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Dental Metric Standards for Sex Estimation in Archaeological Populations from Iran

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Declaration

I hereby certify that this thesis has been composed by myself, is my own work and has not been submitted for any other degree of professional qualification.

Date.....22.5.2017..... Signature....  .....

Abstract

Sex estimation of skeletal remains is one of the major components of forensic identification of unknown individuals. Teeth are a potential source of information on sex and are often recovered in archaeological or forensic contexts due to their post-mortem longevity. Currently there is limited data on dental sexual dimorphism of archaeological populations from Iran. This dissertation represents the first study to provide a dental sex estimation method for Iron Age populations.

The current study was conducted on the skeletal remains of 143 adults from two Iron Age populations in close temporal and geographic proximity in the Solduz Valley (West Azerbaijan Province of Iran). 2D and 3D cervical mesiodistal and buccolingual and root volume measurements of maxillary and mandibular teeth were used to investigate the degree of sexual dimorphism in permanent dentition and to assess their applicability in sex estimation. In total 1327, 457, and 480 anterior and posterior teeth were used to collect 2D cervical, 3D cervical, and root volume measurements respectively. 2D cervical measurements were taken using Hillson-Fitzgerald dental calliper and 3D measurements were collected using CT images provided by Open Research Scan Archive (ORSA) - Penn Museum. 3D models of the teeth were created using manual segmentation in the Amira 6.01 software package. Since tooth density largely differs from crown to apex, root segmentation required two threshold levels: the segmentation of the root from the jaw and the segmentation of the crown from the root. Thresholds used for root segmentation were calculated using the half maximum height protocol of Spoor et al. (1993) for each skull, and thresholds used for crown segmentation were set visually for each tooth separately. Data was analysed using discriminant function analysis and posterior probabilities were calculated for all produced formulae where sex was previously assessed from morphological features of pelvis and skull. Bootstrapping was used to account for small sample sizes in the analysis. Statistical analysis was carried out using SPSS 23. The percentage of sexual dimorphism was also used to quantify the amount of sexual dimorphism in the sample.

The results showed that incisors and canines were the most sexually dimorphic teeth, providing percentages of correct sex classification between 80% and 100% depending on the measurement used. Root volume measurement was shown to be the most sexually dimorphic variable providing an accuracy of over 90% in all functions.

The present study provided the first dental metric standards for sex estimation using odontometric data in Iranian archaeological populations. Dental measurements, particularly root volume measurements, were found to be of value for sex assessment and the method presented here could be a useful tool for establishing accurate demographic data from skeletal remains of the Iron Age from Iran.

To my twin sister Anahit

I know at the end of the day we are always going to have each other

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List of abbreviations

MD	Mesiodistal
BL	Buccolingual
RV	Root volume
UI1	Upper first incisor
UI2	Upper second incisor
UC	Upper canine
UP3	Upper third premolar
UP4	Upper forth premolar
UM1	Upper first molar
UM2	Upper second molar
UM3	Upper third molar
LI1	Lower first incisor
LI2	Lower second incisor
LC	Lower canine
LP3	Lower third premolar
LP4	Lower forth premolar
LM1	Lower first molar
LM2	Lower second molar
LM3	Lower third molar
ORSA	Open Research Scan Archive

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CHAPTER 1 INTRODUCTION

"Show me your teeth and I will tell you who you are"

Baron George Cuvier (Hillson, 2002, p.1).

In the field of human osteology, sex estimation is an important step in developing the biological profile of individuals and populations. Sex estimation is an integral and foremost step for developing a reliable biological profile during examination of skeletal remains. Accurate estimation of sex is vital in estimation of age at death, ancestry and stature as there are observable differences in ageing and growth patterns between sexes, and variations in morphological traits related to ancestry (White and Folkens, 2005). Also, in forensic cases, correctly sexing an unknown individual can reduce the number of possible matches to missing persons by fifty percent (Moore, 2013). Moreover, bioarchaeologists analyse sex profiles of populations to see how demographic profiles have changed over the centuries to try and understand patterns of mortality or to assess how funerary customs and social attitudes to death have changed through time. Also, the sex-related health status differences as revealed by human skeletal remains and more particularly, palaeopathology help the bioarchaeologist identify the health differences between the sexes by examining the influence of sex (biologically-determined) and gender (socially-determined) on the prevalence, distribution and pattern of disease in skeletal populations (Storey, 1998).

There are a number of methods that can be used to estimate the sex of human remains, varying from visual assessment to metric analysis of sexually dimorphic traits. It has long been established that the pelvis is the most reliable area for sex estimation, because of variation in the size of the female pelvis due to reproductive requirements (Pickering and Bachman, 1997; Byers, 2002; Bass, 2005). After the pelvis, the skull was for a long time considered the next most reliable sex-related skeletal indicator. Yet the results of previous studies (e.g. France, 1998; Spradley and Jantz, 2011) show that most elements of the postcranial skeleton perform better than the skull when assessing sex if metric methods are used. In a majority of archaeological excavations,

however, not all the bones of a skeleton are recovered, due to the influence of environmental and taphonomic conditions. A more durable and stable element in the human body would therefore be preferable for the development of a widely applicable and reliable sex estimation method. Tooth enamel is the hardest and the most highly mineralized substance in the human body (Nanci, 2007; Bush et al., 2006), and is extremely resistant to post-mortem damage and disintegration. This resilience makes teeth very important in the identification of skeletal remains, particularity when standard identification methods cannot be applied due to poor preservation (Anderson et al., 1995; Hutt et al., 1995; Scott and Turner, 2000; Schmidt, 2008; Fereira et al., 2008). Applications of discriminant function analysis in several studies have resulted in 77-100% accuracy in odontometric sex estimation (Ditch and Rose, 1972; De Vito and Saunders, 1990; Acharya and Mainali, 2007; Hassett, 2011; Zorba et al., 2012; 2014; Viciano et al., 2015; Tardivo et al., 2011; 2015), further increasing the role of dentition in this field.

Sex assessment from dental tissue is mainly based on a comparison of either the differences in tooth size between males and females, or the frequencies in their non-metric dental traits (Vodanovic et al., 2007); for example, Carabelli's trait in upper molars, shovelling of the upper central incisors, or the distal accessory ridge of the upper and lower canines (Teschler-Nicola and Prossinger, 1998). Sex estimation using tooth measurements also relies on the general trend of males having larger teeth than females. The most commonly reported tooth measurements for sex estimation are the maximum mesiodistal and buccolingual crown measurements (Black, 1978; Hattab et al., 1996; Kondo and Townsend, 2004; Acharya and Mainali, 2007; Pereira et al., 2010; Gonçalves et al., 2015; Sharma et al., 2013). These measurements, however, are difficult to obtain in crowns that are embedded in the jaw or that are highly affected by dental wear, which is the most frequent condition in archaeological samples. In addition, common dental pathologies such as occlusal caries and the expression of non-metric dental traits can also considerably impact the efficacy of crown measurements. To solve these problems, alternative measurements of cervical tooth diameters were proposed by Hillson et al. (2005). These measurements are taken at the cervical margin of the crown along the cemento-enamel junction. Hillson et al. (2005) and

Stojanowsky (2007) proposed that cervical measurements provide similar results to traditional crown measurements and are much less affected by dental wear. These measurements are particularly useful in studies of prehistoric skeletal remains as they allow for the inclusion of teeth with alterations on the crown due to wear, pathology (e.g. caries), cultural modification or post-mortem damage. This allows a larger dataset to be obtained, with a broader range of ages represented. Different studies have used cervical measurements for sex estimation and have confirmed their efficacy in this respect (Vodanovic et al., 2007; Hassett, 2011; Viciano et al., 2011; 2013; 2015, Tuttösí and Cardoso, 2015; Peckmann et al., 2015).

A large number of studies have demonstrated that the degree of sexual dimorphism in teeth varies between populations (Bishara et al., 1986; Ates et al., 2006; Acharya and Mainali, 2007; Prabhu and Acharya, 2009; Khamis et al., 2014; Peckmann et al., 2015), as a result of genetic and environmental factors (Kieser, 1990; Hughes and Townsend, 2013). To be able to use dental measurements for identification, it is therefore necessary to first determine specific population values. The data can then be used to assess sex in particular cases, both in individuals and in groups, such as in archaeological sites or in the case of mass disasters (Ghose and Baghdady, 1979; Balciuniene and Jankauskas, 1993; İşcan and Kedici, 2003). Sexual differences in dental measurements have been well studied in many different archaeological populations (Owsley, 1982; Stojanowsky, 2007; Vodanovic et al., 2007; Hassett, 2011; Viciano et al., 2011; 2015; Tuttösí and Cardoso, 2015); however, currently, there are no reference studies for sex estimation using odontometric data in Iranian archaeological populations, which form the focus of the current study. Due to this lack of research, establishing population structure using Iranian collections is very difficult. But it is clear that the data obtained from other populations may not be accurate. This study took advantage of two unique skeletal collections, from the Hasanlu and Dinkha Tepe sites, to develop the very first dental metric standards for sex estimation in Iranian archaeological populations. The Hasanlu collection alone contains a total of 263 individuals, which makes it one of the larger skeletal collections not just from Iran but from the Near East as a whole. Moreover, the Hasanlu and Dinkha Tepe osteological collections represent two of only a few well-preserved skeletal collections

from Iran. These sites were excavated over ten seasons from 1957 to 1977 by a joint team from Iran and the United States, directed by Robert Dyson. The early samples of these skeletons were initially shipped to the University of Kansas and were then divided between the University of Tennessee and the University of South Carolina. The later skeletons (1965–1977) were housed in the University of Pennsylvania Museum of Archaeology and Anthropology. The collection was completed when in the late 1980s, the other skeletons from the site were also sent there.

The Hasanlu skeletal collection is important for two main reasons: first, the scarcity of the remains from this particular region and, second, the exceptional archaeological context within which it is located: the Hasanlu site consists of a cemetery group (*c*. l450–*c*. 800 BCE) and a collection of individuals that belong to a sacked city. The present study is mainly focused on the contemporaneous Iron Age sub-samples that were obtained from the cemetery located in the Low Mound (*c*. l450–*c*. 800 BCE) and the destruction level belonging to the High Mound (*c*. 800 BCE). The majority of the skeletons (210 individuals) were obtained from the latter, which is referred to as the Pompeii of the Iron Age Near East, due to its being able to provide an exceptional collection of data regarding a large settlement in this period.

1.1. Research Objectives

In the presents study, the sex of the skeletons was estimated using 1) morphological features of the pelvis and skull, and 2) dental measurements. A comparison was then made between the results obtained from osteological methods and those obtained from dental methods. To collect the odontometric data, the present study initially used the cervical mesiodistal (MD) and buccolingual (BL) measurements proposed by Hillson et al. (2005) for sex estimation, utilising the Hillson-Fitzgerald dental calliper. Dental samples from Hasanlu and Dinkha Tepe, similar to other archaeological samples, presented medium to severe dental wear, which prevented the author from using crown measurements. In the course of the cervical measurement collection it became clear to the author that Hillson et al.'s (2005) method presents a set of limitations which reduces its applicability and efficacy for odontometric sex estimation, particularly in

the case of archaeological samples (see Chapter 8). The decision was therefore made to see whether it would be possible to tackle these limitations and introduce a more suitable and efficient method instead. The researcher used Computed Tomography (CT) scan images to collect cervical measurements on 3D models of each tooth separately. 3D images offer researchers a non-destructive, non-invasive method of studying skeletal and dental remains, which is very advantageous, especially when dealing with fragile material. This technology also enabled the researcher to introduce a complimentary parameter for sex estimation using those parts of the teeth, such as tooth root volume, which it is not possible to measure accurately using traditional 2D measurement methods.

The objectives of the presents study are therefore as follows:

1) To develop the first dental metric standards for sex estimation in archaeological populations from Iran via a case study of the Hasanlu and Dinkha Tepe skeletal collections.

2) To assess the applicability of 2D cervical measurements in sex estimation for the Hasanlu and Dinkha Tepe collections.

3) To examine the application of Hillson et al.'s (2005) method to archaeological samples.

4) To explore in what ways the 2D cervical measurement method can be modified, and how reliable these modifications are for sex estimation in the Hasanlu and Dinkha Tepe collections.

5) To assess whether tooth root volume be used as a new parameter for sex estimation, and how reliable this method is.

1.2. Organization of the Dissertation

The dissertation is divided into nine chapters, each of which contributes to the objectives presented here. Chapters 2, 3 and 4 discuss the most common methods of sex estimation in adults. Chapter 2 provides an overview of morphological and metric sex estimation methods using different bones, with a focus on methods involving the pelvis and skull, as they are used in this analysis. Summary tables are provided outlining some of the publications regarding different sex estimation methods using different bones.

Chapter 3 discusses odontometric sexual dimorphism and the factors related to size differences between male and female dentition. This chapter also reviews the common odontometric methods for sex estimation and the limitations that each method presents, and summarises key publications related to dental measurement sex estimation methods.

Chapter 4 includes a brief discussion of virtual anthropology and image analysis techniques in sex estimation studies. This chapter also outlines the advantages of 3D analysis methods compared to traditional 2D analysis methods. A summary table of previous publications is provided in this chapter in order to offer a better understanding of the various methods' efficacy in sex estimation.

Chapter 5 gives a description of the Hasanlu and Dinkha Tepe sites and excavations, and also outlines previous research on the collections. This chapter also describes the skeletal collections, explaining the number of individuals and the period they are associated with. It also provides a complete description of the 2D cervical, 3D cervical and root volume (RV) measurement methods used in data collection and statistical analysis.

Chapter 6 outlines the age and sex distribution of the samples, the total number of teeth used in each method, and provides the results of the statistical analysis.

Chapter 7 explains the limitation of the present study and the methods used to tackle these limitations.

Chapter 8 provides a discussion of the results of the research. This chapter offers a summary of the results and compares the results of each method to the literature, as well as to other methods used in the research, in order to determine which method is the more suitable for sex estimation in archaeological samples. The various objectives of the study are also presented and discussed.

The author concludes this dissertation with Chapter 9, which includes a summation of the data presented in previous chapters and discusses future research directions.

1.3. Contribution of the Present Study

Iran is a country with a rich history and many archaeological sites. Every year several archaeological excavations are held in different regions and human remains are often one of the main findings. Unfortunately, since biological anthropology is not being taught extensively at Iranian universities, there are few specialists able to analyse the skeletal remains uncovered. However, this lack of expertise and scientific knowledge in the field has greatly affected the study and publication of skeletal materials from Iran. Thus, there is not a lot of data available, and even fewer studies using the most recent methods of skeletal and dental biology. Most of the remains are left in museums and are being neglected without being analysed and studied by experts. This is tragic, as these remains can provide valuable sets of information that could shed light on dark aspects of the past populations living in Iran. This calls for urgent research and scientific analysis of Iranian archaeological human remains so that this wealth of information is not wasted, and so that past Iranian populations can be studied and analysed in more accurate detail.

There have been only a few studies conducted in recent years on human remains from Iran. In these studies, laboratory-based methods such as isotope and DNA analysis

have been used to analyse the origin of agriculture, paleodiet, and immigration in the Neolithic and Palaeolithic periods (Trinkaus et al., 2008; Broushaki et al., 2016; Gallego-Liorente et al., 2016). However, these studies do not deal with basic aspects of bioarchaeology, such as sex estimation methods, which is the first step in creating a biological profile of human remains from Iran. This becomes even more important in terms of dental and skeletal metric sex estimation methods which are population-specific; the standards from one population cannot be used on other populations. The present study provides the first dental metric standards for sex estimation in Iranian archaeological populations. The focus of this study is on skeletal remains from the Hasanlu and Dinkha Tepe collections, which are among the most important collections in Near Eastern archaeology, and especially in Iran. This collection is the only relatively large well-preserved skeletal collection from Iran, and is the only collection of which the physical and virtual data were available. This made this collection the best collection for analysis due to the purposes of this study, which is focused on introducing a new parameter for sex estimation, volume of the tooth root, which cannot be studied using traditional 2D methods.

The dental metric standards for sex estimation for Iranian archaeological populations provided in this study are important in regards to their application to unknown skeletal remains from Iran around the same period (the Iron Age), and are also a good starting point for developing further standards for different regions and different periods. In addition, using tooth root volume for sex estimation could be very helpful in estimating sex in poorly-preserved and fragmented archaeological skeletal collections.

The excavations conducted in Hasanlu provided the researchers with a large amount of archaeological material and associated data. In spite of much of the collection having already been scientifically tested and studied, there is still a wide range of research topics left to be conducted on it. The current study's analysis of the skeletal remains of Hasanlu provides a better understanding of the inhabitants of this site in terms of the level of sexual dimorphism. It will be a valuable source for those studying, for example, the biological relationships within or between Hasanlu and Dinkha Tepe, or performing further research on sex estimation techniques, for instance using non-

metric dental variations. The data presented here can also be used as a comparative base for the analysis of other skeletal remains that have been obtained from the area, such as those of Khoda-Bandeh.

The present study also develops the application of 3D technologies to the achievement of anthropological goals. The methods proposed here are very useful for sex estimation, particularly in more fragile samples, such as archaeological remains, due to the non-invasive nature of the image analysis methods. In addition, the RV measurement method can be used in teeth with a higher degree of wear or other pathological conditions, which limit the efficacy of other dental measurements; this makes the RV method an extremely valuable technique in poorly-preserved archaeological samples.

The present study provides a set of interesting data and information regarding the Hasanlu and Dinkha Tepe skeletal collections. It should be noted here, however, that due to these collections being a valuable source of biological information, it is also possible to analyse and study them in the light of many other research topics. Even during the process of data collection in this study, several projects presented themselves that could be conducted in the future. Examples would be carrying on developing further new and advanced techniques to determine the sex of archaeological skeletal material, studying the metric dental variations between the Hasanlu and Dinkha Tepe populations, and understanding the biological relationships within and between the Hasanlu and Dinkha Tepe collections. In addition, both 3D cervical and RV measurement methods could be examined further on larger modern/archaeological collections from different periods and regions, to check the applicability of these methods in sex estimation in other populations. In addition, the methods suggested in this study can also be used for sex estimation in immature individuals, considering the fact that the crowns of permanent teeth develop early and, once formed, remain unchanged during growth and development. Sex estimation of immature individuals is useful for specific additional analysis in this particular collection because it is thus possible to determine the demographic patterns of the population (survival and mortality), nutritional stress, diseases, growth and

development, and distribution of pathological conditions (caries, fractures, infectious diseases, etc.). These important aspects of the lives of children in the past have remained hidden because, as a rule, anthropological work on archaeological populations has been focused on the adult sample, leaving aside the subadults, thereby producing a bias in the paleodemographic profile of the population. The sex estimation of subadults in the Hasanlu and Dinkha Tepe collections is beyond the scope of the current study, but the methods presented here provide a good starting point for further analysis in this field.

Before and during this study, the researcher confronted a series of limitations regarding the knowledge that could be gained from this research. These limitations are related to accessing the collection, collecting data from archaeological samples that generally are more incomplete in comparison with modern samples, and determining how far the skeletons under study represent the overall population. A detailed discussion of these limitations and how they have been tackled or have affected the results is presented in chapters seven and eight.

It is hoped that the current study will provide a strong foundation on which future skeletal and archaeological studies related to Hasanlu and related sites can be based. Further research discussion will be discussed in chapter 9.

CHAPTER 2 SEX ESTIMATION BASED ON BONES

2.1. Introduction

Physical and forensic anthropologists mostly prefer to use the term 'sex' instead of 'gender'. Sex is defined as the biological and physiological traits by which men and women are defined, while gender is related to the roles, activities, and behaviours that are socially constructed and therefore regarded by society as appropriate for men and women.

It is due to sexual dimorphism that male and female skeletons can be differentiated. Sexual dimorphism "generally refers to size and shape differences between males and females of a given species" (Langley et al., 2013, p.140). The differences between men and women in all known human populations are in their primary and secondary sex traits; the former referring to those characteristics that are directly linked with reproduction (male and female genitals), and the latter referring to all the other traits that are not directly linked to reproduction, such as women's breasts, the larger average size of men compared to women, and their greater amount of body hair, strength, and subcutaneous fat (Kornblum, 2011). Sexual dimorphism is usually used for secondary sex traits. The soft tissue differences that are easily detected as the differentiations between male and female bodies are not the only representations of sexual dimorphism; these differences are also exhibited in the hard tissue of the skeletons. Compared to men, the size of the female skeleton is generally smaller and the morphology is more gracile. Therefore, when dealing with a large collection of bones of mixed sex, those elements that are large and most robust are generally considered male, whereas the smallest and most gracile elements are regarded as female. One of the reasons for the differentiation between male and female skeletons is the hormonal differences between the two sexes. From the moment that conception takes place, the sex of the individual is determined in the chromosomes: a female has two X chromosomes and a male an X and a Y. Depending on the chromosomal sex, ovaries or testes are developed in the foetus. It is the hormones secreted by the testes that cause the development of the features of the body that characterize males. As the time of

puberty approaches, there is an increase in the production of sexual hormones, which eventually causes the sexually dimorphic skeletal traits that appear at adulthood to develop. For this reason, it is easier to assess the sex of skeletons of adults and much more difficult for subadults. In addition, there is inconsistency in sexual dimorphism across all human populations, with some groups exhibiting higher levels of sexual dimorphism. This factor makes these methods population-specific. Sexual dimorphism can be affected by diet, lifestyle-related factors (such as activity levels) and random individual patterns of maturation (Taylor and Kieser, 2016).

Using sexually dimorphic skeletal traits, multiple methods have been developed for sex estimation, generally divided into two categories: morphologic analysis and metric analysis. Each of these methods uses certain bones or overall patterns based on the level and the quality of sexual dimorphism in the bone or anatomic region under study. As discussed previously, compared to morphologic methods, metric methods are regarded as more objective. When it comes to sex assessment, however, the most reliable method is a visual assessment of the pelvis. Next in line are methods in which the dimensions of various long bones of postcranial skeletons are used to assess sex, followed by those using the skull measurements (Spradley and Jantz, 2011).

2.2. Morphological Sex Assessment

2.2.1. Pelvis

The classification of methods of sex assessment is made according to the types of data used for sexing. Morphological methods of sex estimation primarily rely on a visual examination of the size and shape of skeletal materials. The pelvis (os coxae, sacrum, and coccyx) is recognized as the most reliable region to estimate the sex of an adult skeleton (Meindl et al., 1985; MacLaughlin and Bruce, 1990; Bruzek, 2002; Ari, 2005; Gonzalez et al., 2009; Decker et al., 2011; Zech et al., 2012; Franklin et al., 2014; Hayashizaki et al., 2015) because the form of these bones exhibit specific functional adaptation in the morphology of male and female reproductive capacity (Chamberlain, 2006). The male pelvic structure has evolved to accommodate bipedal locomotion. In

females, however, pelvic morphology reflects modifications ensuring that childbearing is also possible (Tague, 1995). In overall shape, the female pelvis is more oval and flattened, while the male pelvis is taller and narrower. Additionally, in the female, the inlet is wider and more circular, whereas in the male, it is narrower and more heart-shaped. Females also exhibit greater pelvic diameter and a larger outlet (Pace et al., 1965; Crouch, 1982; Cox and Mays, 2002; İşcan and Steyn, 2013) (Fig. 2.1). Aspects of these morphological differences in the pelvis provide osteological sex indicators.

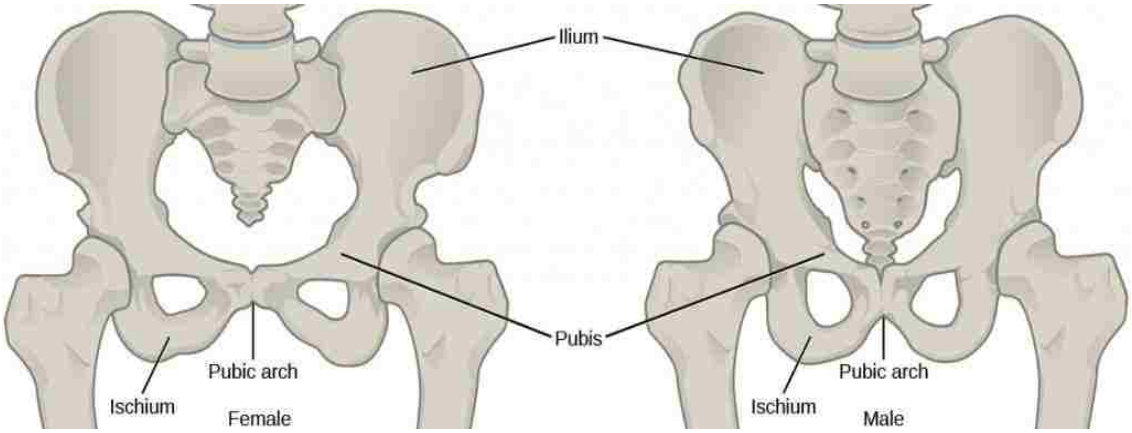

Fig 2.1. Differences between the male and female pelvis. Source: <https://cdn.vortala.com/childsites/uploads/1112/files/Pelvic-differences 1024x354.jpg.>.

In 1969 Terrell Phenice designed an important method for sexing the pelvis. His paper "A Newly Developed Visual Method of Sexing the Os Pubis" describes the most accurate method that has ever been proposed for the assessment of sex from human skeletal remains (White and Folkens, 2005). Phenice's method uses three traits: the ventral arch, subpubic concavity, and the medial aspect of the ischiopubic ramus. He observes that female individuals generally show the development of (1) a ridge on the anterior surface of the pubis known as the ventral arc, (2) the subpubic concavity, a depression located just below the symphysis in the ramus, and (3) medial aspect of the ischiopubic ramus, all of which are not typically displayed by males. The presence of these characteristics, therefore, indicates a female, while their absence indicates a male. Phenice (1969) applied this method to the pubic bones of 175 individuals of white and black origin (72 of black origin and 103 of white origin) and obtained sex

classification accuracy of over 95%. The results showed that the most sexually dimorphic feature was the ventral arc, while the ischiopubic ramus was the most likely to be ambiguous (Table 2.1).

Several studies have been conducted to further validate the utility of Phenice's traits. Some of these validation studies have reported an accuracy rate of over 90%, while some have reported less accurate results (59-83%) (Table 2.1). Ubelaker and Volk (2002) conducted a study on 198 individuals of known sex from the Terry collection to test the Phenice method and achieved a correct sex classification of 88.4%. However, this accuracy increased substantially (from 88.4% to 96.5%) when (1) Phenice's criteria were used in combination with other non-metric pelvic variables, and (2) when the method was attempted by a trained observer. The authors concluded that the Phenice method could be extremely useful for experienced observers. Otherwise, in the case of inexperienced examiners, an advantage is gained by using additional pelvic morphological indicators. Klales et al. (2012) conducted a study to statistically assess the validity of the Phenice method. They expanded on his method by scoring each of the traits on a five-point ordinal scale showing the possible range of variation in the expression of the trait. They scored 310 left innominates from the Hamann-Todd Osteological Collection and the W.M. Bass Donated Skeletal Collection and obtained sex accuracy of 85-94%. Garcia de Leon and Toon (2014) compared the performance of Klales et al. (2012) and Phenice's (1969) methods for sex assessment in a modern Colombian sample of 39 males and 11 females. They showed that the percentage of correct classification of sex was significantly higher (82%) when using the Phenice method than when using Klales et al.'s (2012) method (66%). This, however, may have been the result of the small sample size (Table 2.1).

In 1984 İşcan and Derrick proposed a method that used a variety of pelvic features. They studied a sample of 17 males and 10 females, representing modern American and Asiatic populations. Their analysis was based on an examination of the efficacy of the iliac tuberosity, the postauricular sulcus, and the postauricular space of the ilium as sex determining parameters. According to this study the best indicator of sex in an adult skeleton was the postauricular space (more prominent in females) followed by

the postauricular sulcus (commonly more present in women). Using this method the authors obtained a sex accuracy level of 90%.

