor which can be traced as sharing in stature trends or body ratios with said sample, then two stature factors are overlooked: genetic predisposition and interpopulation secular stature trends.

Wells's (1960: 139-140) comparison between the limb proportion to the full stature of a

**Table 29.** Male stature (EST) and RSS calculated with the OLS formulae by: Trotter and Gleser's (1952, 1958) 20th century "white" formulae, Vercellotti et al. (2009) medieval Polish sample, Sladek et al. (2015) Czech early medieval sample, Boldsen (1984) medieval Danish population, Maijanen and Niskanen (2009) medieval Scandinavian sample, Ruff et al. (2012) European samples ranging from the Mesolithic to the early modern (including medieval samples), and Sjøvold's (1990) 20th century Caucasian sample. All stature estimates are in cm.

**MALE**

| | Axelsson 2024 EST | RSS | Trotter & Gleser 1952 EST | RSS | Trotter & Gleser 1958 EST | RSS | Ruff et al. 2012 EST | RSS |
|---|---|---|---|---|---|---|---|---|
| **F1** | 165.6 | 6.0 | 168.3 | 13.1 | 169.1 | 17.8 | 164.9 | 9.6 |
| **F2** | 165.1 | 4.4 | - | - | - | - | - | - |
| **T1** | 166.8 | 5.1 | 173.3 | 46.5 | 172.2 | 34.2 | 168.1 | 10.2 |
| **H1** | 169.0 | 7.0 | 173.0 | 24.6 | 173.7 | 31.3 | 168.9 | 7.0 |
| **F1+T1** | 167.3 | 3.9 | 171.2 | 20.8 | 171.4 | 22.3 | 166.5 | 5.7 |
| **F2+T1** | 166.5 | 3.0 | - | - | - | - | - | - |
| | **Ruff et al. 2012 EST (Both Sexes)** | **RSS** | **Vercelotti et al. 2009 EST** | **RSS** | **Vercelotti et al. 2009 EST (Both Sexes)** | **RSS** | **Sladek et al. 2015 EST** | **RSS** |
| **F1** | 164.9 | 10.5 | 168.7 | 17.5 | 167.3 | 18.9 | 166.4 | 9.4 |
| **F2** | 168.0 | 15.7 | 166.9 | 16.3 | - | - | - | - |
| **T1** | 167.7 | 9.7 | 172.4 | 37.9 | 171.1 | 32.7 | 166.5 | 22.1 |
| **H1** | 168.7 | 7.1 | 171.3 | 13.3 | 170.3 | 8.8 | 169.8 | 8.9 |
| **F1+T1** | 167.3 | 5.3 | 167.3 | 6.9 | 167.2 | 6.9 | 167.3 | 9.8 |
| **F2+T1** | - | - | 170.8 | 25.3 | 170.3 | 25.3 | - | - |
| | **Boldsen 1984 EST** | **RSS** | **Maijanen & Niskanen 2009 EST** | **RSS** | **Maijanen & Niskanen 2009 EST (Both Sexes)** | **RSS** | **Sjøvold 1990 EST (Both Sexes)** | **RSS** |
| **F1** | 168.3 | 7.4 | 165.9 | 10.5 | 165.9 | 10.5 | 167.5 | 12.9 |
| **F2** | - | - | 165.6 | 8.3 | 165.6 | 8.3 | 166.2 | 12.7 |
| **T1** | 171.7 | 45.9 | 172.7 | 42.8 | 172.7 | 42.8 | 170.9 | 27.3 |
| **H1** | - | - | 168.7 | 7.2 | 167.4 | 9.6 | 172.8 | 23.3 |
| **F1+T1** | - | - | 169.9 | 14.5 | 169.9 | 14.5 | - | - |
| **F2+T1** | - | - | 169.8 | 18.1 | 169.8 | 18.1 | - | - |

British early medieval male sample with that of Trotter and Gleser (1952, 1958) 20th century American samples, suggest that the humeri, were longer in the British early medieval sample, whilst the lower limbs were shorter. An arbitrary comparison can be established, by calculating the percentile contribution towards the full stature of each limb for an archaeological population and compare it to that of Trotter and Gleser's (1952) sample population. However, such a comparison would merely be tentative, as the great disparity in the sample numbers between the two studies do not allow for a one to one comparison. A better solution, is to compare the stature trends and accuracy of a population specific formulae with that of the formulae developed by Trotter and Gleser.

Mays (2016) attempted to investigate the applicability, and accuracy of the Trotter and Gleser (1952, 1958) formulae, whence applied on the remains of the medieval population from Wharram Percy, England. Similar to this study, the anatomical method was used in accordance

**Table 30.** Female stature (EST) and RSS calculated with the OLS formulae by: Trotter and Gleser's (1952; note no female formulae were updated in Trotter & Gleser 1958) 20th century "white" formulae, Vercellotti et al. (2009) medieval Polish sample, Sladek et al. (2015) Czech early medieval sample, Boldsen (1984) medieval Danish population, Maijanen and Niskanen (2009) medieval Scandinavian sample, Ruff et al. (2012) European samples ranging from the Mesolithic to the early modern (including medieval samples), and Sjøvold's (1990) 20th century Caucasian sample. All stature estimates are in cm.

**FEMALE**

| | Axelsson 2024 | | Trotter & Gleser 1952 | | Ruff et al. 2012 | | Ruff et al. 2012 | |
|---|---|---|---|---|---|---|---|---|
| | EST | RSS | EST | RSS | EST | RSS | EST (Both Sexes) | RSS |
| **F1** | 158.3 | 2.0 | 161.1 | 10.5 | 160.1 | 8.9 | 160.5 | 11.0 |
| **F2** | 158.6 | 3.3 | - | - | - | - | - | - |
| **T1** | 158.6 | 3.7 | 162.4 | 28.8 | 158.5 | 6.2 | 159.0 | 8.3 |
| **F1+T1** | 158.3 | 2.9 | - | - | - | - | - | - |
| **F2+T1** | 158.3 | 3.2 | 161.9 | 17.6 | 159.7 | 6.7 | 160.1 | 8.9 |

| | Vercelotti et al. 2009 | | Vercelotti et al. 2009 | | Sladek et al. 2015 | | Boldsen 1984 | |
|---|---|---|---|---|---|---|---|---|
| | EST | RSS | EST (Both Sexes) | RSS | EST | RSS | EST | RSS |
| **F1** | 160.45 | 12.5 | 162.4 | 25.6 | 160.3 | 9.6 | 160.3 | 9.2 |
| **F2** | - | - | 160.1 | 14.1 | 161.8 | 28.2 | - | - |
| **T1** | 158.5 | 5.6 | 161.2 | 22.3 | 156.8 | 10.4 | 161.1 | 12.4 |
| **F1+T1** | 159.7 | 9.0 | 161.9 | 24.4 | - | - | - | - |
| **F2+T1** | - | - | - | - | 159.2 | 7.9 | - | - |

| | Maijanen & Niskanen 2009 | | Maijanen & Niskanen 2009 | | Sjøvold 1990 | | | |
|---|---|---|---|---|---|---|---|---|
| | EST | RSS | EST (Both Sexes) | RSS | EST (Both Sexes) | RSS | | |
| **F1** | 160.2 | 8.3 | 161.5 | 15.9 | 163.3 | 31.2 | - | - |
| **F2** | 159.9 | 11.5 | 161.1 | 18.6 | 161.7 | 23.7 | - | - |
| **T1** | 160.6 | 13.7 | 164.1 | 48.8 | 162.3 | 25.5 | - | - |
| **F1+T1** | 161.3 | 14.5 | 162.5 | 24.3 | - | - | - | - |
| **F2+T1** | 160.9 | 11.9 | 162.5 | 23.9 | - | - | - | - |

with the regression method. However, unlike this study, Mays's (2016) aim was to establish if either of Trotter and Gleser's (1952, 1958) formulae were good fits for British medieval populations. This was achieved by using the results of the anatomical method, which in turn were compared to the Trotter and Gleser formulae applied to the same sample. This comparison was done by comparing the different SEE (Standard Estimated Error) between the different formulae, both OLS (Ordinary Least Square) and RMA (Reduced Major Axis, in accordance to Hens et al 1998; original formulae were only calculated as OLS). However, one issue which arises from this approach, whence attempting to compare the SEE value of different formulae, is that each variable necessary for the calculation of the SEE value of OLS (formulae [19 & 20]) or RMA ([21, 22, 23 & 24]), are not provided in the studies by Trotter and Gleser (1952, 1958), nor for that matter, are typically not included in the majority of other studies. This was a key focus of this study, and was illustrated in the previous chapter, as each variable necessary for calculating the error range on an individual basis, for each long bone, and of each of the sexes, were provided. This allows for a greater empirical results, where each variable and formulae can be tested by a third party through the data and formulae provided in earlier chapters.