In 2002 another method was proposed by Bruzek, combining Phenice (1969) and İşcan and Derrick's (1984) methods. In this study, five morphological pelvic traits (preauricular surface, greater sciatic notch, the composite arch, inferior pelvis, and ischiopubic index) were examined in 402 adult individuals of French (98 males and 64 females) and Portuguese (106 males and 134 females) origin. Using all five variables, Bruzek's method (2002) provided a correct estimate in 95% of cases. Bruzek (2002) also concluded that this method provided a lower level of observer subjectivity compared to the Phenice method. The accuracy of Bruzek's method was tested by Listi and Bassett (2006) on a sample of 876 modern Americans from three different collections (the W.M. Bass Donated Collection, the Robert Terry Anatomical Collection, and the Donated Collection House at Louisiana State University). Although the accuracy rate of their study (89%) was lower than that originally reported by Bruzek (2002), they confirmed both the efficacy of the method by both obtaining success rates similar to traditional methods and confirming lower inter-observer error. As the above-mentioned studies have shown (Table 2.1), the pelvis is one of the most reliable morphological methods of sex estimation in human skeletal remains, due to its high level of sexual dimorphism and high accuracy rate, approaching 100%. This accuracy rate is considerably increased when the entire hip bone is use

Table 2.1. The list of studies using morphological features of the pelvis for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Phenice (1969)	Modern/ America	N=275 (M:180, F:95)	ventral arch, subpubic concavity, medial aspect of the ischiopubic ramus	95%	Ventral arch
Kelley (1978)	Native Americans	N=362 (M:191, F:171)	Phenice's method	90-100%	Ventral arch
İşcan & Derrick (1984)	Modern/ Americans & Asiatic	N=27 (M:17, F:10)	Iliac tuberosity, postauricular sulcus, postauricular space of the ilium	90%	Postauric-ular space

Continued

Table 2.1 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Lovell (1989)	Modern/ Europe	N=36 (M:13, F:23)	Phenice's method	83%	-
MacLaughlin & Bruce (1990)	Modern/ Europe	N=273 (M:152, F:121)	Phenice's method	59-83%	Subpubic concavity
Sutherland & Suchey (1991)	Modern/ America	N=1284	Phenice's method	96%	Ventral arch
McBride et al. (2001)	Terry collection	N=115 (M:80, F:35)	Phenice's method	89.2%	Subpubic concavity
Ubelaker & Volk (2002)	Terry collection	N=198 (M:99, F:99)	Phenice's method	88.4%	-
Bruzek (2002)	Modern/ France & Portugal	N=402 (M:204, F:198)	Preauricular surface, greater sciatic notch, the composite arch, inferior pelvis, and ischiopubic index	95%	Greater sciatic notch
Listi & Bassett (2006)	Modern/ America	N=876	Bruzek's and traditional methods	89%	-
Klales et al. (2012)	Hamann-Todd & Bass collections	N=310	Phenice's method	86.2-94.5%	Ventral arch
Kenyhercz (2012)	Modern/ South Africa	N=105 (M:61, F:44)	Klales et al.'s method	99.2%	Ventral arch
Stull et al. (2013)	Modern/ South Africa	N=112	Klales et al.'s method	92.2-99.2%	-
Garcia de Leon & Toon (2014)	Modern/ Colombia	N=50 (M:39, F:11)	Klales et al. & Phenice's methods	Phenice's method (82%) Klales et al.'s (2012) method (66%)	-
Klales (2016)	Hamann-Todd & Bass collections	N=299 (M:163, F:136)	Klales et al.'s method	68.7%	Ventral arch

2.2.2. Skull

Another reliable group of morphological sex indicators is provided by the skull (Steyn and İşcan, 1998; Rogers, 2005; Williams and Rogers, 2006; Komar and Buikstra, 2008; Saini et al., 2012; Abdel Fatah et al., 2014; Garvin et al., 2014). Males usually reach puberty two years later than females and have an extra two years to grow somatically (Scheuer and Black, 2000), during which period their muscle mass increases. "As a consequence, changes occur both at direct sides of muscle attachment to bone and as a response to the dissipation of forces" (Cox and Mays, 2002, p. 119). It is these changes that result in sexual dimorphism in the skull. Multifactorial influences also have a bearing on this, including genetics, diet, and disease (Cox and Mays, 2002).

Males tend to have a larger and more robust skull, with more marked muscle attachments (Cox and Mayes, 2002). In the male skull, the supraorbital ridges and glabellar region are prominent, the mastoid process is large, the nuchal crest is pronounced, and the upper edge of the eye orbits are blunt. The glabellar region in the female skull, on the other hand, is relatively smooth, while the supraorbital ridge shows small to medium prominence. The superior margin of the orbit is sharp in females while the mastoid process is small and smooth. In addition, within the occipital reign, external occipital protuberance in males is prominent and the occipital condyles are comparatively large (Bass, 2005; Chamberlain, 2006; Steele and Bramblett, 2007; Komar and Buikstra, 2008; Fairgrieve, 2010; White et al. 2012). It is important to note, however, that the range of sex variation of this kind differs from one population to another, with women having more male-type morphology in some populations and men having more female-type morphology in others (Ortner, 2003; Steele and Barmblett, 2007). For this reason, sex assessment criteria in an archaeological population cannot necessarily be transferred to a population of a different period (Ortner, 2003) (Fig. 2.2).

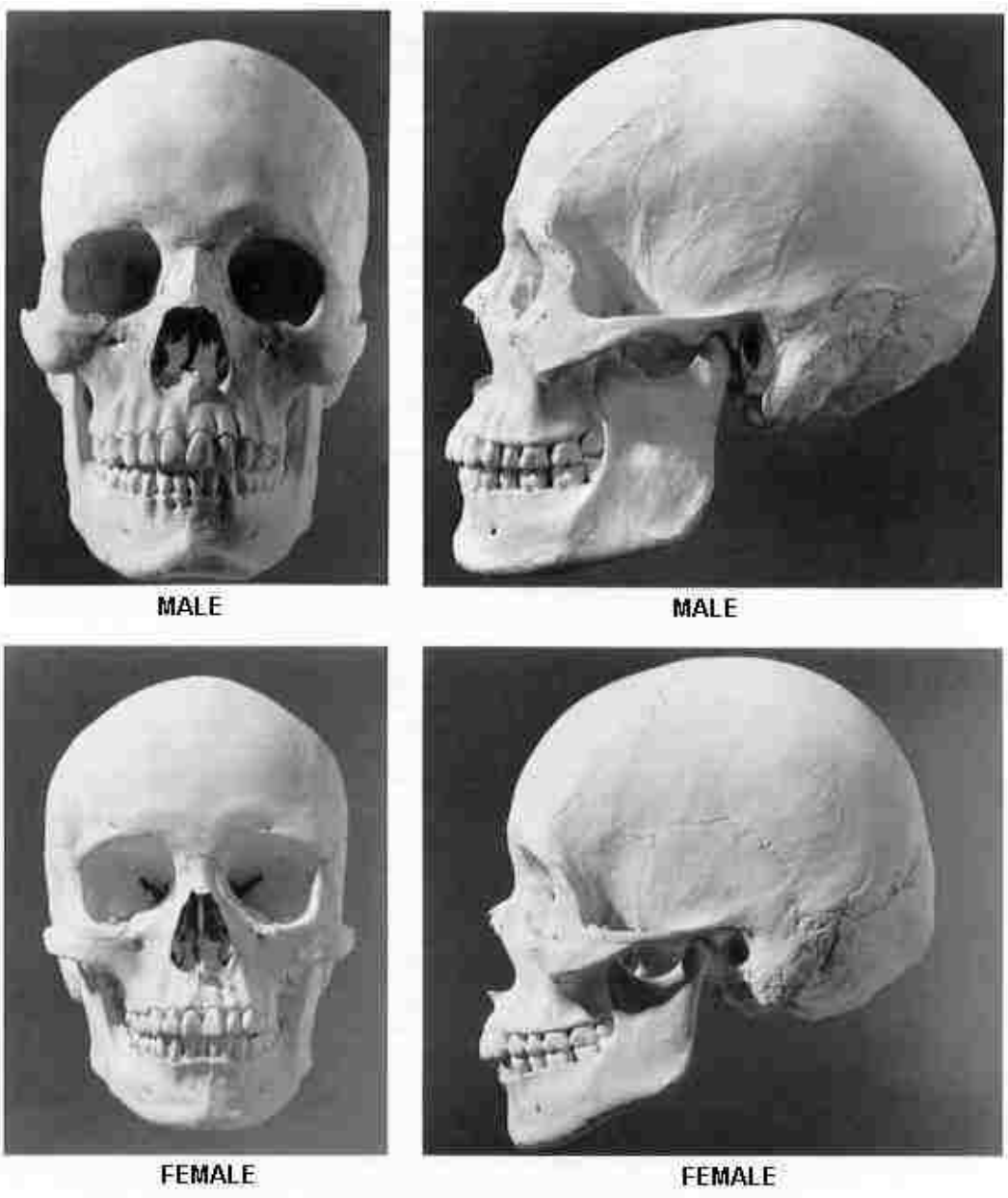

Fig. 2.2. Males have more prominent supraorbital ridges, glabellar region, mastoid process, and occipital protuberance. The male mandible is also thicker, and square shaped with a more prominent mental eminence. Source: White and Folkens, 2005, p. 388.

Researchers have claimed to achieve accuracy rates over 90% in sex estimation using the skulls traits alone and in combination with pelvis (Table 2.2). Buikstra and Ubelaker (1994) present a five-point scale using the nuchal crest, mastoid process, supraorbital margin, glabella, and mental eminence. This is similar to the Acsadi and Nemeskeri (1970) approach that also uses a five-point scale on the same traits, but without the supraorbital margin and including the shape of the orbit and the angle of the mandible. Illustrations for use in scoring the cranial traits had previously been

published by Acsadi and Nemeskeri (1970). Although these diagrams provided a good starting point, they require considerable modification. The Acsadi and Nemeskeri coding system was developed specifically for sexing individuals of European ancestry and does not encompass the full range of human variation. People from other geographical areas often diverge significantly from this European sexual dimorphism pattern (Walker 2008). Due to this problem, Walker (2008) developed a new scoring system that encompass the extremes observed in a worldwide sample of skulls. In this study, a discriminant function analysis was performed using visual assessments of the criteria observed by Buikstra and Ubelaker (1994) with a rating scale of 1 to 5, on a series of 460 samples from a variety of ethnic backgrounds. The author reported a correct sex classification rate of 88%. Later in 2014, Garvin et al. used Walker's (2008) system to assess the reliability of cranial traits in sex estimation, as well as to test the effects of different factors such as population, age, and body size on their expression. This study was based on a sample of 499 White and Black American individuals and yielded an accuracy rate ranging between 74% and 94% (Table 2.2). The authors concluded that population factor had significant influence on cranial trait expressions, whereas age and body size played no significant role.

During the last decade, advances in imaging technologies have allowed further examination of cranial morphological features in sex estimation. Using computer tomography (CT) scan images and surface laser scans, researchers have obtained sex estimation accuracy rates ranging between 62.2% and 97.5%, based on examination of different morphological elements of the cranium (Table 2.2).

The mandible is another dimorphic component of the skull and is therefore important for sex assessment (Muller, 1998; Humphrey et al., 1999; Balci et al., 2005; Hu et al., 2006; Saini et al., 2011; White et al., 2012). Sex differences are reflected in the shape and the size of the mandible. The mandible in males is generally thicker and has a square shape, with a more prominent and broader mental eminence. The female mandible, on the other hand, tends to be thinner, smaller, with a smooth and much less defined mental eminence (Byers, 2002; Bass, 2005; Saini et al., 2011; Indira et al., 2012, White et al. 2012) (Fig. 2.2). In 2006, Hu et al. (2006) analysed 107 Koreans to

examine the likelihood of correct sex assessment using the morphological traits of the chin. Their results showed that in 92% of males the chin tended to have a square shape, while only 55% of female chins exhibited the characteristic pointed shape. The lower border of the mandible in 68% of males was rocker shaped, while in 85% of females it was straight. Their sex assessment accuracy, based on a combination of traits, rated 93% and 74% for males and females, respectively (Table 2.2).

Gonial eversion is a male trait in the mandibular body that has long been considered a useful component from which to assess sex (Acsadi and Nemeskeri, 1970; Novotny et al., 1993; Ferembach et al., 1980). Other researchers, however, have reported contradicting results. Loth and Henneberg (1996), for example, have shown that gonial eversion is a highly heritable trait that, rather than being related to sex, seems to be linked with overall facial architecture. Using this trait they achieved a low sexing accuracy rate of only 50%. Similarly low accuracy rates were obtained in other sexing studies using gonial eversion (Kemkes-Grottenthaler et al., 2002; Oettle et al., 2009) (Table 2.2).

It has been suggested that the mandibular ramus is more sexually dimorphic than the mandibular body (Humphrey et al., 1999). The reason why the mandibular ramus can be used in sex estimation is that the shape of the ramus is affected by the process of mandibular development and masticatory forces, which are distinctly different between the sexes (Loth and Henneberg, 1996). Loth and Henneberg (1996) were the first to describe a single morphological trait on the human mandible: a flexure on the posterior border which was present in males but absent in females. The authors analysed a sample of 547 African and American adult individuals from the Dart Collection and achieved sexing accuracy rates between 91% and 99% in healthy mandibles. They then used this mandibular trait to examine its applicability in 12 fossil hominids (early *Homo sapiens*, Neanderthals, *Homo erectus*, and *Australopithecines*). It was reported that this trait was also clearly evident in fossil hominids. The results of their study, therefore, showed the accuracy and reliability of the mandibular ramus posterior flexure as a sex marker over a long period of time. Other studies have also confirmed the efficacy and validity of this mandibular feature in sex estimation

(Indrayana et al., 1998; Balci et al., 2005; Saini et al., 2011) (Table 2.2). Different studies, however, have criticized the sexing accuracy of the mandibular ramus flexure when used as a single indicator of sexual dimorphism, suggesting that most individuals, regardless of their sex or age, can exhibit ramous flexures (Koski, 1996). Further research has also demonstrated that mandibular ramus flexure is an unreliable sex indicator due to its low accuracy rates and high inter-observer error (Hill, 2000; Hu et al., 2006; Lin et al., 2014) (Table 2.2).

2.2.3. Long Bones

The morphological features of long bones have also been successfully used for sex estimation. For example, Rogers (1999) developed a visual method of adult sex estimation based on four morphological features of the posterior distal humerus (the medial aspect of the trochlea, olecranon fossa shape and depth, and the angle of the medial epicondyle). The author analysed 128 modern adults from Bass and University of New Mexico collections, and reported 92% correct sex classification. This method was re-evaluated by Falys et al. (2005) on 351 left humeri from the documented skeletal collection of St Bride's, London. The study reported olecranon fossa shape as the most sexually dimorphic trait, providing 84.6% accuracy. However, the combination of all traits provided an overall accuracy of only 79.1%. A similar study by Rogers (2009) on 42 documented British and Portuguese adult skeletons resulted in an 81% accuracy rate.

Overall, the evaluation of morphological traits for sex estimation is thought to be relatively subjective and dependent on the experience of the investigator (İşcan and Helmer, 1993). Metric methods for assessing the sex of an individual, on the other hand, are considered more objective and repeatable, and not as biased by previous observer experience (MacLaughlin and Bruce, 1990), which makes them less problematic for sex estimation.

Table 2.2. The list of studies using morphological traits of the skull for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Meindl et al. (1985)	Hamann-Todd collection	N=100	Morphology of different regions (e.g. occipital, chin, supraorbital ridge, etc.)	92%	-
Loth & Henneberg (1996)	Modern/ African & American	N=547	Mandibular ramus flexure	91-99%	Ramus flexure
Indrayana et al. (1998)	Modern/ Indonesia	N=150 (M:75, F:75)	Mandibular ramus flexure	90-94%	Ramus flexure
Hill (2000)	Hamann-Todd collection	N=158 (M:103, F:55)	Mandibular ramus flexure	79.1%	-
Kemkes-Grottenthaler et al. (2002)	Modern & Medieval/ Germany	N=232 (M:163, F:69)	Ramus flexure & genial eversion	59-69.3%	Gonial eversion
Rogers (2005)	Modern/ Canada	N=46	17 cranial traits	89%	Nasal aperture, zygomatic extension, malar rugosity, supraorbital ridge
Balci et al. (2005)	Modern/ Turkey	N=120 (M:95, F:25)	Mandibular ramus flexure	85.8%	Ramus flexure
Williams and Rogers (2006)	Modern/ Europe	N=100 (M:50, F:50)	20 cranial traits	96%	Mastoid, supraorbital ridge, architecture of the skull, etc.
Hu et al. (2006)	Modern/ Korea	N=107 (M:74, F:33)	13 mandibular traits	90%	Contour of the lower border of the mandible
Walker (2008)	Modern/ African Americans, European Americans, English, Native Americans	N=460	Nuchal crest, mastoid process, orbital margin, glabella, supraorbital ridge, mental eminence	88%	Glabella

Continued

Table 2.2 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Ramsthaler et al. (2010)	Modern/ Germany	N=50, (M:29, F:21)	3D CT scans: 17 cranial traits	96%	Supraorbital ridge
Garvin et al. (2014)	Modern & Medieval/ America	N=499	Walker's method	74-94%	Glabella & mastoid

2.3. Metric Sex Estimation

Metric methods of sex estimation are based on the quantitative analysis of those measurable traits which differ between males and females, such as clavicle length or humeral head diameter. Forensic anthropologists and bioarcheologists have relatively recently begun to use metric analysis as a standard for sex estimation. Pearson was the first to suggest the use of postcranial metrics for sex identification in 1915. However, since visual methods of sex assessment are quick and easy to use, and require less sophisticated statistical analysis, it has taken a long time for metric analysis to catch on (Moore, 2013). Metric methods offer several advantages over morphological methods. First, inter- and intra-observer error and subjectivity are typically lower in this type of analysis (Christensen et al. 2014). Second, their replicability is relatively high compared to morphological methods, the reason being that osteometric landmarks appear to be easier to find on a steady basis and valuation is not made according to a judgement against a specific scale (Shehri and Soliman, 2015). Third, observers with varying experience levels can collect metric data. And, finally, these methods are more applicable to statistical analysis and therefore facilitate comparison between different samples and studies (MacLaughlin and Bruce, 1990; Adams and Byrd, 2002; Gonzalez et al., 2009).

2.3.1. Pelvis

The pelvis has long been considered the most reliable source for sex estimation, using both metric and nonmetric methods, due to the modification of the pelvis in females

(wider pelvic inlet) to ensure obstetric success. Arsuaga and Carretero (1994) studied 418 adult hip bones from a modern Portuguese population (227 males and 191 females) using univariate and multivariate analysis to examine the patterns of sexual dimorphism. Their study revealed that, in terms of shape variables, the female hip bone was larger with respect to those traits associated with the pelvic inlet. The sciatic notch was also broader in the female hip bone. Fourteen of the 34 original variables were selected as the best indicators, and sexing accuracy rates of 98.6% for males and 100% for females were achieved. In another study by Murphy (2000), the maximum acetabular diameter of 56 individuals (21 males and 35 females) from New Zealand was measured for sex estimation. The author achieved accuracy rates between 85.2% and 86.2%. In 2009, a similar study was conducted on 114 adult sacra from Italy by Benazzi et al. In this study, digital photographs were used to take the acetabular diameters. The results showed that this method could be used to determine sex with an accuracy rate of 93.2%. Steyn and İşcan (2008) used 192 individuals of a modern Greek population for sex estimation. The measurements were taken from the articulated pelvis, the single os coxa, and the sacrum. The results of this study revealed that the diameter of the acetabulum was the single most sexually dimorphic trait, producing a prediction accuracy rate of 83.9%. In another study, discriminant function analysis was used on a sample of black and white South Africans to investigate metric sex estimation from the pelvis (Patriquin et al. 2005). It was concluded that the ischial length was the most sexually dimorphic trait (86% accuracy) followed by the diameter of the acetabulum (84% accuracy). The results of the multivariate discriminant function analysis using all the variables showed accuracy ranging between 94% and 95.5%. In 2011 Spradley and Jantz found that the single most dimorphic pelvic traits were os coxa height and ischium length, providing accuracy rates of 85% and 83% respectively. A multivariate discriminant function analysis showed that the os coxa could sex 89-90% of the samples correctly (Table 2.3). Osteometric analysis of pelvic bones and the sacrum has also been performed using more technologically advanced forms of anthropological analysis, such as digital images, radiographic films, and CT scan images, on different populations, with sex classification accuracy rates ranging from 63% to 100% (Table 2.3).

Table 2.3. The list of studies using metric traits of the pelvis for sex estimation

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Arsuaga & Carretero (1994)	Modern /Portugal	N=418 (M: 227, F:191)	34 linear + 10 non-metric variables	98.6-100%	-
Murphy (2000)	Archaeological /New Zealand	N=56 (M: 21, F: 35)	Maximum diameter of the acetabulum	85.2- 86.2%.	-
Igbigbi & Msamati (2000)	Modern/ Malawi	N=255	X-ray films: ischiopubic index	87.8-100%	-
Patriquin et al. (2005)	Modern/ South Africa	N=400	9 various variables	94-95.5%	Ischial length
Steyn & İşcan (2008)	Modern/ Greece	N=192 (M:97, F:95)	Articulated pelvis, single os coxae, sacrum	60.90-95.4%	Acetabulum
Benazzi et al. (2009)	Archaeological /Italy	N=114 (M:57, F:57)	Digital photographs: acetabular diameters	93.2%	Sacrum area
Gonzalez et al. (2009)	Archaeological / Colombia	N=121 (M:69, F:52)	Photographic images: greater sciatic notch and the ischiopubic complex	90.9-93.4%	Ischiopubic complex
Ekanem et al. (2009)	Modern/ Nigeria	N+214 (M:114, F:100)	X-ray films: ischiopubic index	69-81%	-
Spradley & Jantz (2011)	Modern/ various populations	>700	Sacrum, os coxa	71.88-90.46%	Os coxa height, ischia length
Decker et al. (2011)	Modern/ America	N=100 (M:40, F:60)	3D CT scans: Phenice method + metric traits	100%	-
Small et al. (2012)	Modern/ South Africa	N=145 (M:87, F:58)	Digital images: subpubic angle	75-86%	-
Zech et al. (2012)	Modern/ Switzerland	N=95 (M:49, F:46)	Post-mortem CT scans: 4 os sacrum traits	76.8-78.9%	Maximum anterior–posterior diameter

Continued

Table 2.3 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Karakas et al. (2013)	Modern/ Anatolian Caucasian	N=109	3D CT scans: subpubic angel	90.8%	-
Torimitsu et al. (2015a)	Modern/ Japanese	N=204 (M:104, F:104)	3D CT scans: 11 various variables	63-98.1%	Subpubic angel
Oladipo et al. (2015)	Modern/ Nigeria	N=93 (M:50, F:43)	Radiographs: ischiopubic index	78.6%	-
Savall et al. (2015)	Modern/ France	N=113 (M:54, F:59)	3D CT scans: 17 metric traits/ decision tree	92%	-

2.3.2. Skull

Many researchers have suggested that the skull is one of the best indicators of sex (Holland, 1986; Dayal et al. 2008; Rooppakhun et al. 2010; Santos et al. 2014) In a study by Uytterschaut in 1986, a discriminant function analysis was performed based on four skull measurements (bizygomatic breadth, glabello-occipital length, nasal breadth, and nasal height) taken from three different populations: Dutch, Zulu, and Japanese. Uytterschaut reported an accuracy rate ranging between 81% and 89%. In another study by Steyn and İşcan (1998) it was found that bizygomatic breadth was the best sex indicator in the cranium. They achieved an average accuracy rate of 80% using a sample of 44 black males and 47 black females of South African origin. This accuracy increased to 86% after the inclusion of five cranial variables. Kranioti et al. (2008) also reported similar results in a sample of 90 male and 88 female Greek individuals. The authors used 16 craniofacial dimensions and concluded that bizygomatic breadth is the single most dimorphic characteristic of the skull, with an accuracy rate of 82%. This increased to 88.2% when the five craniofacial dimensions (bizygomatic breadth, cranial length, nasion-prosthion, mastoid height, and nasal breadth) were included. Rooppakhun et al. (2009) utilized 3D computer tomography to study cranial sexual dimorphism in Thai populations. A total of 21 cranial measurements were used to estimate the sex of 91 known-sex individuals. The overall accuracy of this study was 92.3%, with an accuracy rate of 92.85% among males and

91.42% among females. Similar results have been obtained by other researchers in different populations (Table 2.4).

While a large amount of research in this area has focused on multiple cranial traits and variables, some research has also considered examining specific areas of the cranium, either to develop easy and reliable sex estimation criteria, or to have a necessary means of estimating the sex of fragmentary crania (Jantz et al. 2013). Using single variables such as occipital condyles, the foramen magnum, palate bone, auditory meatus, and bony labyrinth, the researchers could successfully assess the sex of the individuals up to 84% accuracy. Table 2.4 illustrates different cranial osteometric criteria and their sexing validity in different studies.

Another area of the human skull that has received attention as a sex indicator is the mandible. Franklin et al. (2008) examined the mandibles of 225 individuals (120 males and 105 females) from five different South African tribes (Zulu, Swazi, Xhosa, Sotho, and Tswana) to estimate sex both individually and as a group. Using geometric morphometric methods, the authors could correctly classify sex in 84% of cases, and concluded that the mandibular condyle and ramus were the most sexually dimorphic regions of the mandible. The same results (ranging from 80.5% to 84.2% accuracy) were also reported by Dong et al. (2015), who used mandibular CT scan images of a contemporary Chinese population (96 males and 107 females) for sex estimation. Kranioti et al. (2014) conducted a study on the mandibles of contemporary Greeks, reporting an accuracy of 80%. The lower accuracy compared to other studies may be due to the small sample size (N=70), however, Saini et al. (2011) with a larger sample size reported similar accuracy rate (Table 2.4).