Hence due to the above mentioned factors regarding the lack of explicit variables used for the SEE calculation, the formulae used by Mays (2016: 649) is incomplete (as seen below [55]), as the original variables outlined by Vercellotti et al. (2009: 141) and Zar (2010: 356-357, 376) are not available.

$$[87] SEE\,(Mays\ 2016) = \sqrt{\frac{(\hat{y}_i - y_i)^2}{N}}$$

This is not a complete SEE formula (if compared to an OLS SEE formula [12 & 22]), but rather the calculation of the square root of an OLS RSS value, as compared to the formula below:

$$[16]\ S_{yy}^2 = \frac{\sum(\hat{y}_i - \mathrm{y}_i)^2}{N}$$

Mays's formula lacks a summation sign (i.e., $\sum$), yet presumably this is performed for the entire sample. Furthermore, rather than comparing the estimated stature towards the mean (i.e., $\bar{y}$), the estimated stature (i.e., $\hat{y}_i$) achieved through Trotter and Gleser's (1952, 1958) formulae, is then compared towards the specific anatomical stature (i.e., $y_i$), presumably the two values are from one and the same individual, mirroring the OLS RSS formula [16]. This is a poor comparison for if Trotter and Gleser's (1952, 1958) 20th century North American formulae is a good fit for British medieval samples. However, Mays (2016) was not hypothetically completely wrong, only in the approach. A better solution to the issue in regard to comparing two, or more OLS

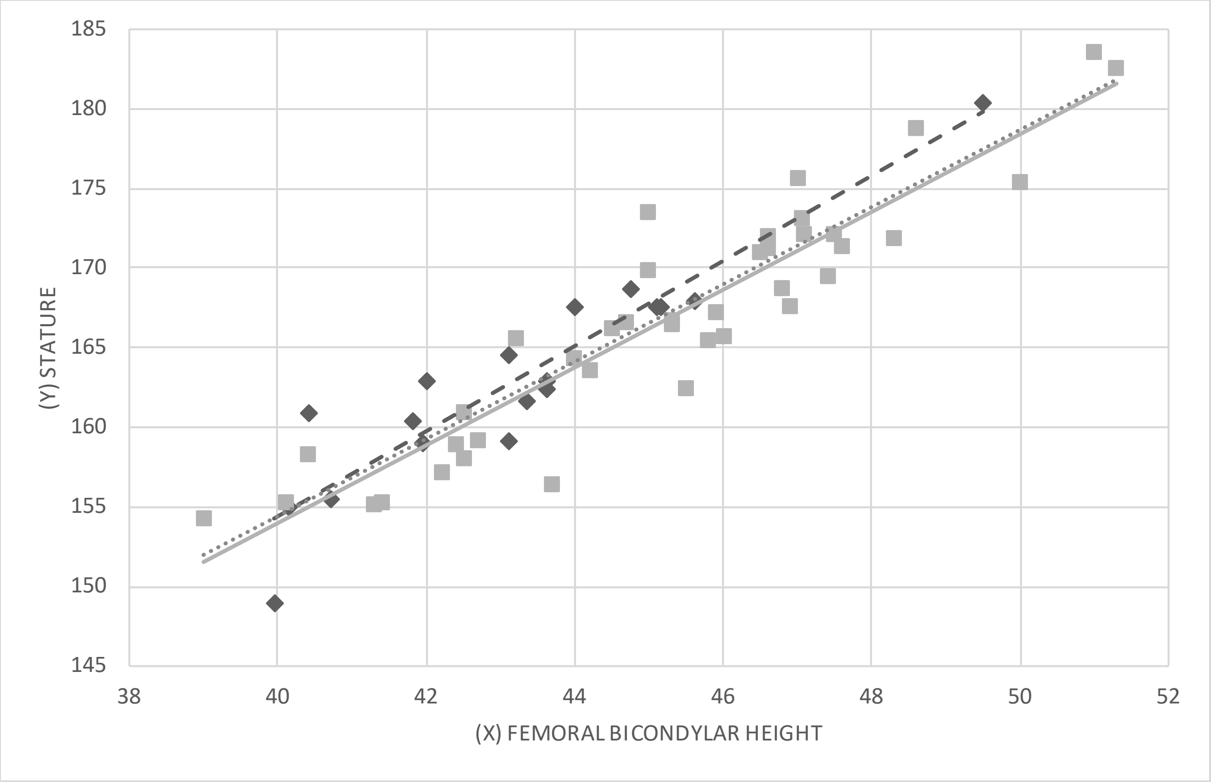

**Fig 39.** An example of non-parallel regression lines (i.e., best fit lines) from two poorly matched populations in geography, temporality and affinity. Diamonds (stripped regression line) is the femoral bicondylar regression line of the Anatolian Early Bronze Age Karataş-Semayük male population (Axelsson 2021), squares (solid regression line) femoral bicondylar regression line of the early medieval male population from this study. Note: the regression line of the pooled sample (dotted), is near parallel to the larger male sample of this study. All measurements are in cm.

formulae, applied on one sample population, would be to utilize the OLS RSS formulae [16], as it calculates the vertical deviation between the sample populations' stature and the estimated stature (see Fig 38.). An RSS formulae cannot be used as a substitute for a SEE value, even with the square root added (as attempted in Mays's (2016) version) or 95%CI (95% Confidence Interval) values. For as previously discussed, the RSS value forms the foundation for the SEE value to be calculated on. The higher the RSS value is, the greater the variability of the stature result and the SEE value. Yet it can calculate the variability of the estimated result through the regression method with that of the original sample stature. Hence utilizing RSS whence comparing two different formulae, on one and the same sample (argued by the author of this study), is the best mode to gauge which formulae is the superior fit, however, if possible to use a comparative studentised residual analysis, between two different formulae, then this approach is preferable. Similar to calculating a regression formulae, a large enough base sample which is representative of a population, temporally or geographically, such as the early medieval

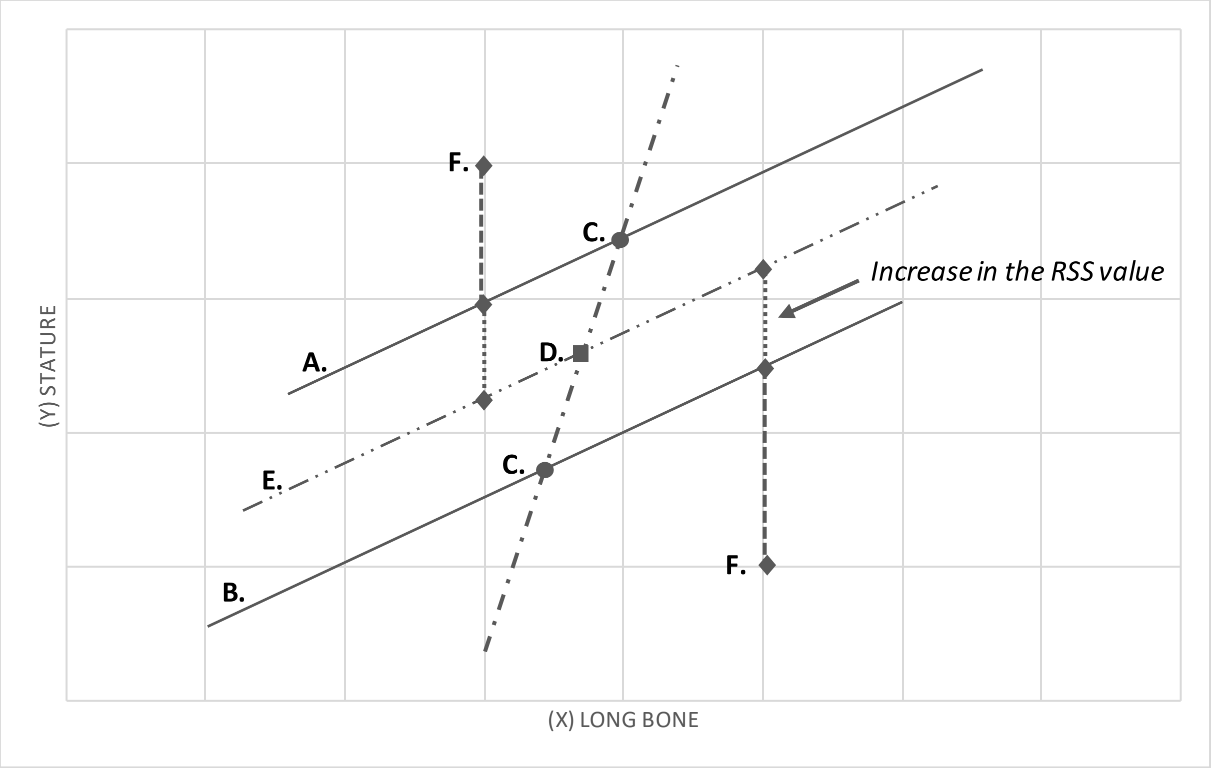

**Fig 40.** A redrawing of the hypothetical example of parallel regression lines between two populations, A. and B., used in Sjøvold (1990: 435), with the dots (C.) representing the intersecting population mean values, and the square (D.) being the new mean intersect value when the two samples are combined, and E. the new regression line calculated on the pooled sample of the two populations. F. represents the widening of the vertical residuals.

anatomical sample used in this study, is necessary.

> […] regression lines from different populations often tend to be parallel, passing through their respective mean values. If a line could be found which passes through all the means,

**Table 31.** The final combined results of the mean estimated stature, calculated on the modified (and unmodified in the case of the female F1, F1+T1, F2+T1) samples of either sexes, along with the standard deviation of each bone elements. Note: only 28 humeri samples were used in the male calculation. All measurements are in cm.

| | MALE | N: 40 | FEMALE | N: 29 |
|---|---|---|---|---|
| FORMULAE | Mean Stature | SD | Mean Stature | SD |
| F1: | 165.6 | 3.4 | 158.3 | 2.5 |
| F2: | 165.1 | 3.3 | 158.6 | 2.6 |
| T1: | 166.8 | 2.6 | 158.6 | 2.1 |
| F1+T1: | 167.3 | 5.3 | 158.3 | 4.4 |
| F2+T1: | 166.4 | 5.4 | 158.3 | 4.4 |
| H1: | 168.7 | 1.9 | - | - |
| F1+T1+L: | 167.0 | 6.1 | 158.0 | 4.6 |
| F2+T1+L: | 167.0 | 6.1 | 158.0 | 4.6 |

> such a line would be practically independent of the value of a particular population, and therefore provide a joint compromise for existing regression equation (Sjøvold 1990: 434).

The increase in sample number achieved through a pooling of unrelated sample populations (as illustrated in Fig 35. & 40.) does not necessarily increase the accuracy of the calculated formulae. As Fig 39. illustrates, in actuality, the trend lines are rarely parallel between two different populations, especially when there is a temporal difference, due to the effect of secular stature trends (Wilson et al. 2010: 688). Nor for that matter, does this approach take into account the variability of the vertical deviation (RSS, as illustrated in Fig 40.), hence risk increasing the error range of the calculated formulae. This is apparent in Table 29. and 30., as each sex specific formulae performed better when applied to the early medieval male and female sample of this study, compared to the formulae based on samples of pooled sex (Further discussed below).