Table 2.4. The list of studies using metric traits of the skull for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Steyn & İşcan (1998)	Modern/ South Africa	N=91 (M:44, F:47)	12 cranial & 5 mandibular measurements	80-86%	Bizygomatic breadth
Graw et al. (1999)	Modern/ German	N=108 (M:67, F:41)	supraorbital margin	70%	-
Wahl & Graw (2001)	Modern/ America	N=410 (M:170, F:104)	Petrous temporal bone	74.19%	-
Franklin et al. (2006)	Modern/ South Africa	N=332 (M:182, F:150)	3D Ct scans: 96 cranial landmarks	87%	-
Lynnerup et al. (2006)	Modern/ Germany	N=113 (M:65, F:48)	Internal auditory meatus	70%	-
Dayal et al. (2008)	Modern/ South Africa	N=120 (M;60, F:60)	21 traits of skull	80-85%.	Total facial height
Kranioti et al. (2008)	Modern/ Greece	N=178 (M:90, F:88)	16 craniofacial dimensions	70.2-88.2%	Bizygomatic breadth
Franklin et al. (2008)	Modern/ South Africa	N=225 (M:120, F:105)	3D: 38 mandibular landmarks	84%	Mandibular condyle, ramus
Rooppakhun et al. (2009)	Modern/ Thailand	N= (M:56, F:35)	3D CT scans: 21 cranial measurements	92.3%	Bizygomatic breadth
Spradley & Jantz (2011)	Modern/ various populations	>700	34 skull measurements	78-90.6%	-
Saini et al. (2011)	Modern/India	N=116	Mandibular ramus traits	80.2%	Coronoid heights
Garvin & Ruff (2012)	Terry collection	N=119 (M:63, F: 56)	3D surface laser scan: Browridge and chin	62.2-79.8%	Browridge
Sumati et al. (2012)	Modern/ India	N=60	Palate bone	70%	-
Ogawa et al. (2013)	Modern/ Japanese	N=113 (M:73, F:40)	Imaging technologies: 10 cranial measurements	79-89.9%	-
Osipov et al. (2013)	Modern/ Crete	N=94 (M:49, F:45)	3D CT scans: bony Labyrinth	84%	-

Continued

Table 2.4 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Abdel Fatah et al. (2014)	Modern/ America	N=222 (M:141, F:81)	3D Ct scans: 11 cranial variables	97.5%	-
Lin et al. (2014)	Modern/ Korea	N=240 (M:120, F:120)	3D CT scans: 10 mandibular traits	88.8%	Upper ramus vertical height
Kranioti et al. (2014)	Modern/ Greece	N=70 (M:36, F:34)	5 mandibular measurements	80%	Bigonial breadth
Dong et al. (2015)	Modern/ China	N=203 (M:96, F:107)	3D CT scans: 11 mandibular measurements	80.5-84.2%	Maximum mandibular length
Uhl et al. (2016)	Upper Palaeolithic/ Romany	N=1	3D CT scans: Osipove et al.'s (2013) method	100%	-
Damera et al. (2016)	Modern/ India	N=80	Digital radiographics: mandibular ramus	83.3%	-

2.3.3. Postcranial Bones

Despite the weight attached to the skull as the second most reliable indicator of sex, it is generally believed that postcranial bones are superior to the skull in sex estimation. To examine the utility of cranial and postcranial traits in sex estimation and to test the widely-accepted idea that the skull is a better sex estimator than postcranial bones, Spradley and Jantz (2011) compared craniometrics to postcranial metrics to assess sexing accuracy across the skeleton. The authors used a large collection for sex estimation, including white and black Americans from the Forensic Anthropology Data Bank. They found that joint size alone, including tibia proximal epiphyseal breadth, femur head diameter, and femur epicondylar breadth, produced correct sex classification rates between 89% and 90%, rising to 94% when multivariate analysis was performed. The authors then compared these variables to craniometric variables, with a univariate sexing accuracy rate of 78% for bizygomatic breadth. However, the correct sex classification rates of breadth measurements were observed to be higher

after performing a multivariate analysis. It was therefore concluded that, due to the higher sex classification rates of postcranial elements, they were preferable to the cranium (Spradley and Jantz, 2011). In an early study in 1959, Hanihara measured Japanese skulls and scapula, applying a discriminant function analysis for nine craniometric measurements and four scapula measurements. The best accuracy rate for the skull was 89.7%, and for the scapula 97%. Hanihara (1959) concluded, therefore, that the scapula was a more reliable sex indicator.

Various studies have used the dimensions of postcranial bones for sex estimation, and the basic principle in most of them is that men exceed women in size (France, 1998; Albanese et al., 2005; Brown et al., 2007; Albanese et al., 2008; Spradley and Jantz, 2011; Spradley et al., 2015). Thieme and Schull (1957) conducted a study to investigate sexual dimorphism in various metric long bone variables such as humeral length, sternum width, femoral head diameter, clavicle length, ischium length, and epicondylar width of the humerus. The authors used a sample of 90 males and 101 females of African-American origin from the Terry collection. The results of the study revealed that the head of the femur was the most sexually dimorphic of all the variables and appeared to be consistently larger in males than in females. It was also found that the maximum length and epicondylar breadth of the humerus were useful in assigning sex. Using all the variables of the different bones combined, the authors obtained a correct sex classification rate of 98%. Safont et al. (2000) demonstrated the applicability of long bone circumference to the determination of sex in skeletal remains that cannot be diagnosed from pelvic or cranial elements. In this study, 151 adult individuals from a late Roman site in Spain were examined, and eight different circumferences from five long bones were measured. The results showed that all the functions obtained by using only one variable provided a correct sex classification rate higher than 80%, and the circumference at the radial tuberosity alone provided the highest accuracy rate of 92.8%. The functions produced by employing more than one circumference yielded an accuracy rate of 91.5% to 100%. The authors also reported that the sex of the individuals was estimated more effectively using arm bone rather than leg bone measurements, because the circumferences of the arm bones were more affected by mechanical stress. Muscular activity also appeared to be extensively higher

in males. Sakaue (2004) collected 47 metric variables of five long bones, including the humerus, radius, ulna, femur, and tibia of 64 modern Japanese individuals. In this study the total accuracy rate of sex assignment ranged from 91% to 95%. In a similar study by Nagaoka and Hirata (2009) on a medieval Japanese population, long bone measurements were used to estimate the sex of 130 adult individuals. According to their study, sex classification accuracy using only one variable was more than 80%, whereas multiple variables yielded more than 90% accuracy. Postcranial bones (humerus, radius, tibia, ulna, femur, and fibula) are among the most highly used elements for sex estimation in the studies of human remains due to their high level of sexual dimorphism and reliability. Table 2.5 lists some of these studies.

Table 2.5. The list of studies using metric features of the postcranial bones for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Thieme & Schull (1957)	Terry collection	N=191 (M:90, F:101)	Long bone measurements	98%	Femoral head
Hanihara (1959)	Modern/ Japan	N=50	4 scapula measurements	97%	-
McCormick et al. (1991)	Modern/ America	N=724 (M=560, F=164)	Clavicle length & circumference	93%	-
Sacragi and Ikeda (1995)	Modern/ Japan	N=106 (M:71, F:35)	Distal end of the fibula	90.6%	-
Safont et al. (2000)	Late Roman/ Spain	N=151	long bone circumferences	80-100%	radius radial tuberosity
Frutos (2002)	Modern/ Guatemala	N=>100	Height & width of the glenoid fossa, clavicle length, midshaft circumference	86- 95%	-
Sakaue (2004)	Modern/ japan	N=64 (M:32, F:32)	47 long bone measurements	91-95%	-
Barrier & L'Abbe´ (2008)	Modern/ South Africa	N=400 (M:200, F:200)	Ulna, radius	76-86%	Radius: distal breadth minimum, Ulna: mid-shaft diameter

Continued

Table 2.5 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Kranioti & Michalodimitrakis (2009)	Modern/ Crete	N=168 (M:84, F:84)	Humerus measurements	85-92%	Vertical head diameter of the humerus
Nagaoka & Hirata (2009)	Medieval/ Japan	N=130 (M:68, F:62)	Long bone circumferences	80-90%	Minimal circumference of humerus
Dabbs (2009)	Hamann-Todd collection	N=803 (M:495, F:308)	Scapula: maximum height	96.81%	-
Dabbs and Moore-Jansen (2010)	Hamann-Todd collection	N=724 (M:447, F:277)	23 scapular measurements	95.7%	-
Spradly and Jantz (2011)	Modern/ various populations	>700	44 postcranial measurements	72-94.3%	Humerus, radius
Papaioannou et al. (2012)	Modern/ Greece	N= 147 (M:81, F:66)	Clavicle, scapula	90-96%	Maximum scapular height
Albanese (2013)	Modern/ Portugal, Canada	N=370	Upper limbs measurements	87.4-97.5%.	-
Giurazza et al. (2013)	Modern/ Caucasian	N=200 (M:100, F:100)	3D CT scans: Scapula	88%	-
Ahmed (2013)	Modern/ Sudan	N=240 (M:120, F:120)	Lower limb measurements	78-89.5%.	Bimalleolar breadth
Aparna Vdapriya & Rajasree (2013)	Modern/ India	N=100	3D CT scan: Fibula	80%	-
Paulis and Samra (2015)	Modern/ Egypt	N=200 (M:100, F:100)	3D CT scans: scapula	87-97%	Longitudinal length
Kranioti & Apostol (2015)	Modern/ Greece, Spain, Italy	N=452	Tibia	88%	Upper epiphyseal breadth
Hishmat et al. (2015)	Modern/ Japan	N=259 (M:150, F:109)	3D CT scans: lower limb measurements	75.8-98.1%	The ratio of the mass volume to maximum length
Gulhan et al. (2015)	Modern/ Turkey	N=200 (M:100, F:100)	3D CT scans: femoral measurements	91%	Vertical diameter of neck
Meeusen et al. (2015)	Modern/ America	N=214	Femoral neck axis length	86%.	-

Continued

Table 2.5 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Atterton et al. (2016)	Medieval/ England	N=48 (M:23, F:25)	Clavicle	89.6%	Maximum clavicular length
Krüger et al. (2016)	Modern/ South Africa	N=360	Long bones	56-98%	-
Kranioti et al. (2017)	Modern/ Greece	N=289	Tibia	69-90%	-

In order to identify the sex of a skeleton or specimen, it is also possible to use other postcranial bones such as the clavicle and scapula, as they differ significantly between males and females. Women generally have shorter, smoother and less curved clavicles when compared to men. The midshaft circumference of the clavicle is another important sex indicator, especially when used in combination with bone weight and length in fresh anatomical specimens (Jit and Singh, 1966). The sexing effectiveness of clavicle length and circumference were tested by McCormick et al. (1991) on a modern European-American population from east Tennessee. Although the authors did not employ discriminant analysis or cross-validation – a model validation technique that is used to evaluate how the results obtained through a statistical analysis will generalize to an independent data set (Madsen and Thyregod, 2010) – they did obtain single cut-off values that yielded an overall sex classification rate of 93%. In the case of the scapula, its maximum length and the maximum length of the glenoid cavity have been recognized as sexually dimorphic (Steele, 1988). Frutos (2002) could correctly assign sex to 86% to 95% of skeletons in a study of a Guatemalan forensic sample using a combination of clavicle (35 females and 62 males) and scapula (38 female and 65 males) variables, including height and width of the glenoid fossa, clavicle length, and midshaft circumference. Papaioannou et al. (2012) also used the measurements of the clavicle and scapula for sex estimation. In total, 14 measurements were taken from 147 clavicles and scapulae from 81 males and 66 females from a contemporary Greek population. The percentage of cases correctly classified was 90% for the clavicle and 96% for the scapula. For more information about sex estimation studies using the scapula and clavicle, see Table 2.5.

In addition to the bones mentioned above, other bones of human skeletons, such as the hyoid bone, ribs, carpals, metacarpals, tarsals and metatarsals have also been used to estimate the sex of individuals, providing classification accuracy rates ranging from 74% to 98%. Some of these studies are summarised in Table 2.6.

Metric analysis, however, despite its high level of objectivity and repeatability, has some limitations. Similar to morphoscopic methods, metric techniques are population specific. Metric methods of sex estimation have a tendency to yield error due to their dependence on absolute differences in measured dimensions of skeletons. In addition, they are based on those sectioning points used to differentiate between the two sexes, which can only reliably be applied to the population being analysed (Rogers, 2005). Nevertheless, skeletal remains, as organic matter, do not survive in poor conditions. It is necessary, therefore, to use teeth, as the most durable and resistant human remains to mechanical, physical, and chemical types of destruction, to determine sex. The next chapter will discuss dental sexual dimorphism and its effectiveness in estimating the sex of individuals.

Table 2.6. The list of studies using metric features of the different bones for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Miller et al. (1998)	Modern/ Americans	N=315 (M:188, F:127)	Image analysis: 30 hyoid measurements	69.2-75.2%	-
Kim et al. (2006)	Modern/ Korea	N=85 (M:52, F:33)	Digital photograph, 34 hyoid measurements	88.2%	-
Kindschuh et al. (2010)	Terry collection	N=398 (M:200, F:198)	10 hyoid measurements	82-85%	-
Balseven-Odabasi et al. (2013)	Modern/ Turkey	N=85	33 hyoid measurements	77.4-81.3%	-
D'Anastasion et al. (2014)	Medieval/ Italy	N=64 (M:44, F:20)	10 measurements of hyoid body	75-88%	Body height & length
Barrio et al. (2006)	Modern/ Spain	N=79 (M:37, F:42)	Metacarpal measurements	81-91%,	2nd metacarpal
Cologlu et al. (1998)	Modern/ Turkey	N=294	Sternal ends of the fourth rib	86-90%	-
Wiredu et al. (1999)	Modern/ Ghana	N=346, (M:221, F:125)	Sternal end of the fourth rib measurements	74-80%	-
Ramadan et al. (2010)	Modern/ Turkey	N=340 (M:197, F:143)	Image analysis: sternum & 4th rib measurements	82.2%	Sternal area, 4th rib width
Macaluso et al. (2012)	Modern/ Spain	F=117 (M:60, F:57)	Sternal extremity of the fourth rib	86.3%	Height
Kubicka & Piontek (2015)	Modern/ Poland	N=176	1st rib measurements	81.5%	Sternal end
Manolis et al. (2009)	Modern/ Greece	N=151 (M:84, F:67)	Metacarpal measurements	83.2-89.8%,	-
Khanpetch et al. (2012)	Modern/ Thai	N=249 (M:154, F:95)	6 metacarpal measurements	83.7-89.7%,	5th & 2nd metacarpals
Nathena (2015)	Modern/ Crete	N=108	7 metacarpal measurements	85%	-
Mastrangelo et al. (2011a)	Modern/ Spain	N=100 (M:50, F:50)	9 carpal measurements	97.8%	Lunate
Mastrangelo et al. (2011b)	Modern/ Mexico	N=136 (M:78, F:58)	9 carpal measurements	81.3-92.3%	Maximum width

Continued

Table 2.6 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Mountrakis et al. (2010)	Modern/ Greece	N=186 (M:97, F:89)	Metatarsal measurements	80.7-90.1%.	-
Harris & Case (2012)	Modern/ European-Americans	N=160	18 tarsal measurements	88.1-93.6%.	Talus, cuboid, and 1st cuneiform
Navega et al. (2015)	Modern/ Portugal	N=300	18 tarsal measurements	88.3%	Calcaneus, talus, 1st & 3rd cuneiforms, and cuboid

CHAPTER 3 SEX ESTIMATION BASED ON THE DENTITION

3.1. Introduction

Dental anthropology is an important aspect of bioarchaeology and forensic anthropology. Because teeth are one of the most stable substances in the body, they are often the best-preserved human data in forensic and archaeological cases, and are sometimes the only usable evidence available for analysis (Anderson et al., 1995; Rodríguez, 2004; Vodanovic´ et al., 2007; Fereira et al., 2008; Schmidt, 2008; Zorba et al., 2011). Teeth are formed deep within the jaws and then erupt through the gum tissue once nearly complete. Unlike the changing shapes of other skeletal elements, tooth crown morphology can only be altered by attrition, breakage, or demineralization once the crown erupts (Robinson, 2004). Tooth morphology can be used to effectively differentiate between populations. The stability and adaptive significance of tooth form establish the dentition as a centerpiece in many comparative populational and evolutionary studies. Finally, teeth are the only hard tissues of the body that are directly observable without dissection or radiography. The following provides a short description of the structure and development of the teeth and will then discussed the level of sexual dimorphism in dentition.

3.2. General Tooth Form and Functions

Teeth constitute approximately 20% of the surface area of the mouth, the upper teeth significantly more than the lower teeth (Nanci, 2007). The functions of teeth vary, depending on their individual shape and size, contour and alignment and location in the jaws. Each type of tooth has its own function and shape. Mastication is the function most commonly associated with the human dentition, but teeth also are essential for proper speech and, in modern times, for esthetics. Dentition interacts directly with the environment through food material mastication. Both the internal composition and the external morphology of teeth are adapted to this function in considerable detail among mammals. Teeth are part of the digestive system. Mastication is the primary function of all teeth and are used in cutting, holding or grasping, shearing and chewing or

grinding. In adult hominids, incisors are the eight spatulate teeth in the front of the upper and lower jaws and are designed to cut food without the use of heavy forces. Canines located at the corners of the arch and are designed for cutting and tearing foods. In humans there are four premolars in the upper jaw and four in the lower jaw. Premolars have both pointed cusps and a broader surface to hold and chewing food. Molars make up the rest of human dentition. These are the largest teeth; their extensive chewing surfaces emphasize crushing and grinding rather than shearing of food material. There are usually six molars in both upper and lower adult human jaws.

All human teeth consist of two main elements: a crown that projects above the gum and a root (or roots) that is embedded within the alveolae, or bony sockets of the jaws. Where the crown and root meet is the neck, or cervix. The base of the crown is called the cervical margin and, girdling the cervical one-third of the crown, there is often a broad bulge called the cingulum. Within the tooth exists a small cavity, the pulp chamber or cavity, corresponding to the general outline of the tooth. The pulp within this cavity is connected to the periodontal membrane through the narrow root canal (Hillson, 2002).

Structurally the tooth is composed of enamel, dentin, cementum, and pulp. The enamel is the structure that covers the outside of the crown of the tooth. Enamel, dentin and cementum are relatively hard since they contain considerable mineral content, especially calcium. Only two of these tissues are normally visible in an intact extracted tooth: enamel and cementum. The other two tissues (dentine and pulp) are usually not visible on an intact tooth.

Enamel is the white, protective external surface layer of the anatomic crown. It is highly calcified or mineralized, and is the hardest substance found in the body. As a dental covering, enamel is highly adapted to withstand the forces of mastication and to resist wear. It is 96% mineral by weight and the remaining substances include 5% water and enamel matrix (Avery et al., 2002). Enamel develops from the enamel organ (ectoderm) and is a product of specialized epithelial cells called ameloblasts (Scheid and Weiss, 2012).

Dentin is the hard yellowish tissue underlying the enamel and cementum, and make up the major bulk of the inner portion of each tooth crown and root (Scheid and Weiss, 2012). Dentin is extremely sensitive to temperature and to changes in osmotic pressure. Much of the protective feedback that prevents tooth damage during everyday use comes from the dentine but importantly also from the periodontal ligament that supports the tooth in its socket of alveolar bone (Dean, 1999). Dentine is not normally visible except on a dental radiograph, or when the enamel or cementum have been worn away. Mature dentin is composed of about 70% calcium hydroxyapatite, 18% organic matter, and 12% water, making it harder than cementum but softer and less brittle than enamel (Scheid and Weiss, 2012). Dentine is a product of cells called odontoblasts which are located at the junction between pulp and dentine (Dean, 1999). Cementum is an interstitial material surrounding the root and binding it to the periodontal ligament (Steele and Bramblett, 2007). The cementum is very thin, especially next to the cervical line. It is composed of 60% calcium hydroxyapatite, 30% organic matter, and 10% water (Scheid and Weiss, 2012). However, Melfi et al. (2000) states that the mineral content of cementum is about 50%. Cementum meets the enamel tissue at the cemento-enamel junction that is located at the neck of the tooth. The function of cementum is to protect the root and provide rough surface anchorage for attachment of Sharpey's fibers, which are connective tissue fibers of the periodontal ligament (Dofka, 2013). Cementum is about as hard as bone but considerably softer than enamel. It develops from specialized cells of the periodontal membrane called cementoblasts (Steele and Bramblett, 2007).

Pulp is the soft tissue in the cavity or space in the center of the crown and root called the pulp cavity (Scheid and Weiss, 2012). Tooth pulp is the only non-mineralized tissue of a tooth. It is a soft connective tissue and like other connective tissue, is made of cells, intercellular substance, and tissue fluid (Melfi et al., 2000). The pulp cavity has a coronal portion (pulp chamber) and a root portion (pulp canal or root canal). The pulp cavity is surrounded by dentine, except at a hole (or holes) near the root tip (apex) called an apical foramen. Nerves and blood vessels enter the pulp through apical foramen (Scheid and Weiss, 2012). Like dentine, the pulp is normally not visible, except on a dental radiograph or sectioned tooth. In life, the pulp cavity houses the

arteries, nerves, and odontoblasts lining the pulp cavity (Steele and Bramblett, 2007) (Fig 3.1).

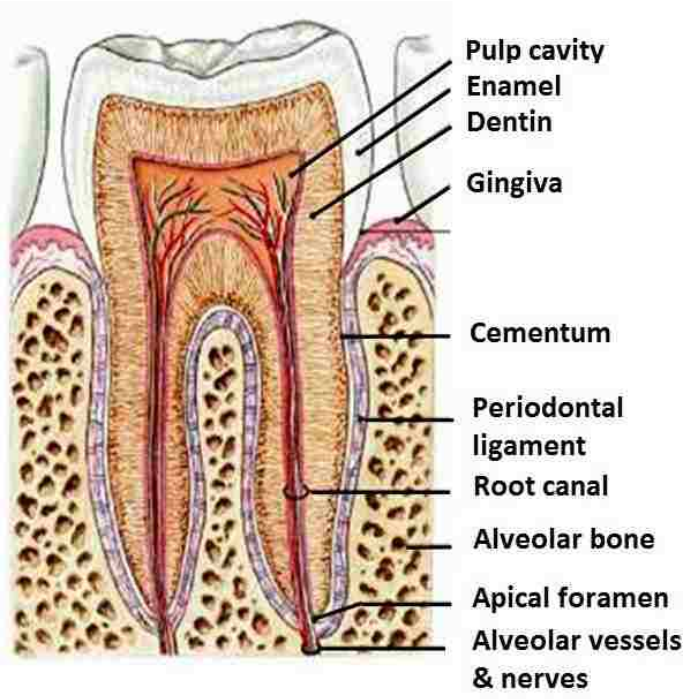

Fig 3.1. Tooth structure

http://3.bp.blogspot.com/-BOHbs2_d6Co/TrdTfoZ2lII/AAAAAAAABOs/EDvT0uEOT-Y/s1600/periodontium.jpg

3.3. Development of the Tooth (Odontogenesis)

The timing initiation of development of the teeth and their eruption into the oral cavity is very important for healthy dentition. This knowledge is also useful in forensics, odontology, archaeology, and palaeontology. Dental development is the most accurate method of age estimation of subadult skeletons (Saunders, 1992), probably because it is under faring tight genetic regulation (Uhl, 2013). However, rate of growth, and the timing of spurts or more gradual changes in speed, varies from individual to individual. Some control is genetic-witness differences between populations and differences between males and females within one population. A proportion of the control is, however, environmental. Nutritional plane, dietary deficiencies, incidence of disease and even psychological stress are all controlling factors (Bogin, 1999). Development of the dentition involves the formation, calcification, and eruption of the crown, as well as root growth and development.

Humans develop two sets of teeth: The deciduous (primary or "milk teeth") is about half-formed by birth and erupts into the mouth during the next two years. It is replaced gradually by the permanent dentition, for which the first tooth starts to form just before birth, and the last tooth is finally completed in the early twenties. Each dentition is divided into four quadrants: upper left, upper right, lower left and lower right. There are 20 deciduous teeth in human dentition, with 5 teeth per quadrant, and 32 permanent teeth, with 8 teeth per quadrant (Fig 3.2). The deciduous dentition is smaller in all respects in comparison to their permanent counterparts. Since the deciduous dentition is replaced by the permanent dentition by normally age 13, less developmental emphasis is placed on building highly mineralized deciduous teeth. In such, the deciduous dentition is not as strong as the permanent dentition, and the enamel is neither as mineralized nor as thick due to differences in diet and facial musculature (Tersigni-Tarrant and Shirley, 2013).

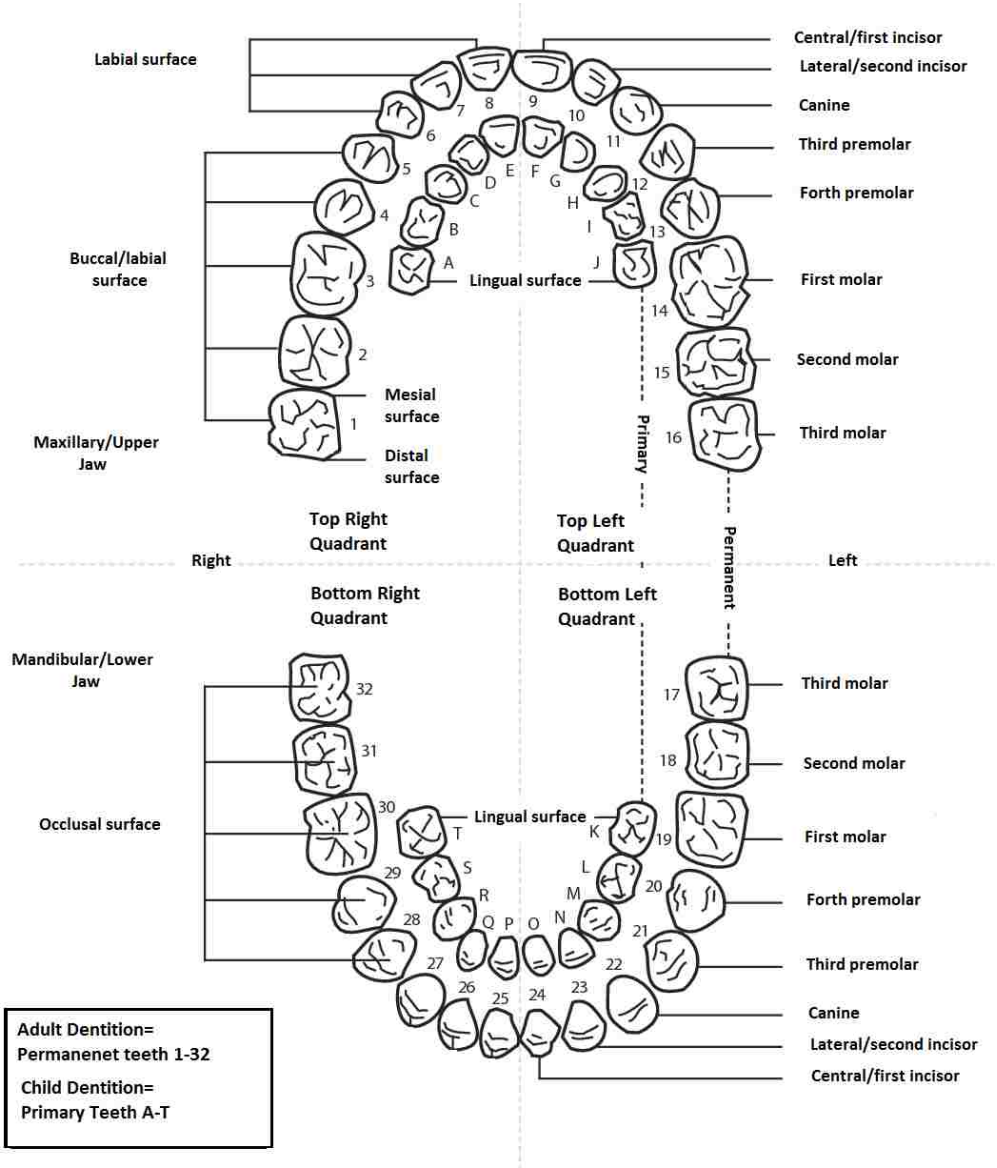

Fig 3.2. Diagram of upper and lower primary and permanent dental jaws. http://cwsda.com/cwsda-worksheets-2

3.3.1. Stages of Development

Tooth development or odontogenesis is a highly coordinated and complex process which relies upon cell-to-cell interactions that result in the initiation and generation of the tooth (Cobourne and Orth, 1999). The surface lining an embryo's developing mouth are covered with a layer of tissue known as epithelium, and this is underline by a tissue called mesenchyme, which will ultimately develop into different types of connective tissue – bone, cartilage, muscle, tendons and blood vessels, dentine and

cement (Hillson, 2005). Teeth and other organs develop as a result of a complex series of interactions between epithelium and underlying mesenchymal tissue. In the tooth 20 primary tooth germs develop initially with 32 additional tooth germs differentiating to form the permanent dentition. Although each tooth germ develops as an anatomically distinct unit, the fundamental developmental process is similar for all teeth (Avery et al., 2002).

Tooth formation is a continues process that may be characterized by a series of distinguishable stages. The stages are classified according to the shape of the epithelial component of the tooth and are named accordingly (MacDougall and Javed, 2010). Three different stages are recognized, for example, bud, cap, and bell stage.