Furthermore, the early medieval specific formulae which were developed on the same sample used in Table 29. and 30., far out performed the other comparative formulae which is either based on semi-contemporary sample populations from continental Europe (Vercellotti et al. 2009: medieval Polish sample, Sladek et al. 2015: Czech early medieval sample, Maijanen & Niskanen 2009: medieval Scandinavian sample) or formulae based on pooled samples (e.g., Sjøvold 1990; Ruff et al. 2012; Ruff 2018). This illustrates the greater potential for accuracy of geographically, temporally, and affinity specific stature formulae. As the sheer number of the base sample is of secondary consideration, compared to a good representation of the sample regarding secular stature trends, sexual dimorphism and affinity of the population in question.

### *10.1.3 Sjøvold's Pooled Sex Method*

The pooling of the sexes when establishing a base sample for stature estimation, as argued by Sjøvold (1990: 442), should bring more benefits than negatives to the regression calculation, as a larger base sample is then made available when the two sexes' body ratios are combined. Sjøvold (1990: 442) stated: *"*[…] *body proportions are adapted to the stature itself and that this adaption is more important than sexual modification* [i.e., sexual dimorphism] *of these proportions."*

However, the pooling of the sexes exacerbates the effects of the erroneous factors discussed in previous chapters, e.g., a pooled sample, will introduce greater variability into the base sample, through the factor of sexual dimorphism, as this increases the greater diversity in the

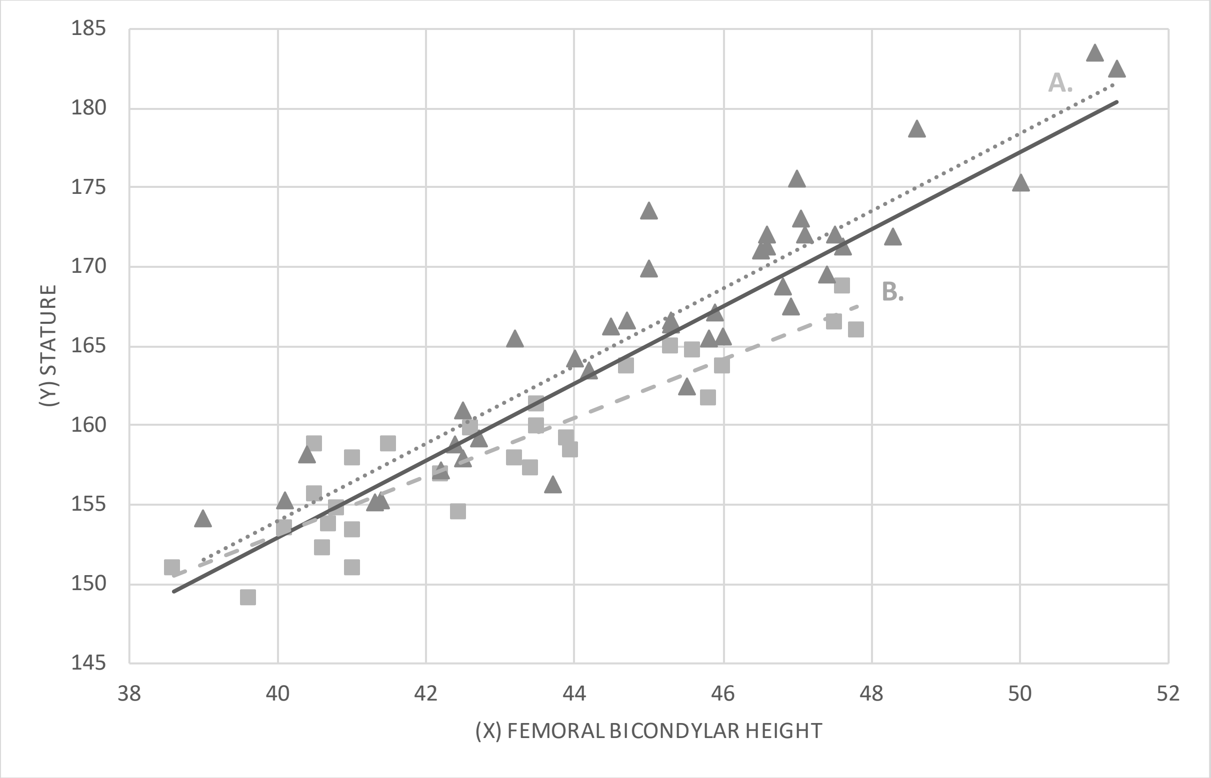

**Fig 41.** The femoral bicondylar height (*x*) plotted out against the estimated stature (*y*), of the early medieval anatomical base sample population of this study, comparing the regression line of the two sexes, A. males (triangles; doted regression line), B. females (squares; striped regression line)), with the regression line (solid) of the pooled sex sample. All measurements are in cm.

genetical and secular stature trends of the sample. This is an issue, as the $\beta_1$ and $\beta_0$ variables, are estimated coefficients, and are reliant on the mean values of the independent ($\bar{x}$) and dependent ($\bar{y}$) variables (see below [12] and [13]). Hence a sample with a greater scatter of the *x* and *y* variables, i.e., greater horizontal (*x*) or vertical (y) deviations from the normative trends of a sample (or *samples*, when combining male and female samples), will cause the calculated regression line to be skewed or cause a steeper or shallower angles, hence the estimated coefficient variables [12 & 13] will be less representative for each of the samples.

$$[12]\ \text{OLS}\,\beta_1 = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$$

$$[13]\ \beta_0 = \bar{y} - \beta_1\bar{x}$$

This issue can be minimized, through the use of a base sample which is large enough, and a good representation of the stature range of a specific population (i.e., sex specific). With a pooled sex sample, the mean values are stunted, for it is not representative of either of the sexes, rather it is placed in the middle of the actual mean values of the two sexes (Fig 41.). This causes a lesser accuracy to be achieved when estimating the stature of either of the sexes with such a formulae.

When the base sample of the British early medieval period of this study had its female and male individuals of the anatomical sample pooled together into one base sample, followed by regression formulae calculated for each of the bone elements, it resulted in greater RSS values (see Table 31.) for each of the long bones.

As discussed above, regarding secular stature trends, the male and female body reacts differently to external stressors during their formative year (Wolanski & Kasprzak 1976: 548; Jantz & Jantz 1999: 65). Wolanski and Kasprzak (1976: 549) determined in their study of late-19th to mid-20th century Polish populations, that younger males during their formative years are far more susceptible to negative and positive environmental stimuli, than their female counterpart. Hence stature trends in male groups tend to be far more heterogenous than female groups from within the same sample population (Wolanski & Kasprzak 1976: 548; Jantz & Jantz 1999: 65). Due to the greater homogeneity exhibited in regards to female stature, using pooled stature formulae will result in far greater RSS values, than when such formulae are applied for male samples, which naturally are more heterogenous. Similar trends were exhibited in this study, as is evident with the greater SD values of each bone element of the male base sample compared to that of the female sample (see Fig 41., Table 32.). Furthermore, as seen in Table 17., the $log_{10}\ \beta_1$ values differ between males and females, i.e., the full stature achieved in adulthood compared to the growth rate of each long bone, which is different between the sexes. With the female sample exhibiting a far more pronounced allometric scaling factor of each of the long bones than that of the male sample. This is caused by the fact that females generally start growing at an earlier stage than males, and reach their full adult stature at an earlier stage in their development (Trotter & Gleser 1958: 101; Coly et al. 2006: 2415; Perkins et al. 2016: 150). Meaning that the growth trajectories between males and females, at different stage during the formative years differ fairly significantly (e.g., F2 $log_{10}\ \beta_1$ value (i.e., growth rate in relation to the full stature), males: 1.31; females: 1.67), hence no generalized reliable pattern can be

**Table 32.** Comparing the SD and RSS value of the early medieval anatomical unmodified of this study, both with the sexes separate and pooled together into one sample. All measurements are in cm.

|  | POOLED SEX N: 69 |  |  | MALE N: 40 |  |  | FEMALE N: 29 |  |  |
|---|---|---|---|---|---|---|---|---|---|
| **FORMULAE** | **Mean EST** | **SD** | **Mean RSS** | **Mean EST** | **SD** | **Mean RSS** | **Mean EST** | **SD** | **Mean RSS** |
| **F1:** | 163.0 | 3.0 | 8.6 | 166.7 | 2.9 | 8.1 | 158.3 | 2.5 | 3.1 |
| **F2:** | 163.0 | 2.9 | 8.8 | 166.7 | 3.0 | 7.6 | 158.3 | 2.5 | 3.9 |
| **T1:** | 163.0 | 2.6 | 9.1 | 166.7 | 2.5 | 8.9 | 158.0 | 2.0 | 5.7 |

established when pooling the sexes together. This is further illustrated in Table 29. and 30. (using formulae from: Trotter & Gleser 1952, 1958; Sjøvold 1990; Vercellotti et al. 2009; Maijanen & Niskanen 2009; Ruff et al. 2012; Sladek et al. 2015; Sjøvold 1990), whence comparing the stature results using the formulae produced in this study, with other formulae applied onto the early medieval sample. Each formulae which were sex specific, produced a lower RSS value, than those formulae based on a pooled sex sample.