The first signs of tooth development are seen during the six weeks after fertilization. At that time, mesenchyme cells proliferate into an arch-shaped zone along the line of the developing jaws. Epithelium grows into this condensation to produce the so-called primary epithelial band, which itself divided into two lobes; the vestibular lamina and the dental lamina (Hillson, 2002). At eighth embryonic week starting at the midline and spreading posteriorly, there is a continued thickening in the dental lamina in 10 areas of the upper arch and 10 areas of the lower arch. These 20 localized thickening correspond to the position of the future teeth (Brand and Isselhard, 2014). Enamel organs for the permanent dentition are initiated from around the sixteenth week after fertilization, with the latest of them appearing only after birth (Hillson, 2002). The initial budding from the dental lamina at the 10 thickened areas in each arch is referred to as the bud stage, the initial stage of definitive tooth development (Brand and Isselhard, 2014) (Fig 3.3). Mesenchyme cells proliferate around the bud of epithelial cells, to become the dental papilla, responsible for dentine and pulp formation (Hillson, 2005). Proliferation of oral epithelial cells results in the formation of a bud-shaped enamel organ. Proliferating mesenchymal cells surround the bud and form an ectomesenchymal condensation. The buds seem to stretch out from the dental lamina as they grow. As development continues, the deepest parts of the buds become slightly concave (Brand and Isselhard, 2014). It is at this point that the tooth germ passes into its cap stage (Fig 3.4). During this stage, the tooth bud grows around the

ectomesenchymal cells and builds the enamel or dental organ. Surrounding the dental papilla and enamel organ, the dental follicle develops forming all the supporting structures of the tooth (Cate, 2003). Also during the cap stage, a critical signaling centre, the enamel knot, is formed within the enamel organ epithelium. The enamel knot acts as a centre of control for the developing tooth germ (Hillson, 2005). Continues growth of the tooth germ leads to the bell stage during which the crown assumes its final shape (morphodifferentiation) and the cells that will be making the hard tissue (ameloblasts and odontoblasts) acquire their distinctive phenotype (histodifferentiation) (Avery et al., 2002) (Fig 3.5). During the bell stage, the cells that have been joined to the oral epithelium begin to disintegrate. At the same time, connective tissue surrounds the enamel organ, and the dental papilla forms a rather dense band of tissue, called the dental sac. Development of the cementum, the periodontal ligament, and the lamina dura of the alveolus occur within the dental sac (Phinney and Halstead, 2004).

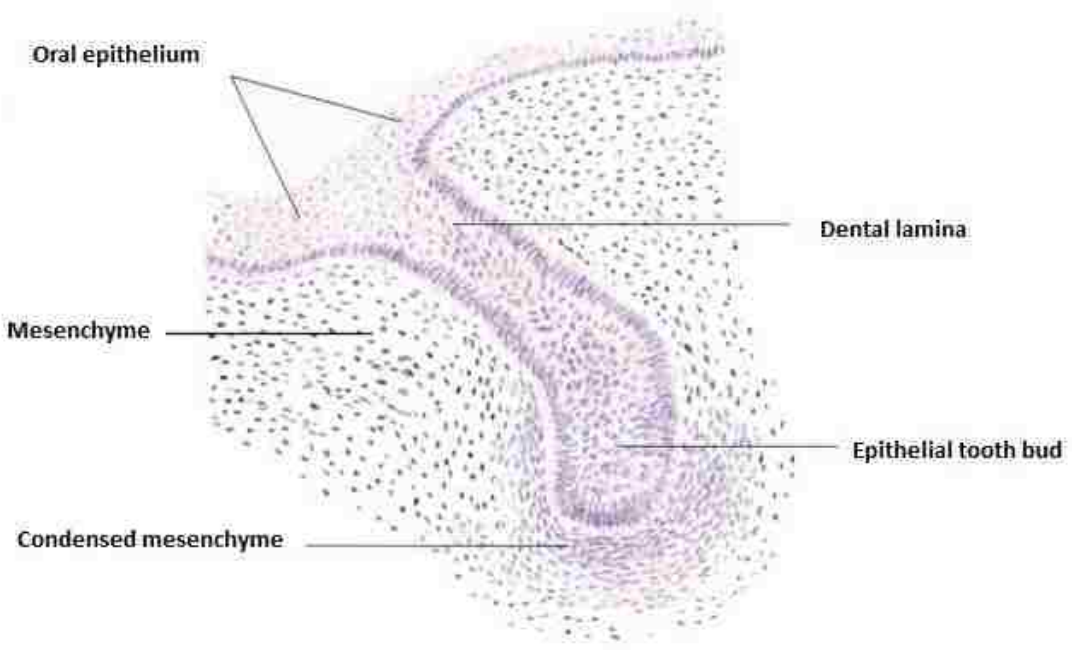

Fig 3.3. Bud stage. Zhang (1998, 201).

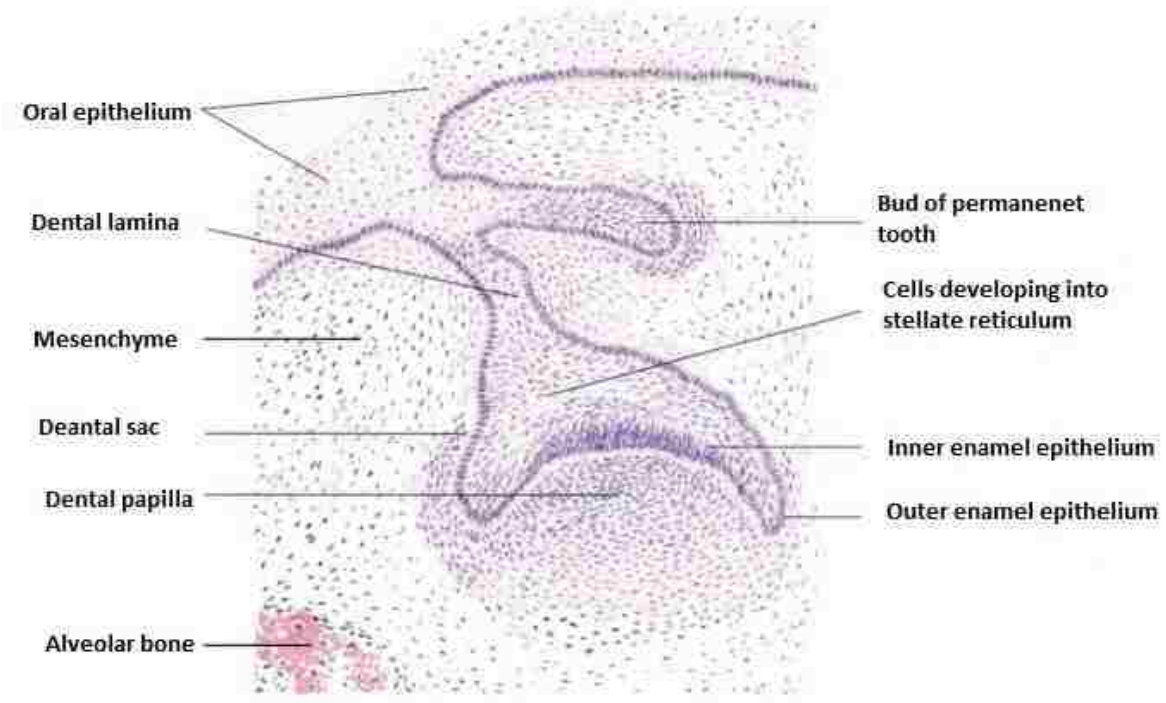

Fig 3.4. Cap stage. Zhang (1998, 201).

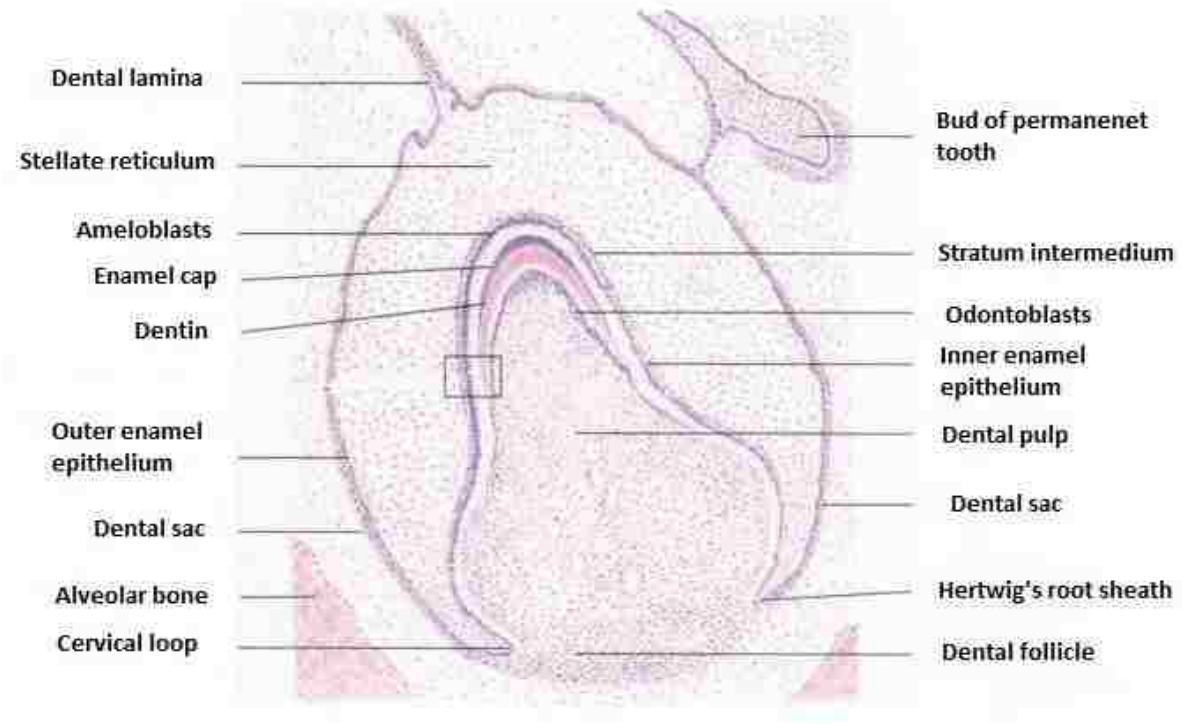

Fig 3.5. Bell stage. Zhang (1998, 203).

3.3.2. Crown and Root Development

The first dental tissue to be laid down is dentine. The development of the dentine occurs just prior to that of the embryonic enamel. Cells on the edge of the papilla called odontoblasts, with processing going towards the enamel organ. They lay down the first layer of dentine matrix, and tooth formation has begun. The dentine is first differentiated on the tip of the developing crown and gradually envelops the entire pulp cavity. Immediately after the first layer of dentine laid down, especial epithelial cells (calls ameloblasts) lining the inside of the enamel organ and deposit the first dome-shaped layer of enamel matrix. These process starts in the deepest infoldings of the enamel organ. The enamel formed here is the base for the main cups and ridges of the crown. Cusps grow by the apposition of layer upon dome-shaped layer of enamel. More ameloblasts come into action at the periphery of each layer, so the domes increase in size. Cusps merged into one another as infoldings incorrect. Where they are separated by deep folds of the enamel organ, ameloblasts continue to work until they are back to back, and then stop, leaving deep features. When the ameloblasts over the cusps tips come to the end of their matrix production phase, enamel is so longer deposited as dome (or cap-shaped layer), but as sleeve-like layers, overlapping down the sides of the crown towards the cervix of the tooth (Hillson, 2002).

The root of the tooth consists of dentin covered by cementum. The development of the roots begins after enamel and dentine formation has reached the future cemento-enamel junction. During morphodifferentiation, the enamel epithelium in the apical portion of the tooth, together with the dental papilla, forms the outline of the root. At this time, the innermost cell layer, or inner enamel epithelium, and the outermost cell layer, or outer enamel epithelium, merge in a loop at the site of the cervix of the tooth. This is called the cervical loop. The layers then grow downward for a short distance as a double row of cells termed Hertwig's epithelial root sheath. It moulds the shape of the roots and initiates radicular dentine formation (Fig 3.5).

The outer and inner enamel epithelium bend at the future cemento-enamel junction into a horizontal plane, narrowing the wide cervical opening of tooth germ. This rim

of the root sheath, the epithelial diaphragm, encloses the primary apical foramen. As the inner enamel epithelial cells of the root sheath progressively enclose more and more of the expanding dental papilla, they initiate the differentiation of odontoblasts from the cells as the periphery of the dental papilla. These cells eventually form the dentin of the root. In this way, a single rooted tooth is formed (Nancy, 2007). Multi rooted teeth form essentially in the same way, except that the primary apical foramen is divided into two or three apical foramen by tongues of epithelium growing towards each other hence dividing the single foramen (Premkumar, 2011).

After the crown and part of the root are formed, the tooth penetrates the mucous membrane and makes its entry into the mouth. Further formation of the root is supposed to be an active factor in pushing the crown toward its final position in the mouth. Eruption of the tooth is said to be completed when most of the crown is in evidence and when it has made its contact with its antagonist in opposing jaw (Kumar, 2004).

3.3. Odontometric Sexual Dimorphism

One of the important applications of odontometrics in physical anthropology is using measures of size and proportion to estimate sex (Saunders et al. 2007). According to several studies, sexual dimorphism occurs in the permanent dentition of humans (Moorrees et al., 1957; Garn et al., 1964; 1966a; 1966b; 1967; Stroud, 1994; Kondo and Townsend, 2004; Hillson, 2005; Acharya and Mainali, 2007; Vodanovic´ et al., 2007; Viciano et al., 2011, 2013, 2015; Sharma et al., 2013; Khamis et al., 2014; Mujib et al., 2014; Tuttösí and Cardoso, 2015; Peckmann et al., 2015). In most contemporary and archaeological human populations, it is often the case that males possess larger permanent teeth than females (Garn et al., 1964, 1967; Alvesalo, 1971; Harris and Bailit, 1987; Kieser, 1990; Harris and Hicks, 1998; Scott and Turner, 2000; Hillson, 2005; Vodanovic´ et al., 2007). Studies of permanent dentition have reported between 2 and 7% of sexual dimorphism in different populations. For example, Kieser and Groeneveld (1989) reported 4% sexual dimorphism in crown measurements of native Africans. A study by Lund and Mornstad (1999) showed a percentage of sexual

dimorphism between 2.80% to 4.23% in tooth measurements obtained from Swedish populations. Sexual dimorphism of 3 to 7% was also reported in Turkish and Jordanian populations (İşcan and Kedici, 2003; Hattab et al., 1996). The same has been observed in primary teeth. Margetts and Brown (1978), for example, report an average of 2.5% as the level of sexual dimorphism in the crown sizes of primary teeth in a sample of 197 children of Aboriginal Australian origin. In another study by De Vito and Saunders (1990) on 152 white Canadian children the recorded average was 4.9%. Harris (1994) conducted a study on 120 contemporary black Americans and found an average of 2.9%. In a worldwide survey by Harris and Lease in 2005, an average of 2% was reported across all studied populations. Zadzinska et al. (2008) recorded a total average of 2.9% for 113 medieval Polish children.

3.3.1. Factors Relating to Dental Metric Dimorphism

3.3.1.1. Genetics

Many possible causes have been proposed for dental sexual dimorphism. In a study by Garn et al. (1967) it was suggested that size differences between male and female teeth were probably the result of genetic factors. This study found family-line similarities in the magnitude of brother-sister dental size dimorphism, which shows genetic control. Nevertheless, in spite of the large amount of work that has been done on family and twin studies (see review in Kieser, 1990), researchers have not yet been able to identify the exact genes responsible for controlling the size of the tooth.

Amelogenin – the gene code for a protein of the tooth enamel – is located on both the Y chromosome and the homologous region of the X chromosome (Hummel and Schultes, 2000). The X chromosome, as Garn et al. (1965a) reported, also influences tooth dimensions. Among sisters, the rate of concordance was higher than those among brothers or brother-sister relationships. Moreover, tooth dimensions were significantly smaller among individuals with Turner's syndrome (XO) compared to those that were XX. Also, males that were XYY were found to have larger teeth than normal males (XY) (Kieser, 1990; Mayhall et al., 1998). Contrary to these findings, some studies

have found no evidence to support the connection between tooth size and genetics (Potter et al., 1983; Townsend and Brown, 1978). It has been suggested, however, that X and Y chromosomes have differential effects on the development of teeth, which may help to explain sexual dimorphism in dental dimensions (Alvesalo, 1997).

Historically it has been observed that sexual dimorphism in tooth measurements is mostly linked to the amount of either enamel (Moss and Moss-Salentijn, 1977; Moss, 1978; Alvesalo et al., 1987) or dentine (Harris and Hicks, 1998; Stroud et al., 1994, 1998), which, as mentioned before, is related to idiosyncrasies in sex chromosomes. In 1997 a study was conducted by Moss and Moss-Salentijn to investigate the processes that cause sexual size dimorphism in human canines. In this study, the dental measurements and the dentine/enamel thickness for each surface (mesial, distal, buccal, and lingual) were examined in 48 males and 51 females. The authors explained that the canine showed the greatest amount of sexual dimorphism in terms of crown diameters, with male values exceeding those of females by 3% to 9%. They also suggested that the reason for sexual dimorphism in canine crowns is the thickness of the enamel, as the male process of crown completion (amelogenesis) continues 70 days longer in males than in females. Another study, however, proposed that rates of enamel formation are the same for both sexes, but that for males it occurs over a prolonged period, which would result in larger teeth (Moss, 1978). Alvesalo and Varrela (1991) proposed that not only do men have a longer period of enamel completion, but they also have a greater amount of dentine. The findings of this study indicated that the X chromosome exerts its influence over enamel, while the Y chromosome promotes the formation of both enamel and dentine. Saunders et al. (2007) examined a sample of 45 individuals collected from a historic cemetery site in Belleville, Canada, and found similar results. The authors analysed the longitudinal cross-sections of the permanent mandibular premolars and canines to determine the level of sexual dimorphism in both enamel and dentine. Male canines and third premolars contained larger proportions of dentine than their female counterparts. The female canines and premolars, on the other hand, had a considerably larger proportion of enamel with respect to overall crown size than the males. These findings fit with those of Schwartz and Dean (2005), who reported that greater male crown dimensions are related to a larger amount of dentine

in permanent teeth. Similar results have also been reported for primary dentition, indicating that male teeth exhibit larger amounts of dentine than females (Harris et al., 2001). The authors did not report any differences in enamel thickness among primary teeth. However, it should be noted that the extent of any sex chromosome contribution to differences in tooth size between males and females is still to be definitively established. Alvesalo and Portin (1980) has shown that there is sexual dimorphism displayed in the dentition, with males tending to have larger teeth than females, reflecting X chromosome linkage with the Y chromosome also having an impact. For example, both 47, XXY males and 47, XYY males have larger teeth than 46, XY males.

Several studies have also been conducted based on sexual dimorphism in root size. Garn et al. (1979a) showed that the measurements of root length could be as effective as crown diameter for sex estimation, exhibiting equal if not additional levels of sexual dimorphism. The authors obtained 80% and 87% sex accuracy rates using a combination of mandibular root length and crown dimensions, respectively. Similar studies also reported that the sex-discriminatory effectiveness of root length exceeded that of crown dimensions. However, crown and root dimensions were reported to be positively related (Garn et al., 1978; Harris and Couch, 2006). In 2004, Lähdesmäki and Alvesalo conducted a study on 47 XYY males and demonstrated that the population control males displayed longer root length than the population control females. The authors recorded a mean sex difference of 5%, which was similar to the amount (6%) recorded by Garn et al. in 1978 for premolars, molars, and mandibular canines. Lähdesmäki and Alvesalo's (2004, 2007) studies confirmed what had previously been reported for crown dimensions: that the influence of Y chromosomes on the development of root length was greater than that of X chromosomes, which may be the cause of sexual dimorphism in root size. In their 2004 study of 47 XYY males, Lähdesmäki and Alvesalo reported an increase in root length relative to normal males, while the 46 XY females exhibited root lengths close to those of normal males. According to Jakobsson and Lind (1973) there is also a distinctive sex difference in extreme root length, with females often showing extremely short roots and males exhibiting extremely long roots.

3.3.1.2. Environment

In 2001 a study was conducted by Dempsey and Townsend to assess the impact of genetic and environmental factors on tooth dimensions. The MD diameters of canines and premolars exhibited a high degree of non-additive genetic variation. Additive genetic variations are those effects that are transmitted directly from parents to children. Non-additive variations, on the other hand, consist of all other types of genetic variation, including dominance and epistasis. Dominance is where the presence of just one allele contributes as much as two of the same allele and epistasis is where alleles act differently depending on what other alleles are present, or gene-environment effects where the contribution of an allele changes depending on the environment (Breed and Moore, 2016). In another study by Garn et al. (1979b), the primary and permanent dentition of 870 white participants in the National Collaborative Perinatal Project were examined. The authors reported a direct relation between maternal health status and MD and BL crown diameters. White children with larger maxillary and mandibular teeth were associated with maternal diabetes, maternal hypothyroidism, and large birth size. In contrast, low birth weight and maternal hypertension could lead to a decrease in the size of the crown diameters. According to this study, maternal and foetal factors could account for almost half of the dental size variations.

Asymmetry of size can also occur among antimeres, which can be classified in three categories: the first category, antisymmetry, is defined as an asymmetry caused by competitive interaction between sides; the second category, directional asymmetry, is when one side has a normal tendency to develop more than the other; and the third category, fluctuating asymmetry, is defined as random variations from normal symmetry. The first two categories are under genetic control; however, the third category is particularly interesting for the study of the impact of environmental factors on tooth dimensions as it demonstrates the inability of an organism to carry out symmetrical development. According to experiments conducted on laboratory rats (Siegel and Doyle, 1975; Siegel et al., 1977; Sciulli et al., 1979), applying heat, cold, or noise to pregnant mothers can lead to higher levels of fluctuating tooth asymmetry

in offspring. In a study by Sciulli (2003) on a sample of Late Archaic and Late Prehistoric individuals from the Ohio River Valley, it was found that such environmental stress could be one of the important factors contributing to the reduction of the organism's ability to shield its normal growth pathways against 'developmental noise'. Nevertheless, according to Smith et al. (1982), it is not easy to find a relationship between fluctuating asymmetry and prenatal stresses. Studies have shown that prenatal alcohol and smoke exposure during pregnancy results in an increase in fluctuating tooth asymmetry in children (Kieser and Groeneveld, 1991). In another study, however, it was found that living children exhibited no relation between fluctuating tooth asymmetry and the indicators of prenatal stress (DiBennardo and Bailit, 1978).

A study by Guatelli-Steinberg et al. (2006) on a single Gullah population reported the significant impact of environmental stress on the degree of fluctuating asymmetry. According to this study, the Gullah population displayed higher levels of fluctuating asymmetry when compared to the Native Americans of the Late Prehistoric Ohio valley. These findings were compatible with the historical and archaeological evidence indicating that the level of environmental stress was considerably higher in the Gullah population.

Another environmental stress factor that seems to contribute to tooth size is nutritional status. The impact of nutrition on the reduction of tooth size has been examined in archaeological contexts. It has been suggested that in nutritionally stressed populations it is more probable that teeth do not grow to their maximum genetic size potential (Guagliardo, 1982; Simpson et al., 1990). In a study conducted by Larsen (1983) on prehistoric maize agriculturalists on the south-eastern U.S. coast, a substantial tooth size reduction in primary teeth was reported in comparison to hunter-gatherers. The authors suggested that since primary teeth crowns are mainly formed *in utero*, the reduction of tooth size in the later period was due to a decline in maternal health status and placental environment.

It is clear that tooth size variability is controlled by a complex interaction of genetic

and environmental factors (Hillson, 1998). Due to these factors, tooth size is different from one population to another and therefore cannot be applied to the world at large (Jain, 2013).

3.3.1.3. Body Size

Compared to females, males tend to be 15% heavier in body mass and 7% taller in stature (Gustafsson and Lindenfors, 2004; Smith and Jungers, 1997). Body composition is also sexually dimorphic: the muscle mass of men is greater in comparison with that of women, whereas the latter's bodies contain more fat mass (Plavcan, 2012a). Among nonhuman primates, body mass dimorphism ranges from a few species in which females have slightly larger bodies than males, to those species, such as the gorilla, where male bodies are double the size of their female counterparts (Smith and Jungers, 1997). By nonhuman primate standards, the degree of body mass dimorphism in humans is low. Body mass in humans is slightly more sexually dimorphic compared to gibbons and some of the monogamous and polyandrous monkeys. Their dimorphism of size, however, is less than that of chimpanzees and bonobos, and so is placed at the low end of the primate range (Gordon et al., 2008; Plavcan, 2012b).

There may be a relation between body size and tooth size. Primates, as a whole, exhibit high levels of positive correlation between body size and crown size (Gingerich, 1977), at least in males (Lucas, 1982), and there also exists a correlation between body size sexual dimorphism and crown diameter (Leutenegger and Kelly, 1977). In other words, those primates that exhibit low levels of body size dimorphism also exhibit low levels of canine dimorphism, and those species that exhibit high levels of body size dimorphism also exhibit high levels of canine dimorphism (Johanson and Edgar, 1996). It is widely accepted that there exists, within any given population, a low but positive correlation between tooth size and body size (Garn et al., 1966a, 1968; Henderson and Corruccini, 1976; Lavelle, 1977; Perzigian, 1981; Brace et al., 1987; Hillson, 2002). With reference to modern primate species, there is a link between a polygynous social structure and a pronounced sexual dimorphism in body weight,

while the height of the canine teeth is an indication of the greatness of the level of aggression in males (Clutton-Brock et al., 1977; Plavcan, 1993; Fleagle, 1999). Nevertheless, the link between body weight and the height of the canine is still unclear; there has been a gradual decrease in the sexual dimorphism of body weight. However, in the early stages of human evolution, the height of canine teeth was already low; as, for example, in the case of *Ardipithecus ramidus* (Plavcan and Schaik, 1997; Suwa et al., 2009). It was estimated that, in comparison with a female *Australopithecus afarensis*, a male's body would weigh 1.5 times more, while the estimation of canine dimorphism was much smaller (Fleagle, 1999). This ratio varies slightly in other species: modern humans (1.1-1.2), modern chimpanzees (1.2-1.3), and modern Gorillas (1.5-1.7) (McHenry and Coffing, 2000). The height of canine teeth, on the other hand, was very small in *Australopithecus afarensis*. The same thing was observed in modern humans (Hillson, 2005) Such inconsistencies were explained by Plavcan (2000), who cited different selection for canine teeth and body weight; according to this study, high levels of sexual dimorphism occurred in both traits due to predation pressure, that is the effects of predation on a natural community especially with respect to the survival of species prayed upon. The regular use of tools (weapons for fighting, for example), however, may be the cause of the reduction of the function of the canine teeth in males.

As mentioned earlier, the other factor that contributes to dental sexual dimorphism is associated with high rates of male violence and polygyny. However, this factor is mostly discussed in relation with the canine, as the most sexually dimorphic tooth in humans and non-human primates.