### *10.1.4 A Note on Error Ranges*

Another issue encountered with Trotter and Gleser's formulae, regards the erroneous calculation of the error ranges, as no t-test variables were used. A t-test measures if the differences between two samples are statistically significant (Mishra et al. 2019: 408), i.e., if the stature estimate achieved through a regression formula, significantly deviates from the original sample which the formulae were based on, i.e., the anatomical sample. Rather, Trotter and Gleser merely multiplied the SE (Standard Error) value (i.e., SE = $\frac{\sigma_{\hat{y}}}{\sqrt{N}}$) of the regression formulae by two (Jeong & Jantz 2016: 82) [73]:

$$[73]\,2\left(\frac{\sigma_{\hat{y}}}{\sqrt{N}}\right)$$

The $\sigma_{\hat{y}}$ variable is the standard deviation of the estimated stature ($\hat{y}$) of the sample. The SE value is a poor predictor of the accuracy of a regression formula, as it merely determines the standard deviation of the dependent variable ($y$). Whilst a 95%CI value rely on the estimated distribution in relation to the base value (RSS) (Wilson et al. 2010: 686). Furthermore, the 95%CI includes considerations of the mean values of the independent variable ($x$), which is lacking in the SE calculation. Whence Trotter and Gleser's SE formula [73] is applied to the material of this study, and compared to the mean 95%CI value of each of the bone elements, of each of the sexes, an average underestimation of the error range by c. 45% (Table 33.). This suggests a gross miscalculation of the error ranges, hence the errors provided in Trotter and Gleser's (1952, 1958) stature studies should be treated as arbitrary estimates, and not as a reliable calculation of the actual accuracy of their formulae.

A further common erroneous trend in regards to the presentation of the error ranges, is to only present the mean SEE (Standard Estimated Error) value [17 & 22] in the results section of a study where new regression formulae has been calculated (e.g., Maijanen & Niskanen 2009; Vercelotti et al. 2009 (95%CI is included in the appendix); Ruff et al. 2012; Sladek et al. 2015; Koukli et al. 2023).

*Vertical deviation of the dependent variable (y), i.e., the Stature Estimate (RSS)*

*Variability of the independent variable (x)*

$$[17\ \&\ 24]\ 95\%CI = t_{0.05N-2}\sqrt{S_{yy}^2\left(1+\frac{1}{N}+\frac{(x_i-\bar{x})^2}{x_\sigma^2(N-1)}\right)}$$

*Two sided t-test variable, with a 95% confidence (0.05), with two degrees of freedom (N-2)*

*Sample size variable*

*The corrected sum of squares of the measured skeletal elements*

This is not in accordance with the original instructions (though flawed) presented by Trotter and Gleser (1952, 1958). This practice has a tendency to misrepresent the true prediction error range of the calculated formulae, i.e., accuracy. However, the 95%CI can easily be calculated for such studies in which only the SEE value has been given. This can be achieved with the t-test formula [23] used in this study. By multiplying the SEE value with a two sided t-value ($t_{0.05N-2}$), with a 95% confidence interval (i.e., .05), which corresponds to the number of individuals utilized in the study, with two degrees of freedom (N-2). For example, the male femoral SEE value of 3.21, taken from Ruff et al. (2012: 606) study of European stature ranging from the Mesolithic to the 20th century, with a male femoral sample number of 268 individuals, hence the $t_{0.05N-2}$ value is: c. 1.98 (i.e., $t_{0.05N-2}$ of a ≥100 sample size):

95%CI of Ruff et al. (2012: 606) femoral formula: $3.21*1.98 \approx 6.4$

With the female femoral SEE value: 2.92 of Ruff et al. (2012: 606):

95%CI of Ruff et al. (2012: 606) femoral formula: $2.92*1.98 \approx 5.8$

Hence when only the SEE value is included in the results, the actual mean error range is not presented, unless the 95%CI have been calculated, e.g., Ruff et al. (2012: 606) male femoral

**Table 33.** Trotter and Gleser's (195, 1958) mode [88] of calculating the error ranges (2xSE) applied to the material of the study, and compared to the 95%CI value produced in previous chapters.

| | Male | N:40 | Female | N:29 |
|---|---|---|---|---|
| | 95%CI | 2xSE | 95%CI | 2xSE |
| F1: | 4.8 | 2.3 | 3.7 | 1.7 |
| F2: | 4.2 | 2.2 | 3.2 | 2.0 |
| T1: | 4.6 | 1.9 | 4.1 | 1.8 |
| F1+T1: | 4.7 | 2.1 | 3.6 | 1.8 |
| F2+T1: | 4.4 | 2.1 | 3.8 | 1.8 |
| H1: | 5.7 | 2.2 | - | - |
| F1+T1+L: | 4.1 | 2.3 | 2.7 | 1.8 |
| F2+T1+L: | 4.4 | 2.3 | 2.9 | 1.8 |

formula (as shown above), having an error range of: c. ±6.4cm, with the female error range being: c. ±5.8cm.

### *10.1.5 A Short Note on the Erroneous Application of the Anatomical Method's Age Range*

The anatomical method, similar to the regression method, has not been without issues, e.g., the errors induced by the early forms of the method (Dwight 1878; Toppinard 1885; Fully 1956). Yet with the reassessment of the anatomical method by Raxter et al. (2006), greater success has been achieved in its application by further scholars, than with the regression method, due to its ease of use. Yet issues have occasionally arisen in its application, e.g., Sciulli and Hetland's (2007) study of the stature of Native American populations in Ohio Valley, or Mays (2016) study of the medieval population of Wharram Percy, England. Both of these aforementioned studies applied the age factor of formula [4] incorrectly (Sciulli & Hetland 2007: 108; Mays 2016: 648), as the estimated age of an individual were used as a numerical multiplier for the stature degradation, e.g., a 30-year-old individual was calculated as (age factor = 30, i.e., 0.0426*30), e.g.:

$$1.009x_i-(0.0426*30)+12.1$$

Rather than the correct application of the formula for an individual with an estimated age of 30 years old at the time of death (age factor = 1):

$$1.009x_i-(0.0426*1)+12.1.$$

This is an erroneous usage of the anatomical method's age factor in regards to the stature degradation with age. As the vertebral column starts to deteriorate over time after reaching the age of 30, due to shrinkage in the soft tissue in the vertebral column (Mays 2016: 648), and is estimated to negatively affect the stature by c. 0.0426cm (c. 0.06cm according to Trotter & Gleser 1951a: 318; Trotter & Gleser 1952: 464) per year (Raxter *et al* 2006: 376-377). Hence with an individual with an estimated age of 30, then the age factor should merely be added as one (i.e., 0.0426*1), with the addition of one for each year after that. Adding the age factor as: 0.0426*30, is rather calculating the stature of a 59-year-old individual (c. -1.3cm underestimation of the actual stature), as the input suggests 30 years of stature degradation through a collapsing spine.

## *10.2 Stature and (non-)Temporal Demographical Comparisons*

When analysing the demography of British early medieval populations, migration is a key factor to consider, especially concerning stature. As discussed in previous chapters, stature is both affected by secular stature trends and genetic predisposition. As Leggett (2021; Leggett & et al. 2022), and Gretzinger et al. (2022) established, the early medieval populations of England were of diverse origin, hence may have had a wider range of genetic predisposition affecting the development of stature. Hence attempting to calculate stature regression formulae for this period, runs the risk of not being achievable within acceptable error ranges. This challenge is posed due to the diversity of the population, and the accompanying diverse stature trends caused by the two aforementioned factors of genetic predisposition and secular stature trends. The greater the diversity of the sample population, the larger the risk of greater variability in stature trends, as seen in the previously discussed studies utilizing samples with a varied geographical and temporal origin (e.g., Sjøvold 1990; Ruff et al. 2012; Ruff 2018). The complete sample used in this study has not had their ancestry or origin explored through isotope or aDNA analysis, beyond a few exceptions: Apple Down, Eastry, and Polhill, yet Gretzinger et al. (2022: 112-113), argued that larger portions of the English early medieval populations' origin can be traced to northern Europe.

Despite migration being an important factor, the early medieval material used in this study allowed for reliable stature regression formulae to be calculated, this is evident in the fairly low RSS values (Table 29., 30. & 34.; this is further illustrated in the fairly low numbers of outliers established through the studentised residual analysis in prior chapter) compared to other non-related formulae, especially in the case of the female sample. The fit of the samples (both males and females), were further modified through censoring the sample outliers or anomalies which negatively affected the accuracy of the formulae, based on the results of formula [25]. This is likely suggestive of shared stature trends (to a certain degree) between the local Britons and the newly arrived Germanic foreigner. The effect of these shared or similar stature trends were further exacerbated by the secular trends affecting the development of stature; as discussed by Leggett (2021) concerning the apparent acculturation of several foreign individuals at the early medieval site of Finglesham, Kent, where similar secular stature trends likely developed over time. Acculturation of foreign migrants at other contemporary sites to Finglesham is likely, hence these predominantly Germanic foreigners to a similar degree would exhibit similar secular stature trends as the local Britons after settling permanently in the British Isles (further discussed below).

To this day, no stature studies have been conducted on contemporary early medieval Germanic populations of the Lower Saxon region, or for that matter, wider Germany. The closest Germanic stature study (though not chronologically contemporary), was conducted on a small sample of 22 individuals (13 females and nine males) from a Prussian high medieval (c. 14th to 15th century A.D.) cemetery, located in modern Bezławki, northeastern Poland (Ramsier et al. 2021). This Germanic sample population likely shares an affinity to a greater degree with the Polish high medieval sample used in Vercellotti et al.'s (2009) study, rather than the early medieval sample used in this project. Hence future stature studies focusing on early medieval populations uncovered in Lower Saxony or adjacent German regions could elucidate possible shared stature trends between British early medieval populations, and those regions where the other populations originated from. Furthermore, wider stature studies in north-central Europe can further add to the discussion of migration.

No reliable temporally focused studies of other European early medieval populations (at the time of writing) have been published, rather high medieval materials have seen greater attention in the scholarship (as discussed above). Walther's (2017) study of stature and body proportions of populations in Roman and early medieval Britain, presents good anatomically estimated stature, for either period (as cited below), yet lacks empiricism and a good methodological approach when calculating regression formulae. This erroneous approach is especially apparent in the latter period, as only 23 individuals (15 males, and eight females), were utilized in the calculation of the regression stature formulae. Only tentative results and formulae can be achieved when utilizing a base sample of this size, especially regarding the female sample of only eight individuals. This tentativeness is the reason for Walther's (2017) formulae's omission

**Table 34.** Male and female stature (EST) and RSS calculated with the OLS formulae compared to the formulae by: Boldsen (1984) medieval Danish population, Maijanen and Niskanen (2009) medieval Scandinavian sample. All stature estimates are in cm.

| | AXELSSON 2024 | | BOLDSEN 1984 | | MAIJANEN & NISKANEN 2009 | |
|---|---|---|---|---|---|---|
| **MALE** | **EST** | **RSS** | **EST** | **RSS** | **EST** | **RSS** |
| **F1** | 165.6 | 5.2 | 168.3 | 7.4 | 165.9 | 10.5 |
| **F2** | 165.1 | 4.1 | - | - | 165.6 | 8.3 |
| **T1** | 166.8 | 4.9 | 171.7 | 45.9 | 172.7 | 42.8 |
| **H1** | 169.0 | 7.0 | - | - | 168.7 | 7.2 |
| **F1+T1** | 167.3 | 5.0 | - | - | 169.9 | 14.5 |
| **F2+T1** | 166.5 | 4.5 | - | - | 169.8 | 18.1 |
| | **Axelsson 2024** | | **Boldsen 1984** | | **Maijanen & Niskanen 2009** | |
| **FEMALE** | **EST** | **RSS** | **EST** | **RSS** | **EST** | **RSS** |
| **F1** | 158.3 | 3.1 | 160.3 | 9.2 | 160.2 | 8.3 |
| **F2** | 158.6 | 2.3 | - | - | 159.9 | 11.5 |
| **T1** | 158.6 | 3.8 | 161.1 | 12.4 | 160.6 | 13.7 |
| **F1+T1** | 158.3 | 2.9 | - | - | 161.3 | 14.5 |
| **F2+T1** | 158.3 | 3.2 | - | - | 160.9 | 11.9 |

from Table 29., 30. and 34. Further empirical issues are present in the methodological approach of Walther's (2017: 105, 192-193) study, as the SEE (lacking consideration for the *x* variable, i.e., the bone elements) and 95%CI value is erroneously calculated, with no t-test performed for the final error range. This further emphasizes the importance of one of the key aims of this study: the codification of proper and empirical stature methodology in archaeology, which this study has addressed in the previous chapters.

With the lack of reliable contemporary stature studies of Germanic populations, and the tentativeness of Walther's (2017) study, only two previous studies are left for comparison, the stature study of the Danish medieval population of Viborg by Boldsen (1984), utilizing 65 individuals (31 males and 34 females) and the Swedish study of the high medieval population of Westerhus by Maijanen and Niskanen (2009), basing its formulae on 60 individuals (28 males and 32 females). It should be noted, that the site of Westerhus is located further north in Sweden than the southern region which Gretzinger et al. (2022: 5) traced as one of the regions of origin for migratory movements to Britain in the early medieval period. This geographical disparity would suggest the previous study of Boldsen (1984) as a better comparative material, as was identified by Gretzinger et al. (2022: 3-7). Yet no larger disparity in the RSS value were produced when applying the maximum femoral height (F1) formulae, of either of the two comparative studies, for the early medieval sample population of this study. The maximum tibiae height (T1) formulae fared worse, especially in regard to the male sample (Table 33.). Neither studies' formulae can produce results that exhibit RSS values less than those achieved with the formulae calculated in this study. This not only highlight the importance of geographical consideration, but furthermore, the possible changes in secular stature trends over time, hence temporality is a further key aspect, thus further emphasising the need for empirically developed, population-specific regression formulae.

### *10.2.1 Health and Stature in Early Medieval Southern Britain*

Many factors can affect the development of stature, however, malnutrition (e.g., diets rich in carbohydrates yet lacking in protein, as is the case with the predominate diet of $C^3$ plants of the early medieval period), and infection (though difficult to detect in the material), tend to exhibit the most profound effects on the outcome of stature growth, which can either cause stunting or temporarily arrest growth.

The general health and stature of the mother is the greatest predictor of the growth potential of the child. The health of the mother affects the child *in utero*, hence if the general nutritional intake of a population is poor, it will affect the succeeding generation even before their birth. Through paediatric studies (e.g., Wales et al. 1992; Skuse 1989; Money 1992; Rogol *et al.* 2000; Johnson & Gunnar 2011), with comparatively supporting evidence found in anthropological studies (e.g., Sussane 1980; Perkins et al. 2016; Soliman et al. 2021), nutritional intake during the formative years has been concluded as one of the key determining factors for the stature achieved in adulthood. Furthermore, other determinative factors range from poor environment (e.g., marshy areas where malaria is common), to metabolical diseases, which can prevent the genetically predisposed stature of an individual from being achieved in adulthood (Hoppa 1992: 285). The average adult height of a population may be a useful indicator of access to nutrition and exposure to disease, harsh environments and living conditions, representing a biological standard of living, and may be indicative of the economic status of a site and its population (Perkins et al. 2016: 151).

The mother's health continues to play an important active role in the child's development even after birth, as the nutritional intake of the mother is transferred to the child through breastfeeding (Jantz & Jantz 1999: 66; Coly et al. 2006: 2417; Perkins et al. 2016: 156; Naaz Muneshwar 2023: 6). The health of mothers and their children, was constantly at risk during the early medieval period, due to the typical diet of the period having been poor in its nutritional value. The period's economy was agrarian, hence it is not surprising that the diet was dominated by $C^3$ plants, as isotope studies focusing on the dietary intake of the early medieval populations of Britain have determined (Mays & Beavan 201: 873; Hannah 2018: 30-31), and concluded to have been fairly homogenous in the food sources, across the social strata (Leggett & Lambert 2020: 194-196; Leggett 2021: 19). These isotope results align with how often calculus is detected on the teeth of adult human remains dating to the period (on average 39.2% of adult individuals) (Roberts & Cox 2003: 193-194). Yet several of the sites included in this study far exceed this norm, e.g., Barrow Clump: 75% (Dinwiddy & Watts 2019: 206), Leadenhall: 84.5% (Schofield & Lea 2005: 256), Collingbourne Ducis: 89.1% (Dinwiddy & Stoodley 2016: 79-80). This high prevalence of calculus is suggestive of diets dominated by the high intake of carbohydrates. A mother whose diet is dominated by carbohydrates rather than, e.g., animal protein, will likely cause stunted development of their child already *in utero*, and following their birth and breastfeeding. This suggests greater developmental stunting of an individual throughout their formative years during the early medieval period. Poor nutritional intake during infancy can lead to an increase in morbidity and mortality, i.e., a reduction in the immune system which leads to further health complications that reduces the developmental potential of the child, including stature growth. These further health complications are evident in the frequency with which linear enamel hypoplasia (LEH) is recorded for early medieval populations, at a rate of c. 22% of individuals (Gowland & Western 2021). Similar to the prevalence of calculus, LEH greatly fluctuates from site to site, e.g., St Peter's Tip: 5.4% (Duhig 1996), Llandough: 10.3% (Loe 2003: 235), Barrow Clump: 53% (Dinwiddy 2019: 208-209), Collingbourne Ducis: 67.5% (Dinwiddy 2016: 81). Typically, these enamel defects form on enamel at an early age, e.g., at Barrow Clump, these defects can be divided into three phases: age one to four (58.1% of the individuals), suggesting poor nutritional intake already during breastfeeding; age four through seven (90.6%) indicative of the weaning process, and a poor adaption to the carbohydrate-rich diet of the adults; a third of the individuals exhibited periods of greater stressors continuing into early puberty (Dinwiddy 2019: 208-209). Further evidence of poor health during the formative years of the population is indicated by the frequency of cribra orbitalia, which point to towards periods of meatbolical stress, e.g., unsanitary living conditions, or lack in the intake of animal protein, vitamin C or D (Schofield & Lea 2005: 261-262; Walker et al. 2009-120; Loe 20058: 221). Cribra orbitalia occurs at a rate of 35.1% of the human remains of the early medieval period similar to the frequency of calculus. Comparatively to the aforementioned pathologies, some variation is to be found in the prevalence of cribra orbitalia between different sites, e.g., St Peter's Tip: 13%, Melbourn 32%, Llandough: 35.8%, Collingbourne Ducis: 40.2%, Blacknall Field: 50%, Barrow Clump: 50% (Duhig 1996, 2003b; Dinwiddy 2016: 83). During periods of nutritional deficiency in a developing child, growth never ceases completely, yet the velocity may be slowed down significantly, especially the longitudinal growth (i.e., height), whilst skeletal maturation tends to be less affected (Hoppa 1992: 276; Perkins et al. 2016: 150; Brødholt et al. 2022: 11). Each of the above-discussed pathologies is indicative of a generally poor diet throughout the early medieval period, the effect being poor stature growth promotion. Unlike the earlier discussed example of the early 19th century North American slave children, who experienced a vigorous catch-up period around the age of 8-12 due to the increase in animal protein in their diet (Steckel 1995: 1923), it is highly unlikely that the majority of the British populations of the early medieval period ever saw any great improvements in their diets throughout their formative years. Hence the effect of stature stunting throughout the formative years likely had a profound effect on limiting the possible stature achieved in adulthood (Coly et al. 2006: 2415-2419), preventing the full stature dictated by genetic predisposition from being achieved.

When comparing the mean stature achieved in the period: the mean male stature: 168.1cm.