3.3.1.4. Sexual Dimorphism of the Canine

Most studies analyse differences between the sexes in mesiodistal and buccolingual tooth dimensions (Moorrees et al., 1957; Garn et al., 1964; Garn et al., 1966a, 1966b; De Vito and Saunders, 1990; Hillson et al., 2005; Stojanowski, 2007; Vodanovic´ et al., 2007; Viciano et al., 2011, 2015; Hassett, 2011; Zorba et al., 2012; Sharma et al., 2013). The results of the studies using these measurements have shown that canines

tend to exhibit the greatest level of sexual dimorphism among all teeth (Garn et al., 1966a; Bishara et al., 1989; Plavcan, 2001; Vodanovic´ et al., 2007; Acharya and Mainali, 2007; Cardoso, 2008; Khamis et al., 2014; Viciano et al., 2015). The sex difference of the mesiodistal diameter of permanent teeth is found to be 4%, with canines again having the highest degree of dimorphism (Garn et al., 1964). According to Ditch and Rose (1972), the accuracy of sexual size dimorphism is 93% when identifying the sex of a skeleton from the canine, as the most useful tooth for sex estimation. Kieser et al. (1985) performed a canonical discriminant analysis to examine posterior and anterior teeth, and showed considerable sex differences in all the studied cases. The results showed that the maxillary canines, second molars, the mesiodistal dimension of mandibular canines, and the buccolingual dimension of the first premolar were the most sexually dimorphic, yielding sex accuracy rates ranging between 70.9% and 93.3%. In another study, 720 teeth of a Saudi population were examined (Hashim and Murshid, 1993), and it was suggested that the canine was the only tooth with sexual dimorphism. In 2003, Kaushal et al. examined 60 individuals from North India and found that the mandibular canines exhibited statistically significant sexual dimorphism. The mandibular left canine and the right mandibular canine were the two largest teeth (8.8% and 7.9% respectively) contributing to sexual dimorphism. It was also revealed that when the width of the canine was greater than 7mm, the probability of being a male subject was 100%. In another study conducted on a sample of 100 individuals of Turkish origin (50 males and 50 females), Işcan and Kedici (2003) reported that the upper and lower canines and lower second molar were the most sexually dimorphic teeth. Vodanovic´ et al.'s (2007) study on 86 skulls from a medieval cemetery near Osjek recorded consistent sexual dimorphism in the maxillary canine. In another study by Acharya and Maniali (2007) using a Nepalese population, canines were determined as the most significant univariate sex indicator, followed by the first and the second molars. In 2011 Zorba et al. conducted a study of 133 Greek individuals (70 males and 63 females) to measure the mesiodistal and buccolingual diameters of 839 permanent teeth. According to the results of this study, the most dimorphic teeth were canines followed by first premolar, maxillary second premolar, and mandibular second molar. Viciano et al. (2011) examined the skeletal remains of 117 individuals from the city of Herculaneum (Italy). The authors reported

that the canine had the greatest level of sexual dimorphism, and obtained correct classification rates of 76.5% to 100%. Other studies by Angadi et al. (2013) and Khamis et al. (2014) on two large samples from India and Malaysia also recorded the greatest sexual dimorphism in the lower canines (Table 6).

Although many human sexual characteristics are unique, canine tooth size dimorphism is one of the characteristics shared with other primates, which is linked most closely to agonistic behaviour (Plavcan, 2011, 2012a). A discussion of this similarity can help achieve a better understanding of canine sexual dimorphism in humans.

3.3.1.5. Canines: Humans and Non-Human Primates

The level of expression of sexual dimorphism in most living primates is one of their prominent characteristics, and is mostly observed in the sizes of their bodies and their canines (Plavcan 2012a, 2012b; Hillson, 2014). However, this sexual dimorphism is much less pronounced in living humans (Leutenegger and Shell, 1977; Plavcan, 2001, 2012a, 2012b; Plavcan and van Schaik, 1997; Schwartz and Dean, 2001; Hillson, 2014). In a study conducted by Schwartz and Dean (2001) on a sample of 52 canines, it was reported that the degree of sexual dimorphism in mean crown height varied considerably among different species: from 11% in humans to 33% in chimpanzees and 66% in gorillas and orang-utans. Both males and females varied with respect to mean crown height, however males displayed higher levels of variation. According to this study, the degree of the expression of canine dimorphism was reflected in the time taken to form canine crowns, with male orang-utans and gorillas taking almost twice as long as their female counterparts. However, chimpanzees and humans exhibited much less difference in timing. Humans and orang-utans had the thickest canine cuspal enamel, taking the longest time to form in terms of overall crown formation time. In terms of these characteristics, canines in modern humans were evidently distinguished from canines in chimpanzee and gorillas. Based on Schwartz and Dean's (2001) study, Hillson (2014) concludes that since early hominins and humans have relatively similar canine morphology, they may also have similar developmental dimorphism. This is an

important issue when interpreting fossil hominins, in which it is difficult to establish the level of dimorphism.

It has been demonstrated that the degree of canine dimorphism among higher primates (monkeys, apes, and humans) is positively correlated with the form of intrasexual competition that the males and females of the species in question normally engage in (e.g. Plavcan, 2013). Those species in which intense male-male competition occurs more frequently than female-female competition exhibit greater degrees of canine dimorphism than those species with less or equal intrasexual competition (Fleagle, 2013). For example, in the case of gorillas, large canines are used in male-male combat. Gibbons (in which both sexes have pronounced canines of similar size) also use their canines in intrasexual competition (Gray and Garcia, 2013). According to Plavcan et al. (1995), this characteristic in gibbons' dentition reflects selection for weaponry in both males and females, indicating that both sexes hold territories and aggressively defend them from members of the same sex (Mitani, 1985). By contrast, the male and females of Callicebus, which does not display such behaviour, have smaller canines (Robinson et al., 1987). This suggests that the degree of canine dimorphism is not only the product of sexual selection acting on males; rather, it is the result of selection acting on both male and female weaponry. Since females are engaged in the competition for resources, it is therefore not unreasonable that at least some variation in canine dimorphism is a consequence of both natural and sexual selection (Plavcan, 2011).

One of the features that distinguishes hominin species from other species such as apes and monkeys is a reduction in the sexual dimorphism of canine size (Wolpoff, 1976; Greenfield, 1992; White et al., 2009; Plavcan, 2011; Gray and Garcia, 2013). Given adequate sample sizes of the earliest groups of *Australopithecus afarensis*, it is proposed that there is little sexual dimorphism in the size of their canine teeth (Kimbel and Delezene, 2009). According to the results of other studies, both earlier hominins (*Sahelanthropus*, *Ardipithecus* and *Australopithecus anamensis*) and later hominins exhibit no considerable canine sexual dimorphism (Plavcan and van Schaik, 1997; White et al., 2009; Plavcan, 2012b; Ward et al., 2010). In a study conducted by Suwa

et al. (2009), it was found that the height of canine teeth in both male and female *Ardipithecus ramidus* was very low and similar to the size of canines in female chimpanzees. Researchers have suggested different theories to explain this change in canine morphology, such as dietary adaptations, fighting and threat displays, and the replacement of handheld weapons with big canines in fighting (Greenfield, 1992). A dietary explanation seems unlikely as, according to Brunet et al. (2002) and Suwa et al. (2009), there is no evidence of a radical dietary change in *Sahelanthropus* and *Ardipithecus*. Other studies have considered the change in canine morphology as a decrease in male-male competition and a tendency towards long-term sociosexual bonds early in hominin evolution (Halloway, 1967; Lovejoy, 2009). According to Lovejoy (2009), for example, the similarities in the size of the canine shows *Ardipithecus ramidus*'s tendency to form long-term, mostly socially monogamous relationships. Dixson (2009) suggests that the reduction of canine dimorphism in hominins is due to the very nature of bipedalism, which enables males to fight differently. In contrast to other animal groups that normally make direct frontal attacks in which canines are situated in front, hominins normally use their arms to grab and punch, an aspect of bipedalism. It also enables them to use weapons when needed (Dixson, 2009).

However, despite the fact that human canines have undergone a considerable reduction in their size, they are still the most sexually dimorphic teeth (Kieser, 1990).

3.4. Sex Estimation and Dental Measurements

The estimation of sex using dental features is mainly achieved by either comparing the tooth measurements of males and females, or comparing the frequencies of non-metric variants such as Carabelli's trait of upper molars or distal accessory ridge of the upper and lower canines (Teschler-Nicola and Prossinger, 1998; Vodanovic´ et al., 2007). Similar to skeletal sex indicators, odontometric features differ among and within populations (Kieser, 1990; İşcan and Kedici, 2003; Hillson, 2005). This means that, in order to use dental variables for identification, it is necessary to first determine population-specific values (Vodanovic´ et al., 2007). In osteoarchaeology and forensic

anthropology studies, metric methods of sex estimation from the dentition are usually based on two sets of measurements: the maximum MD (mesiodistal) and BL (buccolingual) crown diameters, and cervical MD and BL diameters.

One of the main advantages of teeth with respect to sex estimation is that developing permanent dentition could be very useful for assessing the sex of immature skeletal remains. The crowns of permanent teeth develop early and, once formed, remain unchanged during growth and development—except in cases where specific changes and disorders of function, pathology, or nutrition have an effect on the normal dimensions of teeth—so any effect on sexual discrimination in permanent teeth that can be observed in adults should also be present in subadults (Cardoso, 2008). This makes it possible to measure young individuals' teeth and directly compare them against their adult counterparts. Bones, however, cannot be used for sex estimation unless they have reached adult proportions (Hillson, 2005).

The archaeological studies in which dental measurements are used to estimate sex in adults have provided sexing accuracy rates of between 76% and 100% (Rösing, 1983; Ditch and Rose, 1972; Scott and Parham, 1979; Mays, 1996; Duncan, 1998; Vodanovic´ et al., 2007; Viciano et al., 2011; Tuttösí and Cardoso, 2015; Kazzazi and Kranioti, 2016 a, b, 2017). It may be difficult, however, to reliably take dental measurements, because it requires some practice. It is also desirable that all the measurements are repeated so that their accuracy can be established (Işcan and Steyn, 2013).

3.4.1 Maximum Crown Measurements

The maximum MD and BL crown diameters are among the most common types of tooth metric variables. Most dental anthropologists have based their studies on crown measurements with respect to sex estimation (Bishara et al., 1986; De vito et al., 1990; Hattab et al., 1996; Liu et al., 2000; Karaman, 2006; Acharya and Mainali, 2007; Khangura et al., 2011; Angadi et al., 2013; Mujib et al., 2014; Singla et al., 2015). This may be due to the fact that crown dimensions are easier to record, whereas other

measurements, such as cervical diameters, are comparatively more difficult to take, especially when the teeth are still in the jaw.

Over the years, a number of studies have reassessed the definition of MD and BL crown diameters (Miyabara, 1916; Nelson, 1938; Van Reenen, 1966; Schamschula et al., 1972). Among these definitions, Moorrees and Reed's (1964) definition has received considerably more attention than the others. According to this study, MD crown diameter is defined as (1) the largest mesial to distal dimension, and (2) is parallel to the occlusal surface. BL crown diameter is taken as the greatest distance between the buccal/labial and lingual/palatal surfaces in a plane perpendicular to the MD diameter. Therefore, the basis of this measurement system is considered to be the axis of the MD crown diameter (Fig. 3.6). Another method that is widely used is proposed by Goose (1963). Goose's (1963) and Moorrees and Reed's (1964) methods are mostly similar, but the former specifies that MD measurements should be taken at the midpoints of a tooth's contact points with its neighbours. In the case of tooth malocclusion, MD diameters should be taken in the area where the contact points might have been if the tooth were in normal occlusion. According to this method, the BL dimension should be taken at right angles to the plane in which the MD dimension is obtained, with no regard for the position of the crown.

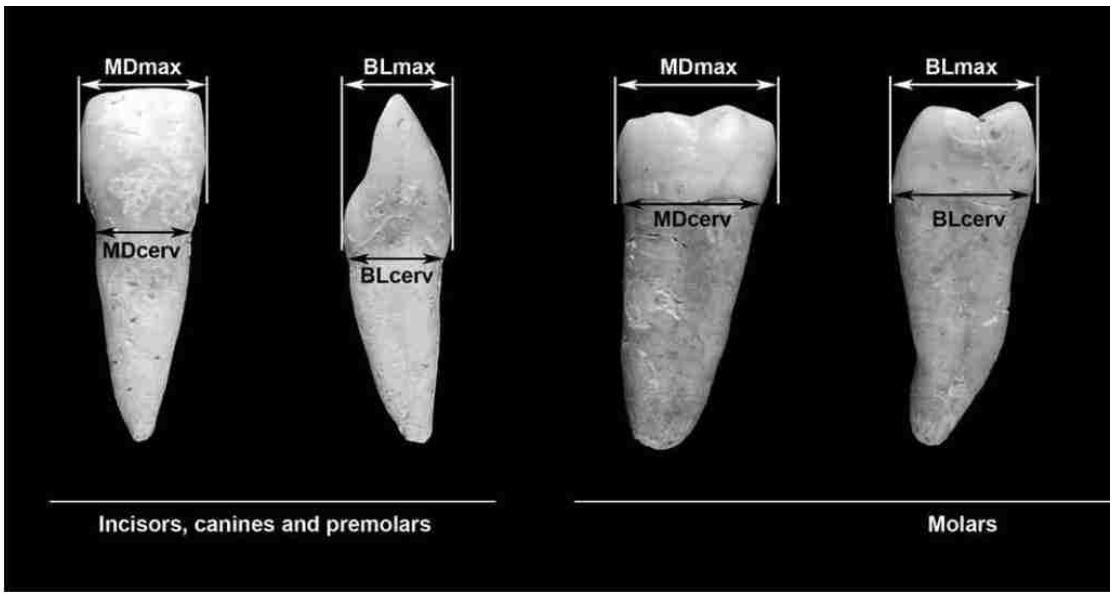

Fig 3.6. Crown and cervical measurements: MDmax, maximum mesiodistal crown diameter; BLmax, maximum buccolingual crown diameter; MDcerv, mesiodistal cervical diameter; BLcerv, buccolingual cervical diameter. Source: Viciano et al., 2011, p. 99.

Crown measurements have been widely used by many researchers for sex estimation in different populations. Garn et al. (1967, 1977, 1979a) used the crown MD and BL measurements of permanent teeth and correctly estimated sex of up to 87% of the individuals studied. Primary crown measurements also successfully classified sex of 60-90% of the sample in studies by Black (1978) and De Vito and Saunders (1990).

Ditch and Rose (1972) were the first to show that tooth measurements can be useful for sex estimation in archaeology when using skeletal remains that are fragmentary or poorly preserved. They used the crown MD and BL measurements of 39 male and 48 female adults from the Dickson Mound site (Illinois). The sex of the skeletons was first assessed using postcranial remains. In total, six stepwise discriminant functions were generated, and 89%-96% of the studied samples were correctly classified. Owsley (1982) used the same method to estimate the sex of 82 Arikara adults (Native Americans in North Dakota). The author recorded the MD diameter of the canine only, and BL diameters of all the permanent teeth. Stepwise discriminant function analysis produced a sexing accuracy rate of 91%, with canine measurements as the most affective variables. Teschler-Nicola (1992) analysed the crown MD and BL measurements of both permanent and primary teeth of 172 individuals (85 males and 87 females) from a Bronze Age population in Austria. Discriminant function analysis using both permanent and primary dentition obtained 75-81% correct sex assignment. In 2003 İşcan and Kedici studied the permanent crown diameters in 100 Ankara University students (50 males and 50 females). The BL measurements of 14 teeth (except third molars) were collected and used for stepwise discriminant analysis. The authors reported a low level of sexual dimorphism in crown BL diameter and could sex only 77% of the individuals correctly. For a more detailed description of the studies on sex estimation using crown diameters, refer to Table 3.1.

3.4.2. The Limitations of Crown Measurements

In spite of the usefulness of dental crown measurements, there are a number of limitations that impact their efficacy. The first limitation is the alteration of crown diameters due to varying levels of expression of non-metric traits (Garn et al., 1968).

When lower molars have extra cusps (e.g. cusp 6, cusp 7, protostylid), for example, the size of the overall tooth at the maximum dimensions of the crown increases. The second limitation, according to Hillson et al. (2005), concerns the difficulty that is normally met with when measuring the MD crown diameters, when the teeth are tightly fixed in the jaw. This is because when teeth are firmly wedged against the adjoining tooth there is not enough space for the calliper points to be placed on the maximum convexity of the mesial and distal crown sides. Researchers, therefore, prefer to work with needlepoint callipers. In some cases, it is possible to slightly move the teeth in the jaw so that there is access for measurement, but it is still nearly impossible to push the points far enough in. Also, there is a high risk of a delicate specimen being damaged very easily (Hillson et al., 2005). The third limitation, again as suggested by Hillson et al. (2005), is related to dental wear when recording the maximum measurement of contact points. Dental wear is the term used to describe a reduction in the size of the tooth crown, which proceeds continuously during life (Wallace, 1974; Hillson, 2002, 2005; Koche and Poulsen, 2009). This reduction is caused by either tooth-to-tooth contact (attrition), or rubbing a foreign object against the surface of the tooth (abrasion) (Kaidonis et al., 1993; Cox and Mays, 2002; Lucas, 2004; DeLong and Burkhart, 2013). As a result of dental wear, crown diameters are altered and the recording of dental morphology is obscured. A moderate wear of the occlusal surface of the crown can lead to a significant decrease in the MD measurement. As with the BL diameter, however, only excessive dental wear can affect it (Hillson, 2002). In the case of extreme dental wear, all the evidence of enamel is erased and the possibilities of making measurements or morphological identifications are eliminated. This is a common problem among archaeological skeletal samples. According to a study by Van Reenen (1982), when the crown is so worn away that the dentine is exposed, the percentage of the reduction in MD length could be as much as 10%. In the case of secondary dentine exposure, this percentage could reach as much as 20% (Van Reenen, 1982; Fitzgerald and Hillson, 2005).

Most researchers exclude teeth that are too worn to measure, which leads to two problems in practice. According to Hillson et al. (2005) the first problem is related to the degree of dental wear. It is not possible to positively determine how much wear is

too much, because a very small degree of attrition can result in a noticeable difference. Researchers have reported dental measurements to the nearest 0.1 mm. Such a difference can easily be caused by a small amount of wear. This leads to the second problem. By excluding a large number of worn teeth, the sample size is drastically reduced (Mayhall, 2000; Hillson, 2002). MD crown diameters have exhibited strong impact from approximal attrition –a type of tooth wear that occurs on those surfaces which form points of contact between adjacent teeth-, which makes the comparison of children's little-worn dentition (permanent) with adult's well-worn dentition invalid. This is problematic when using dental measurements to sex skeletal remains of children, as it is difficult to differentiate between male and female juvenile skeletons. In this method, the sex of adults (as a baseline group) is independently identified using pelvic or skull morphology, but if the teeth in the baseline group are very worn, it is not possible to compare them with the little-worn teeth of children. In addition, other factors such as ancestry, dental pathologies, non-metric variations, or the irregular shape of third molars as a common dental complication in modern or archaeological populations can affect the reliability of comparisons as such.

3.4.3. Cervical Tooth Measurements

Several researchers have proposed alternative dental measurements that are less affected by the problems associated with crown measurements. According to an early work by Goose (1963), a number of studies (Azoulay and Regnault 1893, Black 1902, Goose 1956) have proposed the MD diameter of the neck of teeth as alternatives. This is obtained by measuring the necks of teeth parallel to the normal MD and BL diameters. In a study by Falk and Corruccini (1982), measurements were taken from 100 skulls from 5 different human populations at the intersection between enamel and cementum (cemento-enamel junctions) as the maximum cervical length and breadth. Their study showed that these measurements could produce similar results as those obtained using the maximum dental crown dimensions. In a more recent study, Hillson et al. (2005, 418) provided a thorough description of these alternative tooth measurements. They suggested the addition of diagonal crown dimensions of molar tooth and cervix dimensions at the cemento-enamel junctions (CEJ). They also defined

the MD cervical measurement and the BL cervical measurement as "the distance between the most occlusal points of the cemento-enamel junction curve on the mesial and distal sides" and "The maximum measurement at the cemento-enamel junction from labial/buccal to lingual/palatal" respectively (Fig. 3.1). Examining a total of 2,559 unworn and isolated teeth, the authors reported that cervical tooth diameters could provide similar results to those of crown diameters. In this article, a new dental calliper was also introduced, specifically designed to measure the cervical and crown diameters of teeth in situ. According to their results, the impact of dental wear on these measurements is relatively small, which leads to a great increase in sample size and makes it possible to compare the heavily-worn teeth of adults against less-worn teeth of juveniles. The alternative dental measurements that Hillson et al. (2005) have proposed are particularly useful in taking measurements where there is only a relatively small amount of enamel crown height available. This eventually allows access to MD diameters at the cervical-enamel junction, where the surrounding teeth can no longer obscure them when still in the jaw. Moreover, considering the location of the CEJ with regards to the common non-metric traits of the crown, it is probable that non-metric trait expressions would have little impact on the measurements. Several studies confirm high correlation between these variables and those of tooth crowns. Therefore, it can be concluded that they represent the same genetic expression of dental metric variation as traditional crown diameters (Hillson et al., 2005; Stojanowski, 2007). These advantages make cervical measurements a perfect odontometric method for sex estimation.

In 2007 a test of Hillson et al.'s (2005) method was conducted by Stojanowski (2007). The aim of this study was to evaluate the possibility of using cervical diameters "as proxies for homologous crown metrics" (Stojanowski 2007, p. 234). Stojanowski (2007) based his study on testing the differences between traditional crown measurements and cervical measurements. Using a skeletal sample collected from the Windover Pond site from 7500 BC, the author reported that BL cervical diameters could yield similar results as crown diameters, contrary to MD cervical diameters. His findings were therefore in conflict with those of Hillson et al. (2005). According to Aubry (2014) this difference could be explained by the material used in the two

studies. Hillson et al. (2005) applied the method to a collection of loose teeth, which is very different from typical osteoarchaeological collections. In the study by Aubry (2014), the limitations of the application of Hillson et al.'s (2005) method to archaeological materials were identified. He reported that it was difficult to place the calliper tips correctly at MD landmarks, as suggested by Hillson et al. (2005), for many in situ teeth. Their recommendation that researchers rotate teeth to access the suggested landmarks resulted in large errors, because not all teeth could be rotated. Placing the calliper tips at the MD landmarks described by Hillson et al. (2005) is difficult for many teeth when measured in the jaw because of the shape of the tooth at the cervical margin in cross-section. In addition, Aubry (2014) noticed that the measurements differed depending on the position from which they were taken (buccal/lingual).

The suggested BL dimensions of molars also raise other problems, which produced heterologous measurements across tooth class due to differential reduction in the distal cusps and also the existence of the enamel extension (see chapter 8). To solve these issues, Aubry (2014) suggested some modifications to the Hillson et al.'s (2005) method:

1) Taking the MD measurements only from the buccal side for all anterior and posterior teeth following the cervical margin line.

2) Taking only the buccal portion of the posterior teeth in MD diameters.
3) Taking only the mesial portion of the posterior teeth in BL measurements.

Tuttosi and Cardoso (2015) used both Hillson et al.'s (2005) and Aubry's (2014) cervical tooth methods for sex estimation and concluded that the BL measurements of the molars defined by Aubry (2014) might increase the reliability of the measurements due to landmarks being more clearly defined.

Cervical measurements have been used by many researchers for sex estimation. Vodanovic´ et al. (2007) used crown and cervical measurements for sex estimation in

an archaeological sample from Croatia. A total of 86 skulls dating from the late 19th and 20th centuries were used for sex estimation. Sex was assessed based on both 20 craniofacial features and dental measurements. Crown MD and BL, crown height, and cervical MD measurements were taken on all permanent teeth. The correct sex classification rate using only craniofacial features was 56%, which increased to 86% when combined with dental measurements. The authors also reported a high level of sexual dimorphism in cervical MD and crown BL measurements.

In another study by Viciano et al. (2011) both traditional crown and cervical measurements were used for sex estimation in an archaeological population from Italy (Herculaneum, Naples). In total 38 tooth dimensions from 147 individuals, including 117 adults and 30 subadults, were recorded. Stepwise discriminant analysis correctly classified 76-100% of the samples, with the canine as the most sexually dimorphic tooth in adults. Based on the adult tooth dimensions, sex estimation was also possible for 22 of the subadult individuals. The authors reported that cervical measurements were more useful in sex estimation than crown measurements, as six out of the nine obtained functions involved some cervical diameters. This is because the crowns of the teeth were affected by most of the limiting factors, while the degree to which the cervix was affected was not as great. In 2015 Viciano et al. applied the same method, including diagonal crown and cervical diameter of the molars, to three different Iron Age populations from Italy. 88 metric variables were recorded in 149 adults and used to perform logistic regression analysis. This study reported the lower canine to be the most sexually dimorphic tooth, followed by the maxillary and mandibular first and second molars. The overall sex classification accuracy rate ranged from 84% to 96%. The results of this study also confirmed the utility of cervical diameters for sex estimation, because 18 out of 21 developed logit equations were a combination of cervical or diagonal cervical diameters. Another study by Viciano et al. (2013) on a large contemporary Spanish population (150 males and 119 females) also reported cervical diameters as the most sexually dimorphic measurements, providing an accuracy rate of 79.5% to 93%.

Similar results have been reported by other studies (Zorba et al., 2012, 2013; Mujib et al., 2014). For example, in 2012, Zorba et al. used multiple crown and cervical diameters to sex 107 modern Greek adults (53 males and 54 females). MD and BL crown and cervical diagonal measurements were taken on 344 permanent maxillary and mandibular molars. The results of their study showed that cervical diameters were more accurate and sexually dimorphic than crown diameters. The accuracy rate was found to be 93% for all molar diameters and 88.4% for cervical diameters only. The highest percentage of sexual dimorphism was also observed in cervical diameters of maxillary and mandibular second molars. In a similar study also by Zorba et al. (2013), the sex classification accuracy rate for molar measurements using cervical diagonal diameter was 88.4%, while using crown diagonal diameter it was 85%. This study also confirmed the high degree of sexual dimorphism in cervical measurements compared to crown measurements.

Crown and cervical diagonal measurements of molar and canine teeth were also used for sex estimation in a modern Indian population (50 males and 50 females) (Mujib et al., 2014). Stepwise discriminant analysis was used and correctly classified sex in 71% of cases; however, the accuracy rate of this study was lower than in previous studies, but the authors also confirmed that cervical diameters were more dimorphic than crown diameters. The same measurements were used for sex estimation in a modern African-American population (Peckmann et al., 2015). Four diagonal measurements were taken on the permanent maxillary and mandibular molars of 53 males and 50 females. The results of a direct discriminant analysis showed a sex classification rate of 72.6-100%, however the cross-validated data showed a much lower rate (40-72.3%). Stepwise discriminant analysis showed an accuracy rate of 63.9-77.6% for both original and cross-validated data. The authors also used the discriminant functions which were previously developed for a modern Greek population to sex the American-African individuals. Due to the low accuracy rate of the study (53.8-63.6%), the authors concluded that the degree of sexual dimorphism in tooth size is different between populations and therefore considered odontometric data as population specific. The results of the comparison between cervical and crown diagonal diameters were in contrast to previous studies (Viciano et al., 2013, 2015; Zorba et al., 2012,

2013; Mujib et al., 2014). According to Peckmann et al.'s (2015) study, crown diagonal diameters were presented in most of the stepwise discriminant functions (6 out of 9), showing that the crown diagonal diameters were more reliable for sex estimation then the cervical diagonal diameters.

In 2015 Tuttösí and Cardoso analysed the cervical diameters of the permanent teeth in a small archaeological sample (42 individuals) from Pender Island. The sex of the individuals was first assessed using pelvic morphological traits and then tooth measurements. Logistic regression analysis and sectioning point approach showed that the best sex estimation variables were the mesiolingual-distobuccal diameter of the mandibular first molar and the MD diameter of the mandibular second molar, providing an accuracy rate of 86.7% and 85.71% respectively. Nevertheless, the most potentially sexually dimorphic measurements were eliminated from the analysis due to the small sample size, and more consistent estimations of reliable sex classification accuracy were prevented due to unbalanced sex samples. Hassett (2011) analysed the sexual dimorphism in cervical diameters of canine teeth. The collections studied included 32 known-sex adult individuals and 74 adult individuals whose sex was assessed using osteological features. Discriminant analysis using the cervical diameters of maxillary and mandibular canines classified sex in 94% of the known sex sample and 95% of the osteologically estimated sex sample. Hassett also concluded that cervical diameters were highly repeatable with a low inter-observer error (technical error of measurement 0.20 mm), and could provide more accurate sexing results compared to traditional crown diameters. Some of the studies on cervical tooth measurements in sex estimation are listed in Table 3.1.