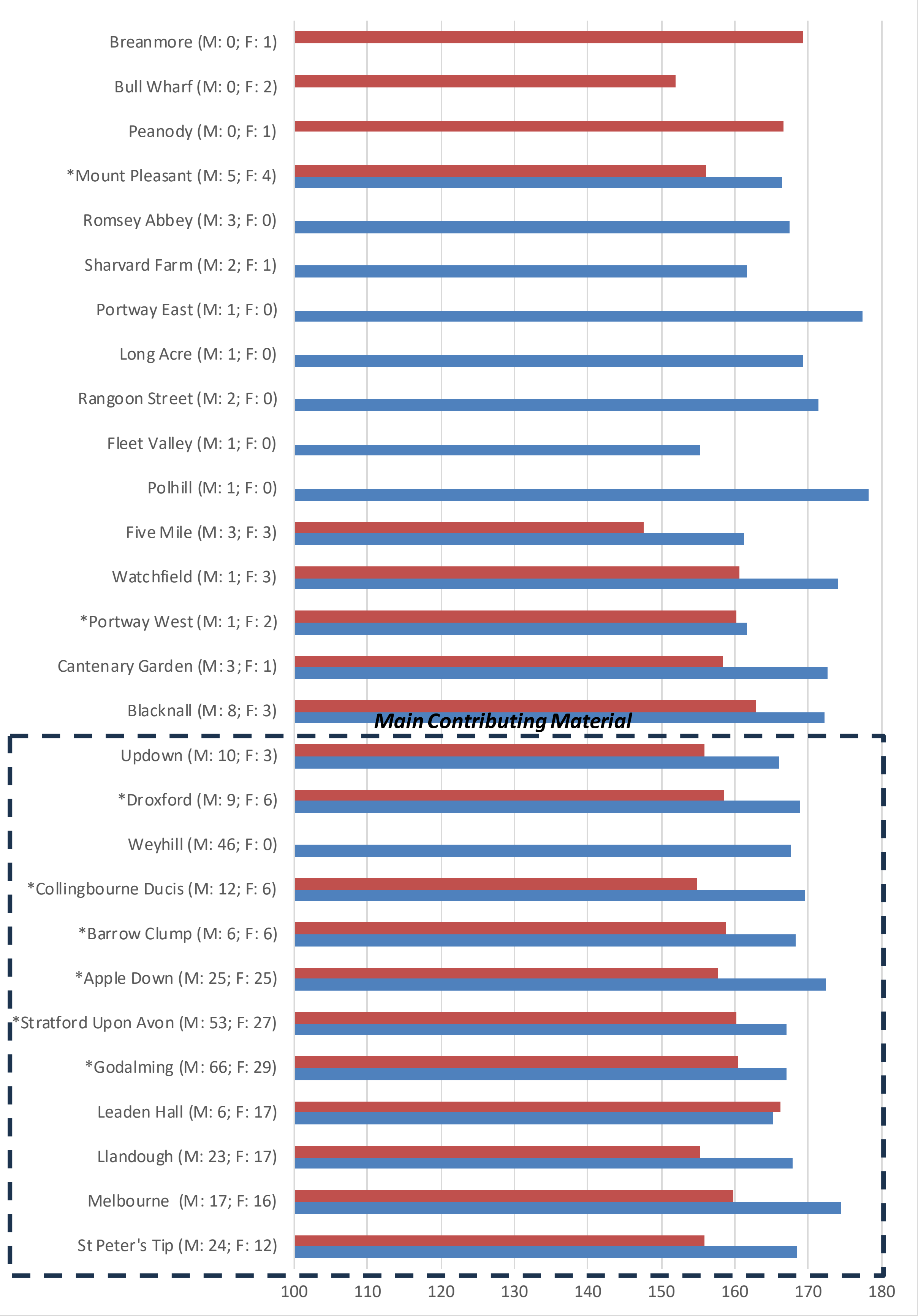

**Fig 42.** The pooled mean stature, i.e., the mean estimated stature of each formulae pooled, for either of the sexes; males in blue, and females in red (M = male, F = female), site names with "*" contributed towards the anatomical base sample. All measurements are in cm.

and mean female stature: 159.2cm (see Fig 42.), to the mean stature of the Romano British period: mean male stature: 164.1cm, and mean female stature: 154.8cm (Walther 2017: 186), an increase is evident. Note only the anatomical stature results of the 63 individuals (36 males and 40 females) of the base sample utilized in Walther's (2017) study are used in the comparison here, as the stature regression formulae produced for the Romano British period suffered from the same erroneous methodology as outlined previously regarding Walther's (2017) early medieval sample's formulae. The male sample of the study period exhibits a stature increase of c.2.4%, whilst a stature increase of c. 2.8% for the female sample when compared to the Roman sample. Hence even with all of the negative health factors affecting the development of stature throughout the early medieval period in Britain, the sample population still follow the common stature trend of an increase over time, from generation to generation (Wilson et al. 2010: 685), or in this case, from period to period. Yet positive secular stature trends over time cannot uniformly be prescribed in archaeology, as, e.g., the decrease in stature of Scandinavian populations following the transition from the Viking age to the high medieval period due to negative secular stature trends (Steckel 2004: 214-216). In the case of the early medieval period in Britain, this increase in stature compared to the Roman era, cannot completely be attributed to secular stature trends, but rather also the influx of foreigners, whose genetic stature predisposition may exceed that of previous populations. The degree to which stature development is determined by genetics or the environment is not completely understood, with estimates ranging from 80-90% (Brothwell 1981; Silventoinen et al. 2003, 2004; McEvoy & Visscher 2009). Hence comparing stature trends between Romano-British populations, and later early medieval populations of Britain, the increase in mean stature of either of the sexes can only tentatively be attributed to be the result of changes in secular stature trends due to, e.g., changes in health standards and environment, and the influx of foreigners with genetical predisposition towards greater average adult stature (Gretzinger et al. 2022; Leggett 2021; Leggett et al. 2022) who likely possessed a genetic predisposition for greater stature achieved in adulthood, than the previous local Briton and Romano populations.

A better stature comparison would be comparing the mean interpopulation stature between sites, over time throughout the period (see Fig 43.). This can be done by plotting out the stature results and organizing it by phase, i.e., early, middle (Final Phase), and late phase, from mid-fifth to late 11th century A.D. To avoid stature anomalies, i.e., smaller site samples with single-digit populations are excluded, as the mean site stature value may be significantly affected by single individuals of taller or shorter stature. The 12 larger (main contributing) sites of the study

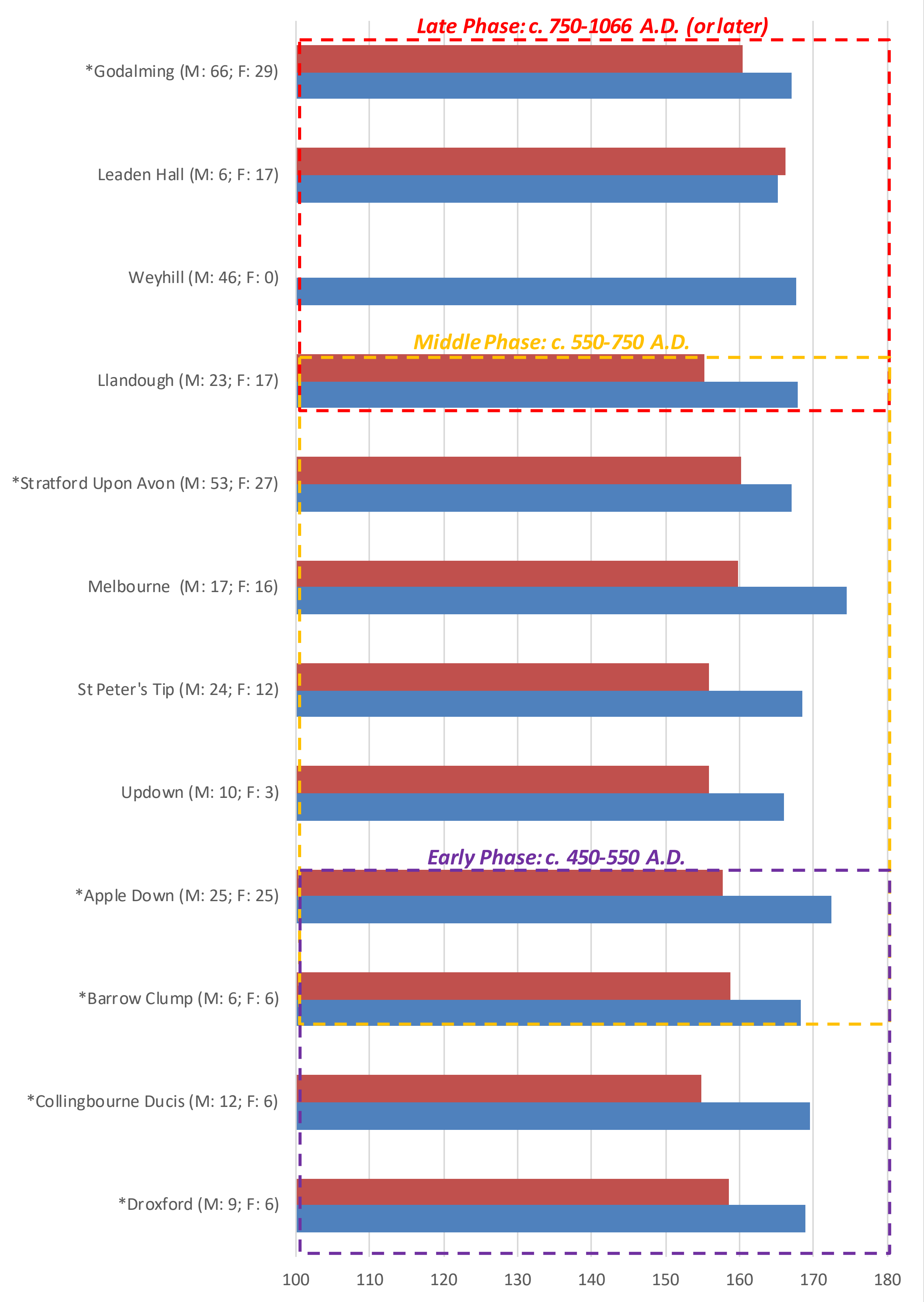

**Fig 43.** The pooled mean stature of the 12 major contributing sites (461 individuals, 297 males and 164 females) organized in accordance to their dating and phasing, i.e., the mean estimated stature of each formulae pooled, for either of the sexes; males in blue, and females in red (M = male, F = female), site names with "*" contributed towards the anatomical base sample. All measurements are in cm.

(461 individuals: 297 males and 164 females) were organized by their material dating in accordance with the three mortuary phases, i.e., early, middle (final), and late phase (see Fig 43.). The mean stature of the early phase: males: 169.8cm and females: 157.5; middle phase: males: 169.5cm and females: 158cm; late phase: males: 166.9cm and females: 160.3cm. A slight decrease in the male stature over time, yet the reverse regarding the female stature, which increases. The female body is more resistant to the changes in external factors and stressors, hence the effect of secular stature trends will be less pronounced (Wolanski & Kasprzak 1976: 548; Jantz & Jantz 1999: 65). Positive and negative environmental stimuli will affect male stature before that of female stature, hence fluctuations in the male stature over time may be a product of short term negative or positive secular stature trends. Changes in female stature over time may rather be indicative of stronger long-term secular trends (Wolanski & Kasprzak 1976: 549). This suggests that when tracing long-term changes, the female population serves as a better metric than the male sample, chronicling long-term improving or declining living conditions. The male sample will on average exhibit greater heterogenous stature trends over time, due to possible short-term factors, e.g., short-term famine, periods of poverty, or conflict, etc. This is representative in the greater error ranges on average achieved with male regression formulae than that of those developed on female samples. In the case of the British early medieval period, the increasing female stature from the early to late phase, an increase of 2.8cm (c. +1.7%), would be indicative of improving health standards throughout the period.

As previously discussed, this increase in stature in the transition from Roman to early medieval period, cannot be attributed to an influx of Germanic males of elite status with greater stature completely (e.g., Thomas et al. 2006), yet it is possible in certain instance, e.g., Finglesham (Leggett 2021). As Gretzinger et al.'s (2022: 117) mitochondrial analysis of the Y or X chromosomal data were able to exclude any subtle levels of sex bias during the admixture, suggesting no greater sex-biases in the Germanic immigration throughout the period, with both males and females arriving in the British isles and permanently settling in fairly equal numbers (Gretzinger et al. 2022: 117; Leggett 2021; Leggett et al. 2022).

The Llandough sample, the only major contributing sample from Wales, exhibits a lower average female stature (155.3cm) than the majority of the sites included in this comparison, only surpassed by Collingbourne Ducis in short female stature (154.9cm). The dating of the material from Llandough covers almost the whole of the early medieval period, as its dating range from the mid-fifth to late-10th century A.D. (Loe 2003: 25; Holbrook & Thomas 2005: 41), hence the stature results of the Llandough material is likely rather reflecting the mean stature of the whole period, rather than a specific phase compared to the other sites. Yet the mean Llandough stature of both males (167.8cm) and females (155.3cm) is lower than the period average (males: 168.1cm; females: 159.2cm). Especially noteworthy is the Llandough female stature, which is c.2.4% shorter than the period average. The only other Welsh site included in this study, Five Mile Lane (three males and three females), which is dated to the 11th to 12th century A.D. (i.e., late phase) (Morgan 2022: 29), yet with a low number of individuals, exhibited an even lower mean female stature of 147.3cm (male stature: 161.4cm). This is likely indicative of less Germanic influence as determined by Gretzinger et al. (2022: 3) for the early medieval Welsh population, but furthermore, suggests secular stature trends less parallel to the contemporary early medieval populations of southern England. These Welsh stature trends, especially of the female sample, are rather more similar to those of the Romano-British period (Walther 2017: 186). Future stature studies utilizing the stature formulae produced in this study on a larger Welsh sample (especially female samples) have the potential to investigate possible parallel stature trends within early medieval Wales compared to contemporary England.

It should be noted, that no Welsh population, or individuals, proved complete enough to be included in the base anatomical sample, that the regression formulae of this study was calculated on, due to the generally low pH values (Fig 7.) of topsoil in Wales, hence good skeletal preservation is rarer, than in southern England. Hence the resulting stature regression formulae can be used with far greater confidence of early medieval English populations, than contemporary Welsh populations. Yet it is unlikely that large enough early medieval Welsh samples will be possible to assemble due to aforementioned issues, hence the formulae produced in this study is likely the greatest stature estimation proxies currently available for early medieval Welsh populations.

On average, the tallest female stature of the period belongs to the Leadenhall female sample: 166.2cm (c. 4.4% higher than the period average), whose stature even exceeds their male counterpart of the site: 165.2cm. This is unlikely to reflect reversed stature sexual dimorphism at the site, but rather is an artefact of the greater number of female individuals possible to calculate the stature for (17 females and six males). The greater levels of urbanization have throughout history had a tendency to adversely affect the general health of the population, and further stunting the development of stature. This is due to the common poor adaptation of past populations to urbanized unsanitary living conditions, hence increasing the rates of mortality and morbidity (Steckel 1995: 1919; 2004: 214), which commonly is the catalyst for negative secular stature trends. The greater level of urbanization likely endured by the population buried within the cemetery of Leadenhall (located within the old walls of Londinium) appears not to have greatly negatively affected the development of stature. This is further evident in the very low rates of LEH (15.4%) detected with the dentition of the population (Conheeney 2005: 260). The low rates of LEH, along with the greater female stature of the Leadenhall population, likely suggests a generally better health status, than that of the wider populations of early medieval Britain. This is the opposite, of what was previously discussed regarding the generally poorer health status of those who inhabited urbanized areas throughout history (e.g., Steckel 1995). The results of Leadenhall may very well be indicative that even larger settlements and urbanised areas in early medieval Britain still exhibited fairly low density in populations, compared to later periods.

#### *10.2.1.1 Final Health Remarks*

To summarize, the high frequency at which calculus, LEH, and cribra orbitalia are recorded for the human remains recovered at early medieval sites in Britain, would suggest a population with a generally deprived health status, which poorly promoted the development of stature. Yet, as is evident with the increasing female stature throughout the period, the general health trends do appear to improve with time, as the average stature achieved in adulthood of a population is entwined with its general health status. This improvement in health is further evident when comparing these female stature results with those of the earlier Romano-Britain period.

# 11. Conclusion

Stature can be interpreted as a metric that reflects the distribution of disease, nutritional intake, or the lack thereof. Furthermore, a mean short stature of a population may represent adverse effects suffered as consequences of, e.g., greater mortality and morbidity, caused by the shortcomings of health factors. When analysing the stature trends of past populations, their shorter stature compared to their modern counterparts is not necessarily solely an artefact of changes in the gene pool caused by later migrations, but rather a product of growth retardation. Stature achieved in adulthood may be up to 20% affected by the cumulative net impact of the nutritional intake (Silventoinen et al. 2003, 2004; McEvoy & Visscher 2009), with the demands of disease and physical labour subtracting further from the net impact (Jantz and Jantz 1999: 66; Perkins et al. 2016: 159). Similar negative stature trends due to aforementioned demands can still be found in modern anthropological studies of populations in developing countries, e.g., Southeast Asia, where undernourishment and excessive physical labour are still common issues in many regions (Subramanian et al. 2010). Comparable negative secular stature trends are evident in the stature results of the early medieval populations investigated in this study.

## *11.1 Interpreting the Early Medieval Stature Results*

Throughout the early medieval period, the generally high intake of carbohydrates, and lack of sufficient intake of animal protein in the typical diet, did not facilitate adequate amounts of nutrients to promote a healthy stature development throughout an individual's formative years. Furthermore, the fairly high rate of linear enamel hypoplasia recorded throughout the period indicates periods of great stressor experience during the formative years. Yet even with the myriad of negative health trends, the early medieval period's population used in this study, consisting of 512 individuals (327 males and 185 females), from 28 sites in southern England and Wales, saw an increase in their average stature: males: 168.1cm (+2.4%) and females: 159.2cm (+2.8%), compared to the previous Roman period. This increase in stature is likely caused by both changes in secular stature trends, i.e., an increase in positive health factors, and the arrival of Germanic foreigners. These Germanic foreigners had likely a genetic predisposition towards greater stature development compared to the earlier Romano-British populations. This is further emphasized by the Welsh materials included in this study (Llandough and Five Mile Lane), which is believed to have been less affected by the Germanic migration, hence the stature trends and mean values are rather similar to those of the earlier Roman period.

The female body is less susceptible to short-term positive or negative external stimuli

(Wolanski & Kasprzak 1976: 548), e.g., malnutrition, hence will exhibit fewer fluctuations in their stature results and trends over time. Due to this lesser degree of stature fluctuation, and rather gradual adaptation to positive or negative secular stature trends, the author of this study suggests that a female population's stature results formulate a far more reliable metric when investigating both stature and health trends over long periods of time, than that of their male counterparts. From the early phase of the period (450-550 A.D.), through the middle phase (550-750 A.D.), to the late phase (750-1066 A.D.), the average female stature increased by 2.8 cm, from 157.5cm to 160.3cm (+1.7%). This gradual positive increase suggests an improvement in the general health status of the population, for both males and females throughout the period, as, e.g., there is little evidence to suggest a general discriminator scheme towards the intake of animal protein between the sexes (Hull & O'Connell 2012: 674-675). The prevalence of metabolically related pathologies, e.g., calculus, LEH (Linear Enamel Hypoplasia) and cribra orbitalia does not appear discriminatory in the frequency of detection for either of the sexes. This is indicative that commonly male and female groups enjoyed similar access to resources, but many times, suffered equally to the adverse effects of disease and poor nutrition which was the reality of the early medieval period in Britain.