Table 3.1. The list of studies using tooth measurements for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Ditch and Rose (1972)	Modern/ USA	N=87 (M:39, F:48)	Crown diameters	89-96%	U & LC
Black (1978)	Modern/ USA	N=133 (M:69, F:64)	Crown diameters (deciduous)	63.9-67.7	UM1
Garn et al. (1979a)	Modern	N=49	Crown diameters & root length	63-80%	LC
Owsley (1982)	Modern/ USA	N=82 (M:41, F:41)	Crown diameters	91%	U & LC
Owsley & Webb (1983)	Modern/ USA	N=176 (M:86, F:90)	Crown diameters	65-81%	LC
Rösing (1983)	Archaeological / Egypt	N=55 (M:28, F:27)	Crown & root length diameters	90-97%	LC- crown
Kieser et al. (1985)	South Africa Caucasoid	-	Crown diameters	70.9-93.3%	UC
De Vito & Saunders (1990)	Modern/ Canada	N=162 (M;82, F:80)	Crown diameter (deciduous)	76-90%	UI2
Teschler-Nicola (1992)	Bronze Age/ Austria	N=172 (M:85, F:87)	Crown diameters	75-81%	-
Tsutsumi et al. (1993)	Modern/ Japan	N=194 (M:96, F:98)	crown length, width & thickness	70.6-78.4%.	Crown width of UI2
Hashim & Murshid (1993)	Modern/ Saudi Arabia	720 Permanent teeth	Crown diameters	-	U & LC
Lund & Mornstad (1999)	Modern/ Sweden	N=58 (M:29, F:29)	Crown & distobuccal-mesiolingual	-	UC
Nair et al. (1999)	Modern/ South India	N=108 (M:50, F:58)	Crown diameters	-	LC
Kaushal et al. (2003)	Modern/ North India	N=60	Crown diameters	-	LC
İşcan & Kedici (2003)	Modern/ Turkey	N=100 (M:50, F:50)	Crown diameters	73-77%	U & LC
Ateş et al. (2006)	Modern/ Turkey	N=100 (M:50, F:50)	Crown diameters	81%	U & LC
Harris & Couch (2006)	Modern/ USA	N=148 (M:57, F:97)	Crown & root length diameters (incisors)	-	Root length-UI1

Continued

Table 3.1 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Vodanovic et al. (2007)	Medieval/ Croatia	N=86 (M:48, F:38)	Crown & cervical diameters	86%	UC
Acharya and Mainali (2007)	Modern/ Nepal	N=123 (M:65, F:58)	Crown diameters	72.95.5%	UC
Stojanowsky (2007)	7500BC/ USA	N=140	Crown & cervical diameters	-	LM1
Boaz and Gupta (2009)	Modern/ South India	N=100 (M:50, F:50)	Crown diameters	-	LC- Reverse dimorphism
Zorba et al. (2011)	Modern/ Greece	N=133 (M:70, F:63)	Crown & cervical diameters	-	UC
Viciano et al. (2011)	79AD/ Italy	N=117	Crown, cervical & diagonal diameters	76.5-100%	U & LC
Acharya et al. (2011)	Modern/ India	N=105 (M:53, F:52)	Crown diameters	76-100%	-
Tardivo et al. (2011)	Modern/ France	N=58 (M:26, F:32)	3D- mineral, total, & pulp volume of canines	100%	Total volume- LC
Hassett (2011)	Post medieval/ England	N=111	Canine- cervical diameters	93.8-95%	-
Zorba et al. (2012)	Modern/ Greece	N=107 (M:53, F:54)	Molars- crown & cervical diagonal diameters	77.4-93%	U & LM2
Zorba et al. (2013)	Modern/ Athens	N=101 (M:51, F:50)	Molars- crown & cervical diagonal diameters	65.5-88.4 %	-
Angadi et al. (2013)	Modern/ India	N=600 (M:294, F:306)	Crown diameters	68.1-74.8%	LC
Viciano et al. (2013)	Modern/ Spain	N=269 (M:150, F:119)	Crown, cervical, diagonal diameters	79.5-93%	U & LC
Khamis et al. (2014)	Modern/ Malaysia	N=400	Crown diameters	70.2-83.8%	LC

Continued

Table 3.1 continued

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Mujib et al. (2014)	Modern/ India	N=100 (M:50, F:50)	crown & cervical diagonal diameters	71%	UC
Zorba et al. (2014)	Modern/ Greece	N=102 (M:58, F:44)	Root length- canines & incisors	58.6-90%.	UI2
Tuttosi & Cardoso (2015)	4500-3000 BP/Pender Island	N=42	Crown, cervical, diagonal diameters	86.7-85.71%	LM1
Viciano et al. (2015)	Iron Age/ Italy	N=149	Crown, cervical, diagonal diameters	84-96%.	LC
Peckmann et al. (2015)	Modern/ USA	N=103 (M:53, F:50)	Molars- crown & cervical diagonal diameters	72.6-100%	LM1
Tardivo et al. (2015)	Modern/ France	N=210 (M:105, F:105)	3D- Total volume of canines	82.3-85.2%.	-
Capitaneanu et al. (2016)	Modern/ Belgium	N=200 (M:100, F:100)	Panoramic radiographs: tooth length & width	80%	Tooth length- U & LC

3.4.4. Tooth Root Measurements

Tooth root measurements have also been used for sex estimation. However, compared to crown diameter, sexual dimorphism in root dimensions has been relatively neglected in sex estimation. There is a significant gap between root-oriented and crown-oriented studies in sex assessment researches, which becomes more important considering the high level of sexual dimorphism of root measurements (in comparison with crown measurements) shown by previous studies (Garn et al., 1978, 1979a; Harris and Couch, 2006). Although there is a very small body of research focusing on sexual dimorphism in root measurements, and although the evidence confirming their effectiveness in sex assessment is nearly non-existent, the functionality of root measurements in transferring the forces of occlusion to the maxillary/mandibular bone indicates their

importance as indicators of sexual dimorphism, considering that a male's bite force is larger than that of their female counterparts (Bakke et al., 1990; Julien et al., 1996).

All of the sex estimation studies based on root dimensions are based on root length measurements. According to Garn et al. (1979a), root length is the maximum length measured from the cemento-enamel junction to the apex of the tooth. Root length can be very useful for sex estimation as root measurements are not affected by tooth wear, as is often the case for crown measurements and, moreover, in cremated material, for example, crowns might not be preserved but roots might, therefore increasing the potential efficacy and usefulness of roots (Gocha and Schutkowski, 2013). In addition, compared to most crown or cervical measurements and non-metric methods (e.g. morphological traits of the cranium or pelvis), root length measurements contain a higher level of objectivity and require less experience (Zorba et al., 2014). Moreover, similar to other dental measurements, root length also can be used for the separation of the remains of female and male subadult individuals with a high level of accuracy (Rösing, 1983).

Garn et al. (1979a) used a combination of crown MD and BL measurements and root length of mandibular permanent teeth for sex estimation. Their results showed that root length by itself provided equal or better sex classification results than crown MD or BL measurements alone. For example, the average of correct sex classification for crown MD, BL and root length were 60.4%, 60.6%, and 64.6% respectively. However, the accuracy rate increased to 80% when using a combination of root length and crown measurements, and to 87% using root length as well as mandibular crown measurements. Rösing (1983) also used crown and root length measurements for sex estimation, in an archaeological collection from Egypt. He sexed the subadult individuals based on the discriminant function formulae developed from adult permanent teeth measurements. The accuracy rate of this study ranged between 90 and 97%. According to Rösing (1983), root length was the least sexually dimorphic variable and its inclusion in the analysis reduced the sex classification accuracy. This was in conflict with the results reported by Garn et al. (1979a), which could be due to the homogeneity with regards to age of the individuals in the former study (Rösing,

1983). In another study by Harris and Couch (2006) the sexual dimorphism of root length was analysed in a modern white American population. Four measurements, including crown MD length, overall crown height, crown height, and tooth length, were taken on the permanent maxillary and mandibular incisors of 148 individuals (57 males and 97 females). Their study showed that root length was more sexually dimorphic than crown measurement (6% and 2% respectively) and had more power to discriminate between males and females. In a recent work by Zorba et al. (2014) the sexual dimorphism of root length in a modern Greek population was examined. The maximum root length was collected from 774 permanent single-rooted teeth of 102 individuals (58 males and 44 females). The results of their study showed that maxillary second incisors and canines were the most dimorphic teeth, and the highest percentage of sexual dimorphism was also reported for maxillary teeth (16.56%). Accuracy of sex estimation ranged from 58.6% to 90% (Table 3.1).

In the last decade, the advances in imaging technologies have provided the researchers with new methods and techniques which can be used non-invasively to gather anthropological information that is beneficial for sexual dimorphism and sex estimation in different population. The following chapter will discuss these new techniques in more details.

CHAPTER 4 SEX ESTIMATION USING 3D METHODS

4.1. Introduction

The phenomenon that in recent years has been referred to as virtual anthropology employs a multidisciplinary approach towards the analysis of human anatomical data, which involves mixing quantitative analysis with digital technologies (Weber and Bookstein, 2011). The measurement-related methods used in sex assessment studies have usually been limited to linear measurements obtained using hand-held callipers. However, after technological advancements in digital imaging and computer technology, new bone and dental phenotypes and measurements can now be defined and measured in 3D. As a result of this new method, better anatomical discrimination and clearer understandings about fundamental biological processes in the development of the bones and teeth can potentially be provided. In recent years, researchers have confirmed the effectiveness and usefulness of image analysis in 2D over hand-measurement methods, due to their reliability and rapidity. 3D methods, on the other hand, allow a substantial increase in the metrical and morphological information that can be obtained from human remains (Smith et al., 2009).

The advantages of hand-held callipers are that they are, by comparison, simple to use and easily transportable, and the reasonable accuracy and reproducibility of manual measurements obtained from skeletal remains have been confirmed by different studies (Moorrees et al., 1957; Hunter and Priest, 1960). Nevertheless, in order to avoid the sharpened beaks of callipers damaging the samples care needs to be taken. This limitation can be reduced by using plastic callipers; however, these still can easily damage the tooth crown, particularly in more fragile cases, and could also lead to the removal of dental pathologies such as calculus from adjacent teeth in archaeological samples. Additionally, it is possible to obtain only a limited number of linear measurements, and they are time-consuming to record (Bolton, 1962; Hunter and Priest, 1960; Richardson and Malhotra, 1975).

Image analysis techniques provide a more reliable and accurate approach, allowing for both high reliability and more extensive examination. The advantage of this system over manual methods is that it permits researchers to obtain multiple measurements from a single image, and that subjectivity is reduced when identifying landmarks due to the automation of procedures during measurement (McKeown et al., 2002). In this chapter two of the most common virtual methods in sex estimation will be explained.

4.2. Geometric Morphometric Methods

Among the most effective tools for studying the size and shape of human remains are geometric morphometric methods. Geometric morphometric analysis is conducted when traditional methods cannot be used to quantify the morphology of rigid structures that contain curves and bulges (Steyn et al., 2004; Kimmerle et al., 2008). By using this method, researchers are able to assess morphological traits in details which show differences among skeletons. The term geometric morphometrics (GM) was first used by Corti (1993), and consists of methods that are predominantly based on 3D co-ordinates of homologous landmarks that describe the object under study (Bigoni et al., 2010). GM enables the researcher to detect the differentiation of variability that is caused by both size and shape when studying the form of biological objects. Compared to the results that have been obtained so far using other methods, the utilization of statistical GM procedures for the quantification of shape and size provides more accurate results and therefore increases the level of reliability (Bookstein, 1991; Rohlf, 2003; Slice, 2007).

One of the most common utilizations of geometric morphometrics in forensic and physical anthropology is related to sex assessment using different parts of the skeleton (Table 4.1). For example, Gonzales et al. (2009) used the greater sciatic notch and ischiopubic complex morphology of 121 individuals from a documented Portuguese collection for sex estimation. Their statistical analysis showed an average accuracy of 90.9% for the greater sciatic notch and an average accuracy of 90.1-93.4% for the ischiopubic complex. Kranioti et al. (2009) performed a GM study of the humerus for sex estimation in a modern Cretan population. In total, 12 landmarks were selected on

the proximal and distal end of the humeri. The study reported a total classification accuracy of over 89% when both size and shape variables were combined. In another study, by Perlaza (2014), lateral radiographs of 60 adult frontal bones were used for sex estimation. This study reported sex classification accuracy of 84.31%. Some of the GM studies on sex estimation using different human bones are summarised in Table 4.1.

Table 4.1. The list of GM studies using different bones for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Green & Curnoe (2009)	Modern/ Thai	N=144 (M;89, F:55)	Cranial traits	86.8%	-
Bigoni et al. (2010)	Modern/ Bohemia	N=139 (M:73, F:66)	Craniofacial analysis	70.4-100%	Upper face
Chovalopoulou et al. (2013)	Modern/ Greece	N=176 (M:94, F:82)	Palate and base of adult crania	74.8-90.4%	Cranial base
Perlaza (2014)	-	N= 60 (M:30, F:30)	Frontal bone	84.31%	-
Franklin et al. (2007)	Modern/ Various populations	N= 96	Mandible/ Subadult	59%	-
Franklin et al. (2008)	Modern/ South Africa	N=225 (M:120, F:105)	Mandible/ Adults	83.1%	-
Oettlé et al. (2009)	Modern/ South Africa	N= (M:46, F:28)	Mandibular gonial eversion	71.4-73.9%	-
Gonzales et al. (2009)	Modern/ Portuguese	N= 121	Pelvis	90.1-93.4%	Ischiopubic complex
Bytheway & Ross (2010)	Modern/ Americans	N= 200	Os coxa	98-100%	-
Kranioti et al. (2009)	Modern/ Crete	N= 97	Humerus	89.7%	Distal epiphysis

GM methods have not been used for sex estimation in odontometric analysis. However, these methods have been used on tooth morphology analysis in hominins (Gomez-Robles et al., 2007; Liu et al., 2010), 3D tooth surface reconstruction (Buchaillard et al., 2007) and bite-mark analysis (Kieser et al., 2007).

4.3. Methods Utilizing Computed Tomography (CT)

Medical imaging such as Computed Tomography (CT), provided the opportunity for three dimensional (3D) imaging of the skeletons. CT is a non-invasive, non-destructive technique that permits the 3D analysis of mineralized tissues as well as of their physical properties. Digital cross sections or slices of an object are rebuilt by CT scanners that can be stacked to generate 3D volumes. These 3D volumes enable the generation of computerized images of samples that, after being manipulated, sectioned, dissected, and measured, reveal both the internal and the external morphology. As a result of such methods, internal information on the morphology of rare, fragile, small, and valuable samples of both species that are extant and those that have become extinct can be accessed (Kim et al., 2007; Swain and Xue, 2009; Abel et al., 2012). In addition to making the visualization of hidden structures and details possible, CT also allows for the investigation of morphological variations within samples and the performance of advanced morphometric analysis (Rossi et al., 2004).

CT can yield a substantial amount of information, due to the ability of the slices to be recreated in any plane, and the data to be represented in the form of 2D and 3D images. The simultaneous or separate demonstration of internal and external anatomy is also possible, as well as qualitative and quantitative assessment of the images (Rhodes et al. 1999). Due to recent technological advances, CT systems can increase the spatial resolution and slice thickness to the micron scale, which results in the further refinement of the detail (Plotino et al., 2006; Swain and Xue, 2009).

CT scanning has allowed for a better examination of the sexually dimorphic characteristics of the human skeleton. Previous studies have proved it to be a suitable tool for establishing sexually dimorphic characteristics in different anatomical areas (e.g. Shearer et al., 2012; Djorojevic et al., 2014; Gulhan et al., 2015; Ekizoglu et al., 2016). For example, in a sex estimation study by Djorojevic et al. (2014) the CT scans of 150 Spanish adults were used to create 3D models of the os coxae. In total, 9 inter-landmark linear distances were examined, and sex was correctly classified in 89.3-95.3% of the sample. Ekizoglu et al. (2016) investigated the morphometry of the tibia

in a modern Turkish population. In total, 7 parameters were measured on 203 adult individuals. The classification accuracy in this study ranged from 79% to 86%. A study by Abdel Fatah et al. (2014) used 3D models of 222 crania from white Americans for sex estimation. The authors reported a correct classification rate of over 95%. See Table 4.2 for more studies on sex estimation using 3D analysis of bones.

Table 4.2. The list of CT scan studies using different bones for sex estimation.

Publication	Population	Sample size	Method	Accuracy rate	Best variables
Roopakhun et al. (2009)	Modern/ Thai	N=91 (M:56, F:35)	Cranial measurements	92.3%	-
El-sherbeney et al. (2012)	Modern/ Egypt	N=120 (M:61, F:59)	Petrous portion of temporal bone	77.96-83.6%	-
Osipov et al. (2013)	Modern/ Crete	N= 94	Bony labyrinth	76-84%	Radius of curvature
Abdel Fatah et al. (2014)	Modern/ Bass collection	N=222	Cranial traits	95.5-97.5%	Bizygomatic breadth
Amin et al. (2015)	Modern/ Jordan	N=192	Mastoid process	90.6%	Intermastoidale distance
Decker et al. (2011)	Modern/ Americans	N=100 (M:40, F:60)	Metric and non-metric-Pelvis	100%	-
Djorojevic et al. (2014)	Modern/ Spanish	N=150 (M:75, F:75)	Os coxae measurements	89.3-95.3%	Acetabular diameter
Torimitsu et al. (2015a)	Modern/ Japanese	N=208 (M:104, F:104)	Pelvis measurements	62-98.1%	Subpubic angle
Jung et al. (2014)	Modern/ Korea	N=72 (M:36, F:36)	Distal humerus	93.1%	-
Hishmat et al. (2015)	Modern/ Japanese	N=259 (M:150, F:109)	Lower limb long bones	75.8-98.1%	-
Gulhan et al. (2015)	Modern/ Turkey	N=200 (M:100, F:100)	Femoral measurements	91%	-
Ekizoglu et al. (2016)	Modern/ Turkey	N=203 (M:124, F:79)	Tibia measurements	79-86%	upper epiphyseal breadth
Badr El Dine & El Shafei (2015)	Modern/ Egypt	N=120 (M:54, F:66)	12th thoracic-first lumbar vertebrae	96.3%	12^{th} thoracic vertebrae
Mahfouz et al. (2007)	Modern/ Bass collection	N=228 (M:133, F:95)	Patella measurements	83.77-90.3%	-

The usage of 3D systems to study dental morphology was developed in the early 1960s. However, they were then very high-priced and, due to the lack of computer power at the time, the possibilities for data acquisition and analysis were very limited. Since data collection was very time-consuming and landmarks were located with a great deal of subjectivity, early methods were limited by low measurement accuracy (Smith et al., 2009). After the introduction of computer tomography and laser scanning, however, a new sphere of activity was opened up in the realm of dental imaging and measurement. One of the advantages of this technology is that it allows for the definition and obtainment of a broader range of measurements, as well as integral calibration. These systems also enable the manipulation and storage of 3D data in electronic form and thus the generation of virtual models of dentition.

Dental CT scans have been used in different research areas, such as dental morphology of fossil specimens (McErlain et al., 2004; Spoor et al., 2010; Smith et al., 2010; Margvelashvili et al., 2013; Crevecoeur et al., 2014), tooth development (Smith et al., 1997; Krarup et al., 2005; Smith et al., 2010; Dong et al., 2014; Smith and Boesch, 2015), dental pathology (Gerloni et al., 2009; Seiler et al., 2013; Dedouit et al., 2014; Ceperuelo et al., 2015), tooth wear (Kasai and Kawamura, 2001; Margvelashvili et al., 2013; Le Luyer et al., 2014), tooth morphometrics (Kim et al., 2007, 2013; Sherrard et a., 2010; Liu et al., 2010), and age estimation (Yang et al., 2006; Someda et al., 2009; Tardivo et al., 2011; Star et al., 2011; Sakuma et al., 2013; De Angelis et al., 2015).

Kim et al. (2007) evaluated the accuracy of micro-CT scans in dental metric analysis. Thirty linear distance measurements were taken on six first incisors and six first molars using four different assessment methods, including dental callipers, 2D photographic images, 2D and 3D images obtained by scanning data, and 2D and 3D images obtained by micro-CT data. The measurements made by imaging methods were compared with direct measurements taken by digital callipers. The results showed that the variables made by the micro-CT scanner were similar to those made by the digital callipers, and showed that micro-CT is an easy and accurate method for taking linear tooth measurements. In another study by Sherrard et al. (2010) the reliability of con-bean

computed tomographs (CBCT) in tooth and root length was examined. A total of 28 premolar and 24 incisor teeth were measured. The tooth and root lengths were collected first by a digital calliper (actual measurements) and the results were compared with the measurements derived from CBCT volumetric data. The results showed that actual measurements and CBCT measurements were not significantly different, and the mean difference between the two sets of data was less than 0.3 mm. A similar study by Liu et al. (2010) reported a difference of -4% to +7% between the actual and the CBCT measurements. Kim et al. (2013) studied the accuracy of both crown and root length measurements in 94 premolar teeth obtained by CBCT in a Korean population. The differences between CBCT-based measurements and direct measurements collected by digital callipers were not significant for both crown and root length measurements; however, the limit of agreement range was wider for root length than crown length measurements

As mentioned before, 3D CT scan images have been frequently used for sex estimation in morphometric analysis, particularly using the pelvis and skull (Decker et al., 2011; Djorojevic et al., 2014; Franklin et al., 2014; Dedouit et al., 2014; Torimitsu et al., 2015a,b; Ji et al., 2010; Uthman et al., 2012; Tambawala et al., 2015; Kanthem et al., 2015). However, unlike 3D CT scan images of human bones, dental 3D scan images have not been widely used for sex estimation. To the best of the author's knowledge, the only studies of this kind are Tardivo et al.'s (2011, 2015). In these studies, the pulp volume and the total volume of the maxillary and mandibular canines were used for sex estimation. The authors reported that canine volume measurements are highly sexually dimorphic and provided an accuracy classification rate of 100% (Table 3.6). However, the validity of this method in sex estimation needs to be tested using other tooth types. In addition, dental pathologies such as caries (particularly occlusal caries) and tooth wear will considerably affect the size of the tooth crown, and in more severe cases will result in pulp exposure (Scully et al. 2010; Van Noort 2013) and eventually alter the measurements. The current study attempts to overcome these issues by measuring the volume of the root from the apical to the cemento-enamel junction (CEJ).

As mentioned in previous chapters, in the field of forensic anthropology and bioarchaeology, a wide range of skeletal remains and methods are available to choose from for sex estimation. The pelvis and postcranial bones, as the most sexually dimorphic elements in the human body, are widely used in both morphological and morphometric sexing methods. However, due to their delicacy they are more prone to post-mortem damage, and this necessitates the usage of a more durable substance, namely teeth, as the most highly mineralized tissue in the human body. Considering the high level of sexual dimorphism in dental measurements, they can be an effective substitute for sex estimation, particularly in archaeological collections. However, similar to osteological sex estimation methods, odontometric methods are population-specific and cannot be universally applied. Therefore, the collection of data from different populations is important for dental sexual dimorphism. As there is currently no odontometric reference data for Iranian archaeological populations, the present study contributes to the development of standards for sex estimation. This study uses 2D, 3D cervical and RV measurements, which compared to traditional dental measurement methods are more effective and useful in studies concentrating on prehistorical skeletal remains, as they make it possible to include teeth with alterations caused by wear, cultural modification, pathology (e.g. caries), or post-mortem damage. This allows a larger dataset to be achieved and a wider range of ages to be represented. The following chapter will explain the material and methods used to examine the reliability and efficacy of these measurements in archaeological samples for sex estimation.

CHAPTER 5 MATERIALS AND METHODS

5.1. Introduction

This study was conducted on skeletal remains from Hasanlu and Dinkha Tepe, both housed at the University of Pennsylvania's Museum of Archaeology and Anthropology (UPM). Hasanlu Tepe is one of the largest and most often studied archaeological sites in Iran. The site is located southwest of Lake Urmia in the Ushnu-Sulduz valley of northwest Iran, in the province of West Azerbaijan (Fig. 5.1). Hasanlu Tepe consists of two separate topographic zones. The Citadel or High Mound is 25 meters high and 200 meters in diameter, surrounded by a Low Mound, which includes a cemetery, standing 8 meters above the surrounding plain. Hasanlu currently measures 600 meters at its widest observable point, however modern villages and local agricultural activities have reduced the actual size of the site (Dyson, 1989). The Dinkha Tepe site is located 15 miles to the west of the Hasanlu site in the Solduz valley. The Dinkha mound measures 400m in diameter and is 200m high.

Fig. 5.1. Hasanlu is located in northwest Iran (in the province of West Azerbaijan, south of Lake Urmia). The orange dot in the map shows Hasanlu.

The lack of the remains from Hasanlu and the exceptional archaeological context that they provide make the skeletal remains of this region particularly interesting. They consist of a cemetery group and an assemblage of individuals belonging to a captured city. The current investigation was mainly focused on the contemporaneous Iron Age sub-samples obtained from both the cemetery (the Low Mound) belonging to *c*.1450 to *c*.800 BCE, and the destruction level (the High Mound) belonging to *c*.800 BCE.

5.2. Material

5.2.1. Hasanlu

The Hasanlu site was first excavated by M. Rad and M. Farhadi under a commercial excavation permit in 1934 (Stein, 1940). Two years later, in 1936, British archaeologist Sir Aurel Stein conducted the first scientific excavation of the site (Stein, 1940). In 1947 and 1949 Iranian archaeologists Ali Hakemi and Mahmoud Rad opened a number of graves in the cemetery area of the Lower Mound (Hakemi and Rad, 1950). These early excavations indicated the presence of Iron Age levels and also "Gray Ware" ceramic assemblages at Hasanlu (Danti and Cifarelli, 2013), which has long been associated with the earliest Iron Age in Iran (Dyson, 1983). The large size, deep stratigraphic sequence, geographic location, and several small surrounding archaeological sites made Hasanlu Tepe an excellent place to start a long-term archaeological project (Dyson, 1983) (Fig. 5.2). The Hasanlu project started in 1956, under the joint sponsorship of the University Of Pennsylvania Museum Of Archaeology and Anthropology, the Metropolitan Museum of Art, and the Archaeological Service of Iran. The research aimed to reconstruct the cultural and political developments in Hasanlu and the surrounding region from Neolithic times until the conquest of Persia by Alexander the Great in the 4th century BCE (Dyson, 1983). Over 21 years, from 1956 until 1977, under the direction of Robert H. Dyson from the University of Pennsylvania, a series of excavations and surveys were conducted on the Hasanlu and other sites in the region such as Agrab, Pisdeli, Ziwiye, Dalma, Se Girdan, Hajji Firuz, and Dinkha Tepe (Winter, 1980).

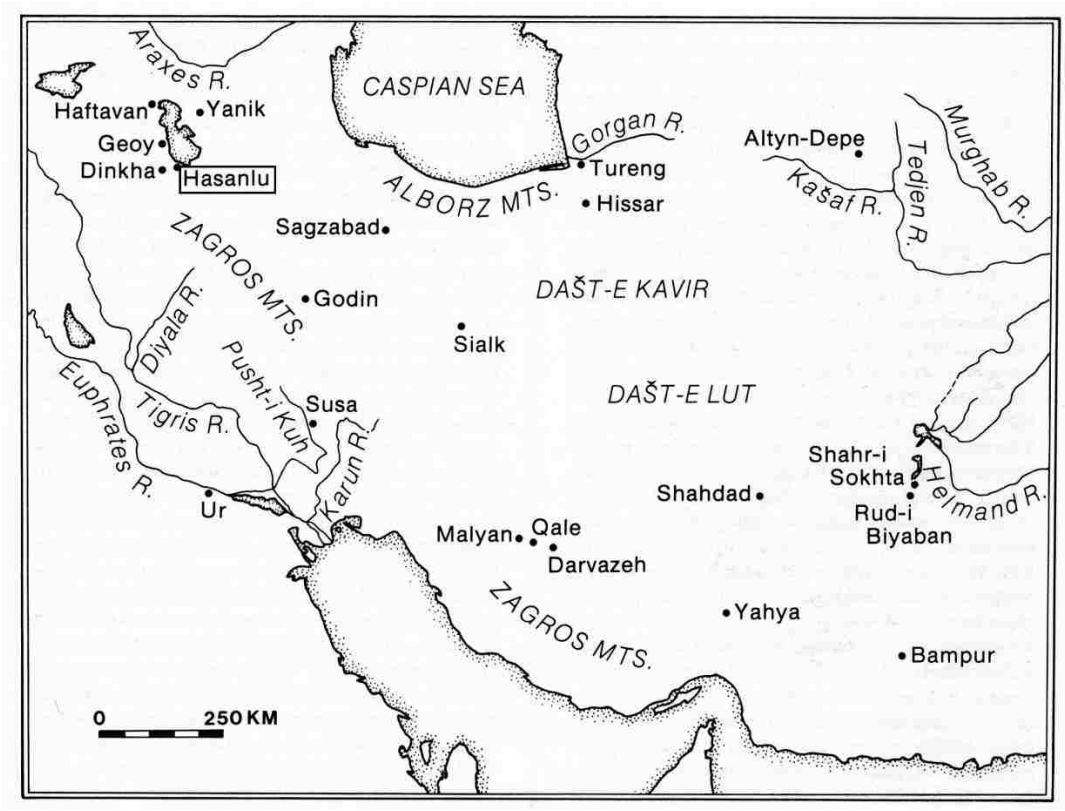

Fig. 5.2. Map of Hasanlu in relation to other archaeological sites (Dyson, 1989).

The excavations revealed that the Hasanlu site was first occupied in the Neolithic period (Hasanlu X, 6th millennium BCE), and that occupation continued until the Ilkhanid period (Hasanlu I, 13th century CE). The site was inhabited continuously from the Bronze Age (Hasanlu VII, late 4th century BCE) until Iron Age II (Hasanlu IVB, 800 BCE), which witnessed the complete and violent destruction of Hasanlu by fire (Table 5.1).

Table 5.1. Hasanlu period chronology (Selinsky 2009)

Periods	Dates
VII	Late 4 cent. - C. 1600 BCE
VI	C. 1600- C. 1450 BCE
V	C. 1450- C. 1250 BCE
IV	C. 1250- c. 750 BCE
III	C. 750- C. 300 BCE
II	C. 300- C. 275 BCE
I	13th and 14th Cent. CE

Plant remains excavated from the site showed that the conflagration probably happened in late summer (Dyson, 1965). It is believed that the violence and fire in the High Mound completely annihilated the people, women and children included, who remained in the buildings. It seems that most of the people were left in the place where they had been killed, in the streets and buildings that then collapsed on their bodies due to the fire (Figs 5.3 and 5.4). A large number of weapons of different types were found in many of the buildings in Hasanlu, probably in storage areas, indicating that those who stayed there in fact had weapons and horses at their disposal. However, since the bodies were scattered all over the city, it shows that they faced a swift and violent end.

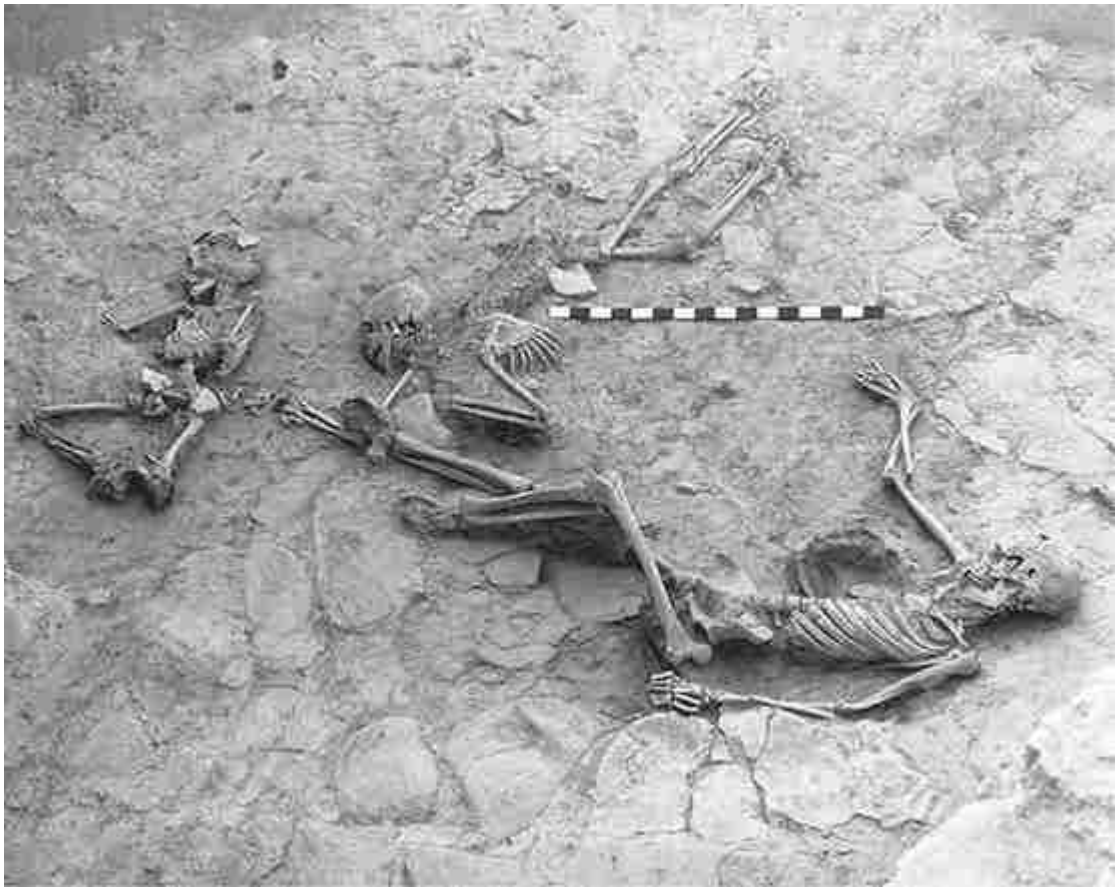

Fig. 5.3. Skeletons from the destruction level (High Mound). Source: https://www.penn.museum/collections/highlights/physicalanthro/the-lovers.php

The information provided by the military artefacts of Period IVB is very limited and cannot be used to identify the attackers. However, when scholars matched the date that was obtained from radiocarbon evidence with artefacts that corresponded to historical

records, they suggested that Hasanlu was destroyed by the Uratian kings Ishpuini (825-810) and/or his son Menua (810-781). Rock inscriptions found close to Ushnu and Tashtepe in the Urmia region, which show the celebration of the military campaigns of Ishpuini and Menua, also support this theory (Burney, 1994; Levine, 1987; Muscarella, 1989; Pecorella and Salvini, 1982; Zimansky, 1995). The fire that destroyed the site made Hasanlu V and IV, the Iron Age levels, the most widely investigated, due largely to the significant material culture recovered, especially the architectural remains and artefacts found in Hasanlu IVB. In addition, hundreds of grave goods were found in the Iron Age cemetery located to the north of the High Mound. The Hasanlu Gold Bowl, the most famous artefact discovered at the site (Porada, 1959; Winter, 1989), was discovered in the ruins of one of the burned buildings on the High Mound. Independently of these remarkable findings, what makes Hasanlu a very important archaeological site is its carefully controlled stratigraphic sequence throughout several periods, which produces the main basis of the regional chronology for north-western Iran.

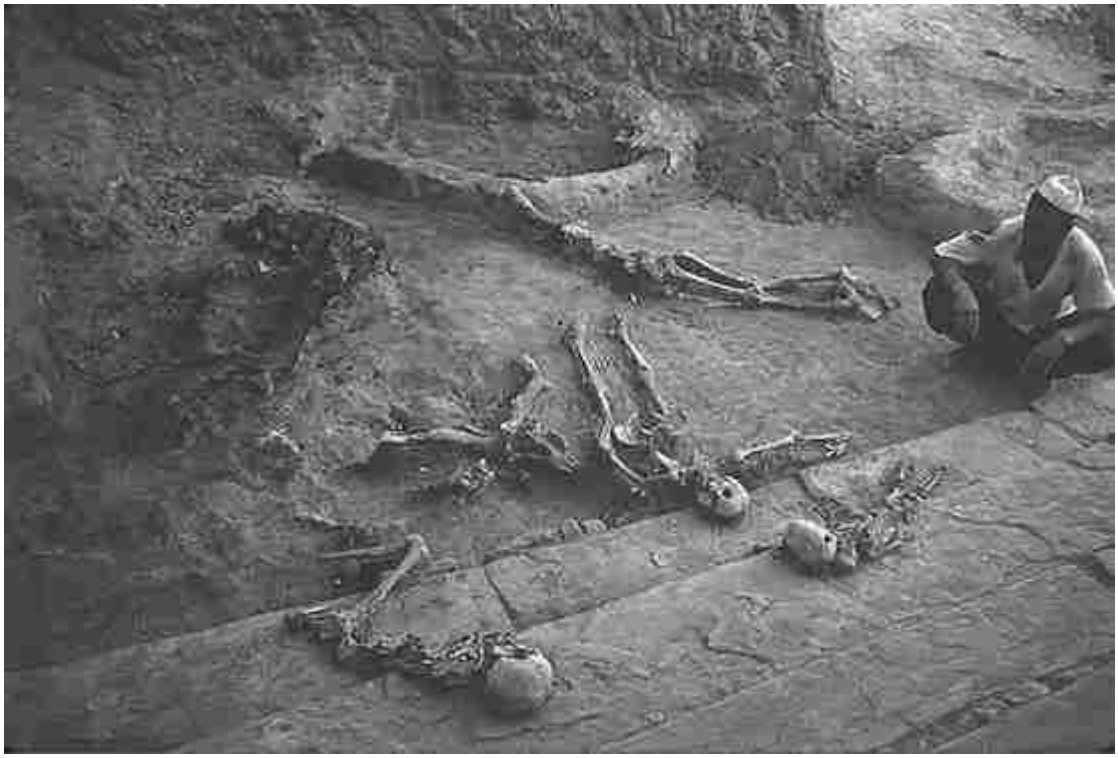

Fig. 5.4. Skeletons from the destruction level (High Mound). Source: https://www.penn.museum/collections/highlights/physicalanthro/the-lovers.php

5.2.1.1. Skeletal Material

The Hasanlu skeletal material forms an excellent source for scholars working on the ancient Near East due to it being one of the largest Iranian skeletal collections available. Additionally, this collection is linked with a rich material culture obtained from the excavations over several decades. The total number of skeletal remains associated with Hasanlu available at the UPM is 263 individuals: 184 adults and 79 subadults (as summarized in Table 5.2). Although these samples belong to individuals coming from different periods in the site's history, the majority of them (n = 212) are related to periods V, IV, and IVB (i.e. Iron Age) in the site chronology (Tables 5.1 and 5.3). Since the largest sample size available for analysis were obtained from the Iron Age period of the site, the main focus of this study also was set on the specimens from this period. Also what makes this timeframe particularly interesting is that it includes samples from both the cemetery and the destruction level.

Table 5.2. Composition by age category of collection (Selinsky 2009)

Age category	Numbers	% of sample
Foetal (preterm)	1	0.38
Infant (birth-3 years)	24	9.13
Child (4-11 years)	26	9.89
Subadult (12-19 years)	28	10.65
Young adult (20-34 years)	58	22.05
Middle adult (35-49 years)	75	28.52
Old adult (+50)	34	12.93
Adult (limited data for aging)	17	6.46
Total	**263**	**100**

Table 5.3. The number of skeletons in different periods

Periods	Number of skeletons
VII	3
V, VI, VIB	212
III	24
II	21
I	1
Unknown	2
Total	**263**

The Hasanlu skeletal collection has previously been studied by several researchers. Rathbun completed both his master's thesis (1966) and doctoral dissertation (1971) on nearly half of the Hasanlu skeletal remains (150 individuals) at the University of Kansas. His research focused mainly on the morphological affinities of the remains and, in 1972, the findings were published in a book titled *A Study of the Physical Characteristics of the Ancient Inhabitants of Hasanlu, Iran*. Rathbun also carried out some studies on the paleopathology of the Hasanlu skeletal remains (1980, 1981). In 1997 a conference presentation about interpersonal violence at Hasanlu was given by McCarthy and Perlin. In 2005 Toebbe used the Hasanlu collection for her doctoral thesis, studying stress markers and the osteological paradox (Toebbe, 2005). In her analysis she used all of the Hasanlu skeletons to collect data but unintentionally included the remains from Dinkha Tepe in her analysis, which eventually resulted in difficulties in interpretation.

Another master's dissertation based on the Hasanlu collection was written by Dulik (2005). He used craniofacial measurements of the Hasanlu skeletons in biodistance analysis to recognize local inhabitants and invaders. This study was extended to extract ancient DNA from teeth from six Period IVB skeletons. This study was not very successful as there was no DNA in the analysed samples (Dulik et al., 2011). Monge and McCarthy (2011) also used cranial trauma to study the warfare and interpersonal violence among the Iron Age skeletal remains from Hasanlu. Their results show that while the pattern of ante-mortem and peri-mortem fractures for males is typical for warfare, for females it represents interpersonal violence against women in the Hasanlu

collection. The largest study of the Hasanlu collection is that by Page Selinsky (2009). She completed her doctoral dissertation on the paleodemography of the Hasanlu skeletal remains. Selinsky collected data on age, sex, and health markers from 195 individuals, in order to address the issue of the age estimation of individuals using dental and skeletal markers, and also to explore patterns of mortality, health, and longevity in the Hasanlu collection.

In 2013 the author of the present study travelled to the UPM to study the Hasanlu skeletal remains. Analysis confirmed that there were 212 individuals belonging to Iron Age levels. However, as there is currently no accurate method of determining sex in subadult remains using skeletal characteristics (Scheuer and Black, 2000), this study only included adult individuals. In the case of the Hasanlu cemetery, the burial environment appears to have been fairly conducive to bone preservation, as most of the remains are in good shape structurally. Some of the skeletons, however, were not well-preserved enough to be used for sex estimation, or did not have any teeth preserved. In addition, the state of some of the sets of dentition made it impossible to use them for this study. Some of the teeth, for example, were broken or the level of dental pathology was so high that observation of metric data was impossible. In addition, in the case of some of the mandibles and maxillae, teeth were glued firmly into their alveolar process, which caused various problems. First, due to the excess glue around the teeth, it was almost impossible to collect an accurate measurement. Second, the places where the teeth were glued were often wrong. For example, instead of a premolar, a canine would be glued into the alveolar process, or the tooth would be glued backwards. Due to these problems with the collections, data were only collected on 105 individuals.

5.2.2. Dinkha Tepe: Archaeology and Skeletal Material

In 1966 and 1968 Dinkha Tepe was excavated by teams from the University of Pennsylvania and the Metropolitan Museum of Art, New York. The excavation was conducted as part of the regional research connected with the Hasanlu project. As a result of these excavations Islamic remains (Dinkha I) were revealed and below this,

on the north side, there was a cemetery. In the Dinkha II and III burials (1350-800 BCE), there was cultural material that paralleled the cultural material of Hasanlu periods IV and V, and Dinkha IV (1900-1300 BCE), which is equal to Hasanlu VI (Muscarella, 1968, 1974) (Table 5.4). Despite the prominent place that Dinkha Tepe occupies in some of the most important debates regarding Iranian archaeology, particularly those concerning the fundamental cultural transformation that marks the shift from 'Bronze Age' to 'Iron Age', the data obtained from the excavations has only been fragmentally analysed and there has been no publication of the bulk of the material. There are only a few publications related to the Dinkha material, and they have a very narrow focus in terms of both theme and amount of data presented.

During the excavation 61 skeletons (52 adults and 9 subadults) were discovered from the Dinkha II and III periods. Of these 51 are present at the UPM (University of Penssylvania Museum of Archaeology and Anthropology). Some of the adult individuals had no teeth present, and also due to the aforementioned problems some of the skeletons were excluded. In total, 38 individuals from Dinkha Tepe were used for this study.

Table 5.4. Hasanlu and Dinkha Tepe period chronology. Danti and Cifarelli (2013, 30).

Hasanlu Period	
I	Ilkhanid
----------Break----------	
II	Seleuco-Parthian
IIIa	Iron IV-Achaemenid
----------Break----------	
IIIb	Iron III
IIIc	Urartian Fortress
----------Break----------	
IVa	Iron III
IVb	Iron II (Dinkha II)
IVc	Iron I (Dinkha III)
V	Late Bronze (Dinkha III)
VIa	Middle Bronze III (Dinkha III-IV)
VIc	Middle Bronze I
----------Potential Break----------	
VIIa	Early Bronze III
VIIb	Early Bronze II
----------Potential Break----------	
VIIc	Early Bronze I

5.3. Methods

5.3.1. Age Estimation

To estimate the sex of each individual and to identify and separate the adults from subadults, the present study collected multiple lines of data. In the case of immature individuals, estimation of age was mainly based on the stage of tooth formation and eruption (Buikstra and Ubelaker, 1994; Scheuer and Black, 2004). Although the sequence of formation and eruption differs from one population to another (Ubelaker, 1999), this method is the most accurate for neonatal stages through to the eruption of wisdom teeth, which typically happens in the late teenage years or early twenties. The stages of epiphyseal formation and union were also assessed in each individual (Scheuer and Black, 2004). This technique is particularly useful when used alone or in combination with dental development. During the teens and early twenties, two of the

most effective techniques for age estimation are the appearance of ossification centres – which can be applied from birth until the age of 15 – and the fusion of epiphyses.

To estimate age in the adult sample, different methods related to both dental and skeletal features were employed in this study. Dental wear was primarily used for age assessment in the Hasanlu sample. A combination of the Miles method (2001) and wear scorevalues was used to evaluate the dental wear (Buikstra and Ubelaker, 1994). This is arguably considered the most effective available technique for the analysis of archaeological populations (Brothwell, 1989; Lovejoy, 1985; Mays, 1998; Molleson and Cohen, 1990; Walker et al., 1991) because the rates of dental wear are estimated within the skeletal population according to subadult and adult dentitions. The application of the Miles method to archaeological skeletal materials has proved successful (Kieser et al., 1983; Mays, 1998), including in the Tepe Hissar collection from Iran (Nowell, 1978). To determine skeletal age, traditional means such as changes in the pubic symphyseal face (Brooks and Suchey, 1990), and alterations to the auricular area (Buckberry and Chamberlain, 2002) were used. When these methods were not available, the closure of cranial sutures (Meindl and Lovejoy, 1985) was used to place individuals in an age category. However, the reliability of this method is still debated due to its extreme variability and the extent to which genetic and/or environmental factors affect the rate and order of closure (Key et al., 1994). In addition, the standard methods established for scoring cranial suture closure are often criticized for subjectivity and a lack of quantitative analysis (Key et al., 1994; Hershkovitz et al., 1997).

5.3.2. Sex Estimation

5.3.2.1. Skeletal Morphology

Sex estimation in this study was only carried out on adult specimens, as there are as yet no reliable means for sex estimation using skeletal features in subadult individuals (Scheuer and Black, 2000). The state of preservation is one of the important factors determining the accuracy of sex assessment in adults, with the pelvis and cranium

being the elements with the highest level of diagnostic accuracy.

In this study, the straightforward visual technique of Phenice (1969) was used to estimate sex using the pelvis. This technique is based on the distinctions of the os pubis. Phenice's method identifies differences in the subpubic concavity, the ventral arc, and the medial aspect of the ischiopubic ramus. This study also uses the sciatic notch as a means for sex estimation due to its high level of accuracy in sex assessment (Pretorius et al., 2006; Walker, 2005).

Walker's modified scoring system, presented in 2008, was used in this study to assess sex using cranial traits (mastoid process, nuchal crest, glabella/supraorbital area, supraorbital margin, shape of orbit, and mental eminence). Mandible features were also used as a means to independently verify the sex estimates. Unfortunately, due to time limitations on data collection, the author could not collect postcranial measurements for sex estimation. However, in addition to morphological features of the skull and pelvis, Selinsky (2009) uses postcranial measurements for sex estimation, including mastoid length, mandible measurements, pelvis and long bone measurements. The sex estimation results of the present study were cross-checked for each specimen separately with the data presented by Selinsky (2009).

5.3.2.2. Dental Measurements

Sex estimation using dental measurements was performed using three different methods:

1) 2D cervical mesiodistal and buccolingual measurements
2) 3D cervical mesiodistal and buccolingual measurements
3) Tooth root volume measurements.

The 2D cervical measurements were taken using the Paleo-Tech Hillson-Fitzgerald digital calliper, and 3D cervical and volume measurements were taken using CT scan images and AMIRA software. For all three sets of measurements, the Hasanlu and Dinkha Tepe samples were pooled together in order to increase the sample size.

5.3.2.2.1. 2D Measurements

Dental measurements of the cemento-enamel junction include the mesiodistal and buccolingual diameters followed the method outlined by Hillson et al. (2005). According to this method, mesiodistal cervical diameter was taken as the "distance between the most occlusal points of the cemento-enamel junction curve on the mesial and distal sides" (Hillson et al., 2005, p. 418). Buccolingual cervical diameter was taken as the "maximum measurement at the cemento-enamel junction from labial/buccal to lingual/palatal (Hillson et al., 2005, p. 418) (Fig. 5.5).

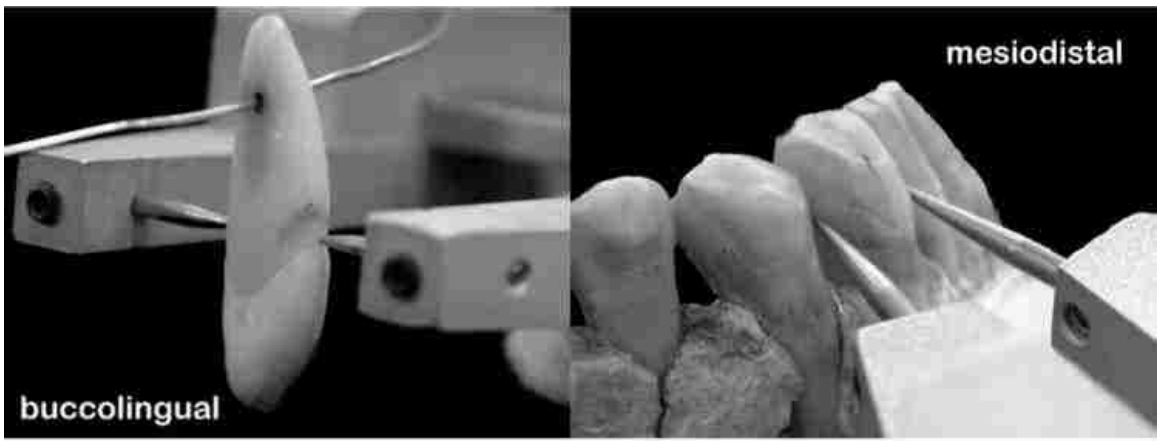

Fig. 5.5. Mesiodistal and buccolingual cervical canine measurements. Source: Hassett (2011)

Cervical buccolingual and mesiodistal measurements were taken on loose teeth as well as on teeth intact in the jaw. Measurements were taken for the entire dental arcade, both right and left sides. However, the right-side measurements were used for sex estimation due to their larger availability. In the case of a missing value from the right side, the left antimere was substituted. To avoid the possibility of incorrect measurements the samples with the most extensive tooth wear (grade 7 and 8) (Smith 1984), caries, heavy calculus deposits, and hypoplastic defects along the cemento-enamel junction were excluded. The Hillson-Fitzgerald calliper was used to take the dental measurements: a modified Mitutoyo digital calliper, calibrated to 0.01mm, fitted with needlepoints for CEJ measurements of in situ teeth (Fig. 5.6).

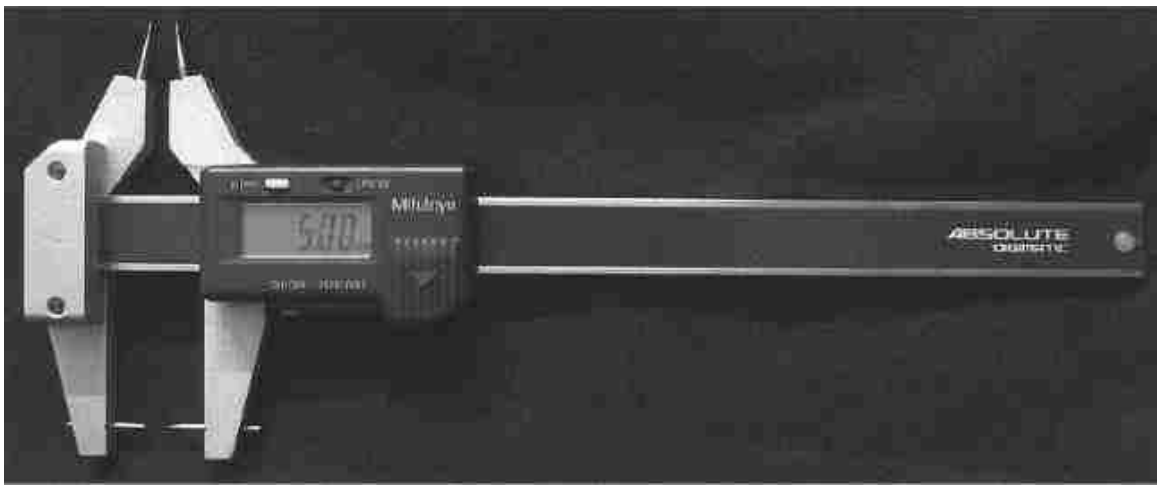

Fig. 5.6. The Hillson-Fitzgerald calliper for taking cervical dental measurements. Source: Hillson et al., (2005)

5.3.2.2.2. 3D Cervical Measurements

3D cervical measurements were also used for sex estimation. CT scans of maxillae and mandibles from the Hasanlu and Dinkha Tepe collections were used to create 3D teeth models. The skulls were scanned at the Hospital of the University of Pennsylvania using a Siemens Somatom sensation 64-slice Computed Tomography machine. Data were collected using a slice thickness of 0.5 mm and a matrix of 512 × 512 pixels. All data were saved in the Digital Imaging and Communications in Medicine (DICOM) format. The CT scans were obtained through the Open Research Scan Archive (ORSA). In this study a total of 457 teeth using 51 CT scans (30 males, 21 females) were used for 3D analysis. The number is considerably smaller than the original sample collection used for 2D analysis; this is due to ORSA's inability to provide CT scan images of more samples.

5.3.2.2.2.1. Data Acquisition

5.3.2.2.2.1.1. Segmentation

As mentioned in the previous chapter, computed tomography is a non-invasive technique that allows for an accurate and detailed visualization of morphological features without causing any tooth destruction. Using this technique, high resolution

3D radiographs are produced in the form of a stack of DICOM image slices. In this study, the transformation of stacked image data into 3D surface models was conducted using the software application AMIRA 6.0.1 for the process of manual image segmentation, a virtual platform used to process medical imaging data. This software allows for the visualization, manipulation, and analysis of biomedical data obtained from all types and sources.