## *11.2 Enhancing the Methodology*

This study approached stature estimation with the hypothesis that a superior less tentative result can be achieved when developing stature regression formulae directly on a past population, rather than using the typical formulae calculated by, e.g., Trotter and Gleser (1952, 1958), who developed their stature formulae on 20th-century North American populations (furthermore includes erroneous assertions in regard to its precision). The issue in reusing Trotter and Gleser's 20th-century formulae stems from the fact that body proportions associated with stature, e.g., the correlation between long bones and stature varies temporally, geographically, and ethnically (Mays et al. 2016: 647). Since the inception of the regression method, over a century ago, this has been a known fact (e.g., 1899), yet to this day, the issue remains largely unaddressed, ignored, or approached as an arbitrary issue. However, as stature has been estimated as a factor of 10-20% (Brothwell 1981, Silventoinen et al. 2003, 2004; McEvoy & Visscher 2009) genetic predisposition, it should not be trivialized, nor should it be treated as a factor for which parallels can be drawn between modern populations' stature trends, and that of past populations, without further evidence to support such assertions. The comparative results presented in Table 29. (male stature), and 30. (female stature) proves that far more accurate results are possible to achieve with formulae that are temporally, geographically, and affinity-related to the population whose stature is being estimated. The greater fit of the formulae produced in this study, for either of the sexes, calculated on the early medieval populations of Britain, was established through the usage of OLS RSS (Ordinary Least Square Residual Sum of Squares) values, along with the results achieved through the analysis of the sample populations studentised residuals. As discussed in the previous chapter, the author of this study argues that RSS values are far better metrics for comparison of applicability and accuracy between two or more formulae applied on one and the same population. In previous studies, the issue of comparison between stature formulae, or approaches, tended to be compared through the calculated error ranges, or estimated stature results. However, stature and error range formulae can be imbued with erroneous factors (e.g., Trotter & Gleser 1952, 1958), hence may be a poor comparative metric. While RSS values are the calculated vertical deviation from the original living stature (or anatomical stature) of the base sample. The greater the vertical deviation of an estimated stature is from the original base sample's stature, the greater the error range will be, suggesting a poor fit. Future stature studies, either approaching the development of new regression formulae or applying the borrowed stature regression formulae developed on other populations, should utilize a similar approach pf RSS values as a determinative metric for which formulae is a superior fit for a specific population (i.e., when a larger base sample is available for comparison).

### *11.2.1 Pooled Samples*

Body proportions are not solely (nor for that matter predominantly) a product of secular stature trends, only c. 10-20% (Brothwell 1981, Silventoinen et al. 2003, 2004; McEvoy & Visscher 2009), the opposite of what Sjøvold (1990) argued, and who further argued that sexual dimorphism only has a negligible effect on the final stature achieved in adulthood. Sexual dimorphism in regards to stature development can be easily traced through the usage of logarithms ($log_{10}\ \beta_1$; Table 17., further addressed below), determining the scaling factor of each long bones in relation to the full stature achieved in adulthood of a sample population. There is a marked difference when comparing male to female growth rates, with the latter being higher, as female individuals achieve their final adult stature at an earlier age than their male counterparts. Furthermore, the greater homogenous trends regarding female stature (as discussed above), means that any stature formulae calculated on a pooled sample will not benefit the female sample. The conclusion which can be drawn from the above discussion and results is that Sjøvold's (1990) pooled sex stature method, introduces far greater heterogeneity to the sample, than that of a sex-specific formulae. This greater heterogeneity negatively affects the results of either of the sexes, as a higher RSS value is the result, but to a far greater degree negatively affects the results of female samples. Furthermore, when a disparity exists between the number of individuals of either sex, as is the case of the base sample of this study (i.e., 40 males and 29 females), then the body ratios of one of the sexes will have a greater effect on the calculation of the regression line. This is seen in Fig 41., with the regression line of the pooled sex sample being drawn near parallel with the male sample, yet straying from the female sample's line. This is an artefact of the greater number of males, and the greater heterogeneity in the stature trends of the sample, illustrated in the greater variation in the vertical and horizontal spread of the male sample.

Comparative to pooled sex samples, similar issues of dilution of accuracy in past stature studies (e.g., Ruff et al. 2012, 2018) are encountered in studies of larger non-temporal and geographical samples that have been pooled together, to achieve a larger base sample (see Table 29. and 30). This is the case, as the regression line will always mirror the trends of the majority of the sample, i.e., the larger segment of the sample will dictate the stature trends of a pooled sample's calculated regression formulae. If an even number is possible to achieve between one population, or several populations that have been pooled together, and their regression lines prove to be parallel, it will result in a new pooled regression line based on the average value of the previous separate lines. This new regression line will not accurately trace the stature trends of any of the populations, rather merely the adjacent trends (see Fig 39., 40 & 41), hence is a lesser approach, compared to developing regression formulae on separate populations, with each of the sexes approached separately.

### *11.2.2 Assembling the Base Sample and Calculating the Regression Formulae*

A common issue faced when utilizing the anatomical method is the low rate of complete skeletons recovered. The preservation and completeness of the 512 individuals included in this study, were fairly uneven. Only 69 individuals proved complete enough as to have their stature estimated with the anatomical method: 40 males and 29 females (see Table 15. And 16.). The reason for this limited number (yet higher in the number of individuals used with the anatomical method than in previous stature studies utilizing single temporal populations, e.g., Boldsen 1984; Maijanen & Niskanen 2009; Vercellotti et al. 2009), is due to the generally high levels of acidity (i.e., pH values of ≤6.5) in British soil (see Fig 7.), which affect the bone preservation in many regions of Wales and southern England (Williams-Wards 2017: 21). Several individuals' almost filled the criteria level of skeletal completeness required by the anatomical method (from the scalp to the heel), yet were commonly lacking in recovery rate of the vertebrae column. This issue was addressed by the use of the missing vertebral elements formulae established by Auerbach (2011), which allowed for the estimate of the cervical and thoracic region when missing, allowing for a further expansion of both the male and the female sample used with the anatomical method. Auerbach's (2011) formulae for estimating missing crucial skeletal elements for stature estimation is critical in the collection of base samples to calculate regression formulae on, hence should be given greater consideration in future archaeological stature studies.

Following the assemblage of a sufficiently large enough British early medieval base sample, of either of the sexes, with each individual's stature established through the anatomical method, the long bone length could be regressed toward the anatomically estimated living stature. When these values had been formulated, then the mode, and formulae used to calculate the regression formulae were possible to analyse. One of the long-standing issues within stature studies regards the use of either OLS (Ordinary Least Squares) or RMA (Reduced Major Axis) formulae when establishing the initial regression formulae, but furthermore, also relates to the calculation of error ranges. This has previously been considered an arbitrary issue, without any clear solution, and has been suggested as having a minimal effect on the final accuracy of the formulae beyond decimal points (e.g., Sjøvold's 1990; Maijanen & Niskanen 2009; Mays 2016; Rosenstock et al. 2019). A simple solution to the issue is to determine if long bone scaling in relation to the adult stature of the sample population, which is either isometric i.e., equal, hence favouring the use of RMA formulae, or allometric, i.e., uneven, either at a greater or lesser degree, which would point towards the preferable use of OLS formulae (Smith 2009: 482; Kilmer & Rodriguez 2017: 8). Through the use of logarithms, it was possible to settle the issue. Each long bone's stature scaling factor, of either of the sexes, proved positively allometric towards the full stature in adulthood. The only exception was the humeri, which exhibited a negative allometric scaling factor. However, this was not possible to calculate for the female sample due to the low number of measured humeri of the base sample, nor was it possible to calculate female regression formulae for it.

With the issues of OLS or RMA settled in favour of OLS, and the length of each long bone (femur, tibia, and humerus) regressed against the full living stature estimated through the anatomical method, linear regression formulae were possible to calculate, for either of the sexes ([27-72]), with accompanying error range formulae. This allowed for the stature to be estimated for the remaining 443 individuals (those who were not recovered in a complete enough state to be considered for use with the anatomical method). The final number of adult individuals whose stature was estimated in this study were 512 individuals (185 females and 327 males), whose remains had been uncovered at 28 British early medieval sites; the majority of the sample, 461 individuals, 297 males, and 164 females belonged to 12 sites, ranging in date. These 12 larger sites allowed for a more detailed analysis and discussion (presented in the previous chapter, Fig 42. & 43.).

## *11.3 A Final Note*

The scope of many past archaeological stature studies has been too narrow, and commonly the discussion and the development of the methodology have been neglected, or lack specificity and empiricism, hence preventing replication. This lack of scholarly interest in stature methodology has typically resulted in erroneous applications of the methodology and the development of new regression formulae, error ranges, and the succeeding analysis of the stature results. Hence due to these aforementioned issues with the application of the methodology, both with the anatomical (to a lesser extent) and the regression method (to a greater extent), a core emphasis of this study has been on transparency, and empiricism, in the breakdown of each step in the calculation of the regression formulae, based on the sample calculated through the anatomical method. One of the aims of this study has been to rectify these past contentious factors of stature estimation based on the metrics of skeletal remains, by codifying proper stature methodology, on a step-by-step basis, ranging from stature equations, calculations, and limitations in the interpretation of the results (e.g., health status). This has been achieved in the methodology chapters and further problematized in the results and discussion chapters.

The methodology assembled in this study is the most complete and detailed to date within the scholarship of stature estimation. Moving forward, the steps outlined in the methodological chapter can benefit future stature studies with similar aims as those of this study to formulate new temporal and geographic-specific stature formulae. The results of this study have proven that far superior stature estimates can be achieved, with reasonable error ranges, when a large enough base sample can be assembled and used with the anatomical method, which results then serves to regress the long bone length in relation to the full stature, allowing for linear regression formulae to be calculated. These succeeding stature formulae produced estimates which exhibited lower stature estimate variability (i.e. RSS: Reduced Sum of Squares) than those formulae typically used in the past which had been calculated on 20th-century populations (e.g., Trotter & Gleser 1952; 1958), or those archaeological studies which utilized pooled samples ranging in geography, temporality and sex (e.g., Sjøvold 1990; Ruff et al. 2012; Ruff 2018). Future stature studies should hence focus on attempting to establish a greater number of temporally and geographically specific stature formulae, rather than borrowing formulae from unrelated periods and populations. This will allow for greater empiricism, more valid stature reconstruction and more confident resultant interpretations surrounding health and society.

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