The task of partitioning the image data into contiguous regions, representing individual anatomical structures according to a certain set of criteria, is referred to as the segmentation of medical images. Uploading a series of images into the AMIRA program is the first stage of manual segmentation. Each CT slice is then examined so that the regions of the slice that represent the anatomical structure required for analysis are selected. AMIRA software provides the user with various tools to select these regions; in the current study, the maximum and minimum threshold voxel grayscale values are used as criteria for the segmentation of the teeth. The selection of grayscale values enables the user to select any voxels that fall between the two threshold values. Different voxel grey values represent different densities of sensed data. In a CT scan, the high density of teeth appears as a high voxel value, which is represented as white. The alveolar bone, which has comparatively lower intensity, appears grey and therefore has a lesser voxel value (Fig. 5.7). Since the crown is covered with enamel and the root is covered with cementum, the density of teeth largely differs from crown to apex (Fig. 5.8). This requires the researcher to define more than one threshold level for tooth segmentation. In this study the threshold level was adjusted two times: first to segment the tooth from the jaw and second to segment the crown from the root. The latter segmentation helps the user to detect the CEJ line more accurately when placing the cervical measurement landmarks: this is due to the difficulty of identifying the CEJ line on 3D models, compared to identifying it using actual teeth.

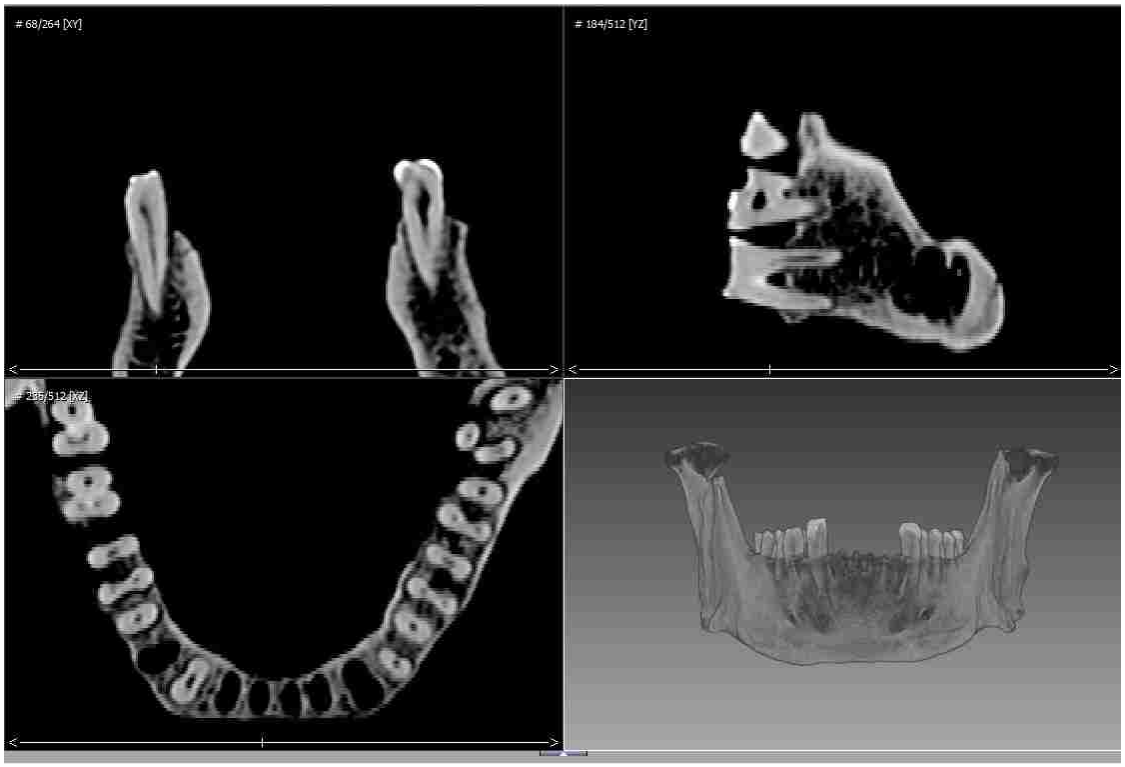

Fig. 5.7. The presentation of teeth and the alveolar bone in AMIRA from different views.

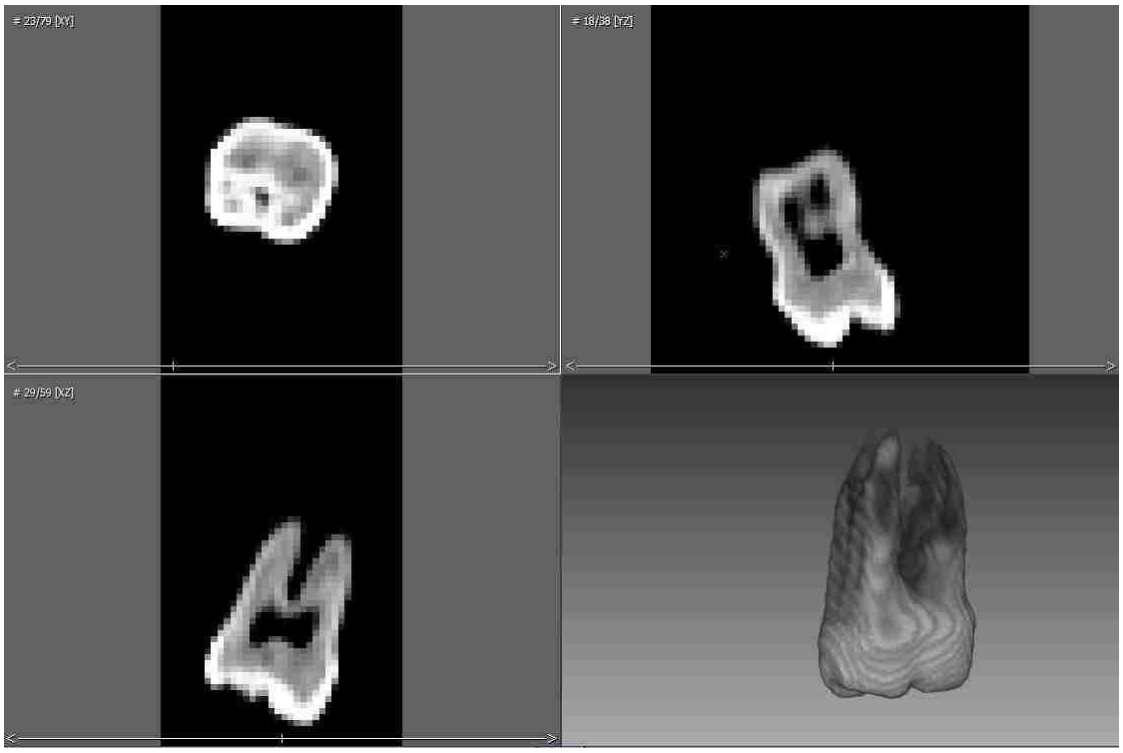

Fig. 5.8. The presentation of tooth crown and root with different densities in AMIRA from different views.

According to Spoor et al. (1993), since in CT images the information is represented as pixels – due to CT scanners being digital image capture methods – the perfect

representation of the smooth, curved lines of the objects is impossible, and they appear stepped instead. In addition, the density information in CT scanners is shown in the form of a range of grey values that are greater than the human eye can discriminate. Although the human eye sees the edge of the object as white, it is in fact several shades of grey (Spoor et al., 1993). The restricted resolution of digital images, therefore, makes the transition area between materials in CT scans a gradual one rather than a true distinctive line (Spoor et al., 1993). Nevertheless, according to Spoor et al. (1993), the true edge of an object in fact lays halfway between the CT number levels or grey values. This level, or grey value, is what is known as the Half Maximum Height Value (HMHV). In the current study, the thresholds used to segment the teeth from the jaws were calculated using the half maximum height protocol of Spoor et al. (1993) for each skull. The Image J program was used to calculate the HMHV, by calculating the average grey value of every third image of the CT scans. The calculation yielded a threshold level of 1,500. Using this threshold, the tooth anatomy was shown with minimal interference from the bone surrounding it and the neighbouring structures (Fig. 5.9). To segment the crown from the root, on the other hand, for each tooth a specific optimal threshold value was visually set to the level at which the crown was clearly seen with minimal interference from the root structure (Fig. 5.9). As a result of visually adjusting the threshold parameters, different threshold levels were obtained for different teeth in the same DICOM data sets and between different data sets. The segmentation was also performed in the axial view from crown to apex. Crown and root of the same tooth were colour coded to facilitate differentiation (Figs 5.10, 5.11).

Using the threshold values mentioned above, the ‘magic wand’ tool in AMIRA was used to go through cross-sectional slices of each tooth and to select the appropriate tooth portion. The magic wand selects contiguous pixels of the grey value range as specified by the user. The same process was applied to all the slices with dental structure, until all the slices were selected. The next stage was to use ‘surface gen’ to merge the selected parts together so that a 3D surface model could be created.

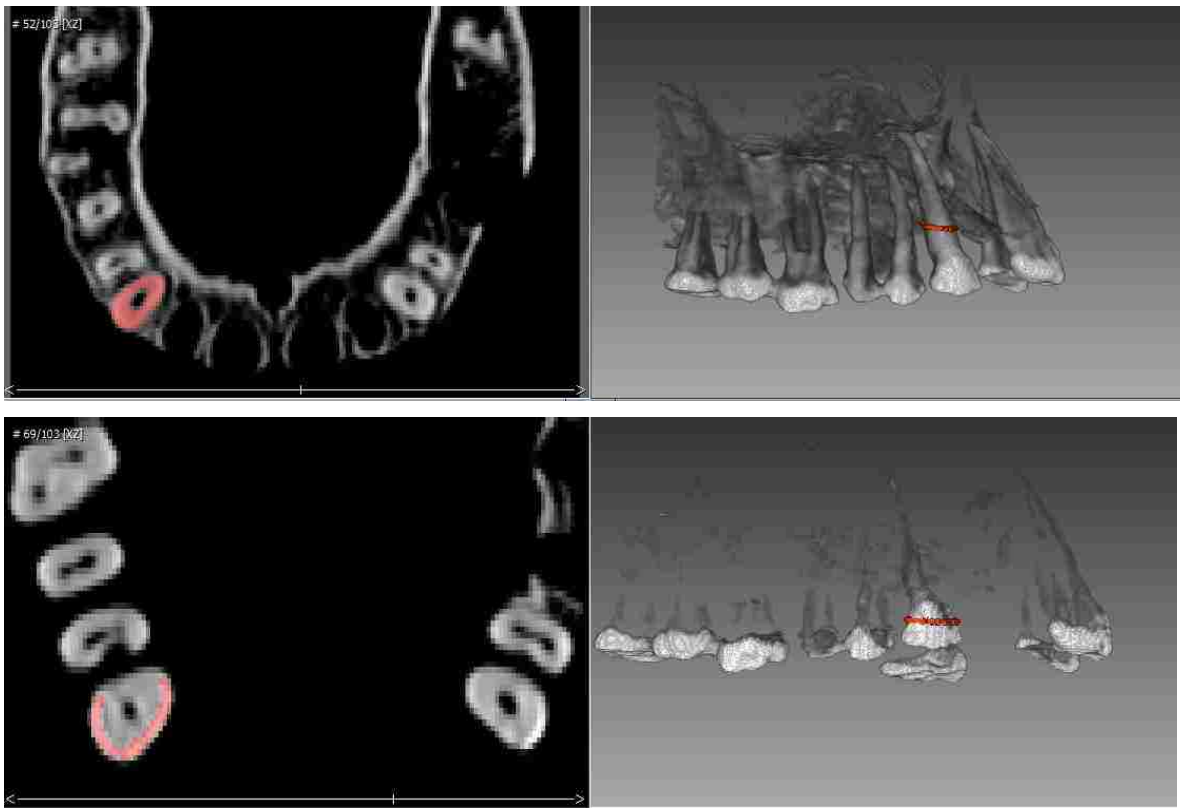

Fig. 5.9. A threshold of 1,500 was used to segment the tooth from the jaw (top image). The threshold was visually set to segment the crown from the root (bottom image). Segmentation was mainly processed in the axial view, from crown to apex.

5.3.2.2.2.1.2. Measurements

Cervical mesiodistal and buccolingual measurements, following Hillson et al.'s (2005) method, were taken of each 3-D model. These measurements were taken from the in situ and right maxillary and mandibular teeth, because the number of CT scans of the right teeth was considerably larger than those of the left teeth. Similar to the 2D measurements, the samples with caries, heavy calculus deposits, and hypoplastic defects along the cemento-enamel junction were excluded, in order to avoid the possibility of incorrect measurements.

3D measurement tools in AMIRA were used to take dental measurements. These tools are calibrated in such a way that they express length measurements as millimetres, with an accuracy of 0.01mm. This study used the 3D measurement tool instead of the 2D measurement tool because in the former the measurement is taken from points directly on the surface of the 3D models, ensuring that all of the measurements

precisely fit the surface of the tooth. The 3D teeth models were used to measure both the cervical measurements and the tooth root volumes (Fig. 5.10).

5.3.2.2.3. 2D/3D MD Cervical Measurements

As mentioned in chapter 3, using Hillson et al.'s (2005) method, the cervical MD measurement could differ when taken from the buccal side or lingual side. To work out the degree of difference, the cervical MD measurements for maxillary and mandibular teeth were collected once from the buccal side and once from the lingual side, and the results were compared. The teeth used for this comparison were either loose teeth or the in situ teeth in fragmented jaws that could be rotated and therefore measured from the two positions (see chapter 8).

5.3.2.2.4. 3D Volume Measurements

In addition to 2D and 3D cervical measurements, a new metric parameter was used for sex estimation. A total of 480 teeth using 51 CT scans from Hasanlu and Dinkha Tepe skeletons (31 males, 20 females) were used to measure the volume of the tooth root for sex estimation. Similar to the 3D cervical measurements, the HMHV protocol of Spoor et al. (1993) was used to segment the teeth from the jaws. A threshold was then visually set to segment the crown from the root. Finally, the crown and the root were given different colours to facilitate their differentiation (Fig. 5.11). No smoothing functions were applied to the 3D tooth structure. Liu et al. (2010) report that use of the smoothing function caused a reduction of the tooth root volume measurement by about 3-12%. Once segmentation was complete, the software automatically computed the volume of the root.

In order to calculate the tooth root volume a measurement was taken from the cemento-enamel junction (CEJ) to the apex of the tooth, including the pulp chamber and canals. Root volume measurements were taken from the in situ and right maxillary and mandibular teeth due to their availability. To avoid the possibility of incorrect

measurements, the samples with root resorption, incomplete root formation, a broken root, root caries, or caries along the CEJ, were excluded.

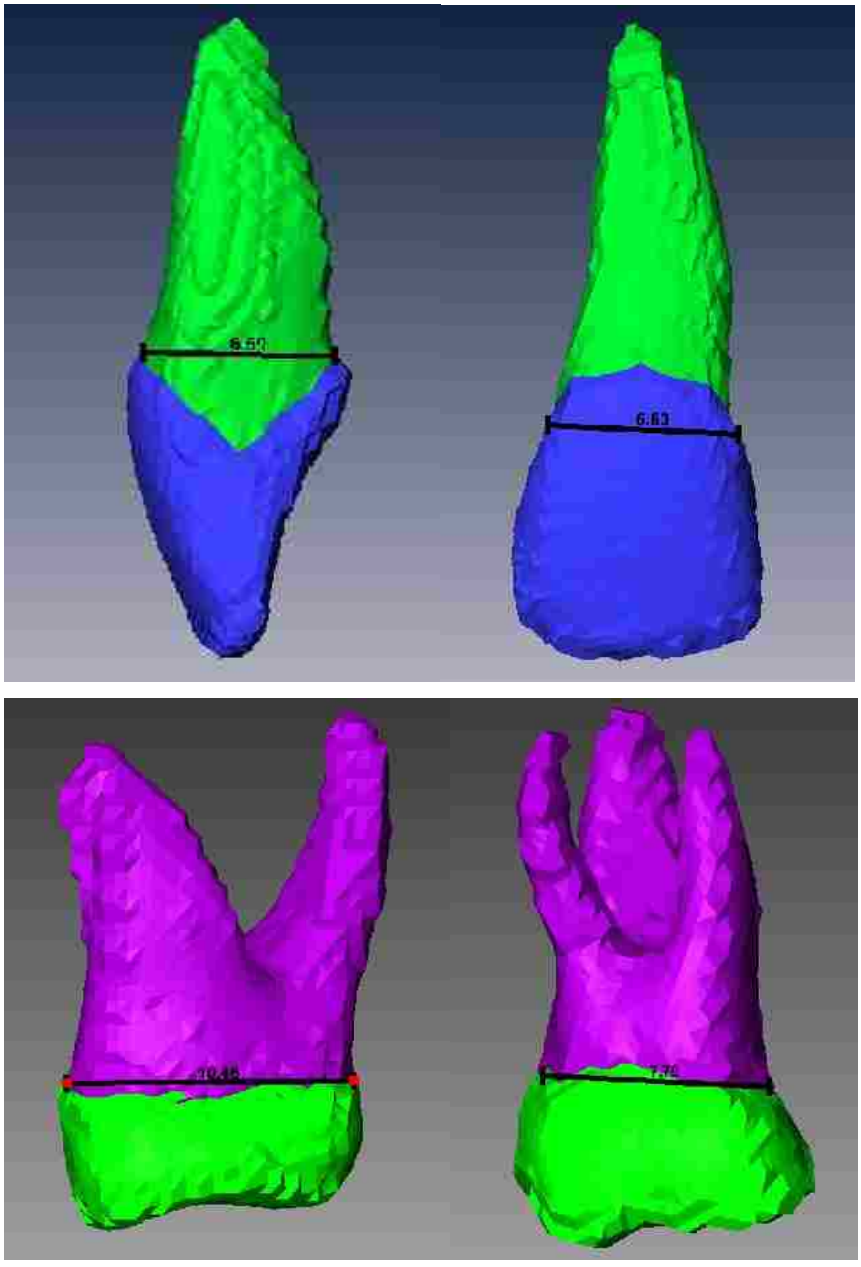

Fig. 5.10. Cervical BL (left) and MD (right) measurements on UI1 and UM1. Crowns and roots were colour-coded to facilitate differentiation.

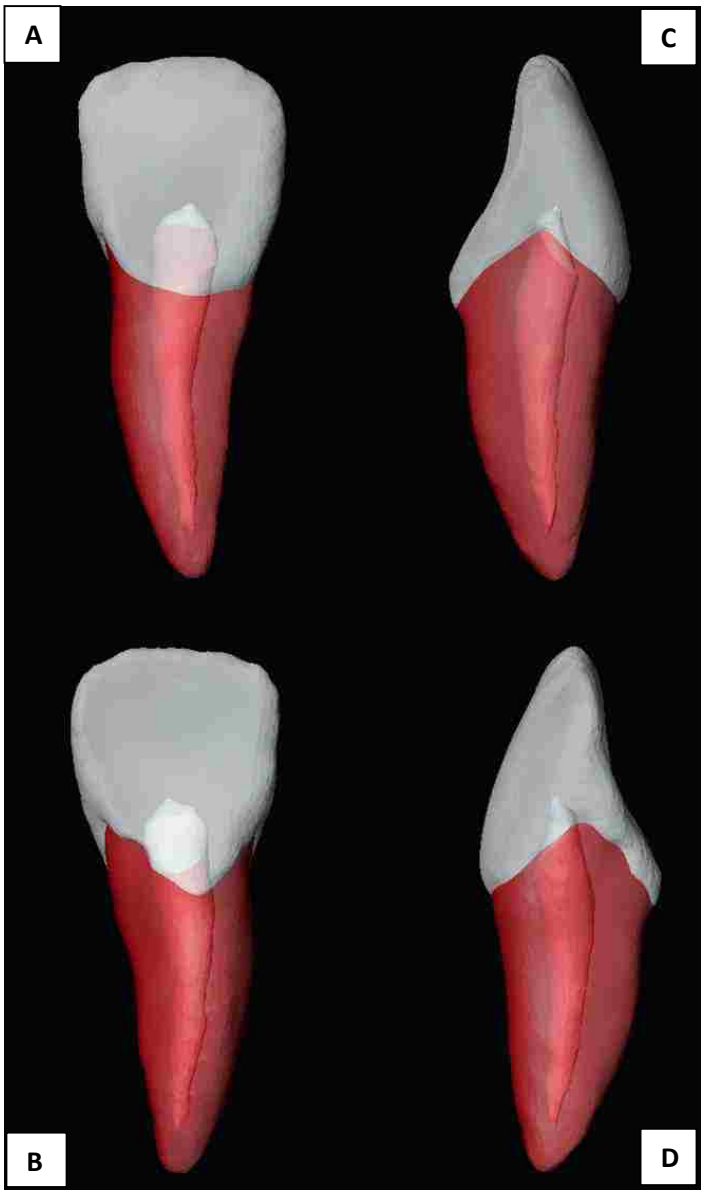

Fig. 5.11. 3D tooth volume of UI1. A, buccal, B, lingual, C, distal, D, mesial. The crown was segmented from the root and the volume was taken from the CEJ to the apex. Crown and root were colour coded to facilitate differentiation.

5.3.3. Statistical Analysis

All the results for each set of measurements were analysed using the SPSS 21 software package for complex statistical analysis. Discriminant function analysis was used to evaluate the measurements and determine the most effective discriminators. The level of sexual dimorphism was also calculated, and the results were compared between the three groups of data. Intra- and inter-observer error was also calculated in order to

assess the reliability of the measurements. The statistical methods used in this study were separately applied to each group of measurements.

5.3.3.1. Intra- and Inter-Observer Error

To check the reliability of the methods used for each set of data, it was important to determine the intra- and inter-observer error associated with the measurements. To assess the intra-observer error of measurements, data were collected twice on a random subset of 50 individuals for 2D cervical measurements, and 35 individuals for both 3D cervical and root volume measurements. All measurements were collected by the author with an accuracy of two decimal places on two separate occasions at least one week apart. A second trained observer with a PhD in osteoarchaeology repeated the same 2D cervical, 3D cervical, and RV measurements on a random subset of 30 individuals to enable determination of inter-observer reliability. Technical error of measurements (TEM), relative technical error of measurements (rTEM), and the coefficient of reliability R (Ulijaszek and Kerr, 1999) were used to determine the differences between measurements.

By using the three error estimation methods, most of the information necessary for the determination of whether a series of anthropometric measurements can be considered accurate can be obtained (Ulijaszek and Kerr, 1999; Harris and Smith, 2009).

One of the most frequently used estimates of precision is the TEM (Ulijaszek and Kerr, 1999; Ward and Jamison, 1991). Ward and Jamison (1991, p.157) state that TEM "provides a standard deviation-like measure of the magnitude of error and it is in the original units of measurement." The estimation of both intra- and inter-observer precision can also be carried out using TEM. When there are two measurements involved, the formula for TEM is:

$$\mathrm{TEM} = \sqrt{(\Sigma D^2)/2N},$$

Equation 1

In this equation, D shows the difference between the first and second measurement, N shows the number of teeth measured. The smaller the TEM values, the more accurate the measurements are. TEM keeps the same unit of measurement and has a direct relation to measurement size. The TEM of a large mean value, for example, is also large, which makes assessment of the comparison of measurements of different sizes impossible (Ulijaszek and Kerr, 1999). In order to surmount this problem, the TEM is converted to relative TEM (%TEM), which is the error presented in the form of a percentage, which corresponds to the total average of the analysed variable (see Equation 2). The authors argue that this equation is simple to calculate and has no units, as well as allowing for direct comparisons of all types of anthropometric measure.

$$rTEM = (TEM / VAV) \times 100$$

Equation 2

Using the coefficient of reliability (R) is another way to obtain the comparability of anthropometric measurement error. The range in this method is from 0, representing 'not reliable', to 1, expressing complete reliability, and can be calculated using the equation:

$$R = 1 - \left(\frac{TEM^2}{SD^2}\right)$$

Equation 3

This coefficient "reveals the proportion of between-subject variance in a measured population which is free from measurement error" (Ulijaszek and Kerr, 1999, p.168). While no values have been recommended for R, Ulijaszek and Kerr (1999) suggest using a cut of the value of 0.95 (i.e. a human measurement error of up to 5%).

5.3.3.2. Normality and Homogeneity of Variances Tests

In statistical analysis, all parametric tests (e.g. t-test, one-way ANOVA) require the normality and homogeneity of variances of the data to be carried out. Checking the assumption before doing any relevant statistical procedures was therefore necessary.

In this study, two methods were used for the test of normality for all three sets of data: the Kolmogorov-Smirnov and Shapiro-Wilk tests. In these tests, the scores in the sample are compared to a normally distributed set of scores that have the same mean and standard deviation; the null hypothesis assumes that the sampling distribution is normal. If the p-value is less than or equal to 0.05, the hypothesis of normality is rejected by the tests. P-value "is the probability, given that the null hypothesis is true, of obtaining data as extreme or more extreme than that observed" (Peacock and Peacock, 2011. P.248). 0.05 (or 5%) is usually used as a cut-off value. Succeeding the normality test allows the user to conclude with 95% confidence that the data fits the normal distribution.

Sample size is one of the factors influencing normality tests (Ahad et al., 2011; Razali and Wah, 2011; Ghasemi and Zahediasl 2012). Ahad et al. (2011) performed a study aimed at identifying the sensitivity of rejecting the normality tests on non-normal data with a small sample size. Their study showed that the Shapiro-Wilk was the most powerful normality test, rejecting the null hypothesis of normality at the smallest sample size ($n > 39$). A similar study by Razali and Wah (2011) on a very small sample size ($n \leq 10$) yielded the same result. Since the sample size for 3D measurements in this study is relatively small ($n < 50$), in order to increase the accuracy of the normality test, the Shapiro-Wilk test was added to the study.

Levene's test was used to assess variance homogeneity in all sets of data. The null hypothesis is that population variances are equal. Similar to normality tests, if the value of Levene's test is less than the 0.05, the null hypothesis is rejected.

5.3.3.3. Student t-test

The student t-test is used to determine whether the means of two groups are statistically different from each other. There are two types of t-test: paired t-test and independent t-test. The paired t-test compares the means between two groups which are related in some way, while the independent t-test compares the means between two groups which are not related in any way. A p-value of less than 0.05 shows that the difference

between two groups is statistically significant. A t-test works in essentially the same way as the one-way ANOVA (which will be explained shortly) and is considered one of its especial cases.

In this study, the bilateral asymmetry of right- and left-side teeth in all sets of data was tested using a paired t-test. An independent sample t-test was also carried out to determine if there were any statistically significant differences between the Hasanlu and Dinkha Tepe collections, and also to compare 2D and 3D cervical measurements.

5.3.3.4. Outlier Detection

Data analyses such as ANOVA and discriminant function analysis might be negatively affected by outliers. An outlier may be caused either by variability in the measurement or might be an indication of experimental error. In a data set, an observation that 'appears' to be inconsistent with other observations is referred to as an outlier. The probability rate of an outlier is very low, and is derived from the same statistical distribution as the other observations in the data set. The presence of outliers can be a problem as it can significantly distort classical analysis of data and the inferences drawn from that analysis. To obtain a coherent analysis, therefore, outlier detection was performed separately for both the Hasanlu and Dinkha Tepe collections and for each set of measurements.

In addition, since Hasanlu is a case of violent conflict, there is the possibility that the bodies of the invaders are mixed with those of the locals; outlier detection was therefore used to see if there were any individuals with tooth diameters that fell outside the overall pattern of the rest of the data. The importance of this lies in the fact that the odontometric standards for sex estimation are population specific and therefore cannot be used for diverse populations (Vodanovic´ et al., 2007).

The present study used two different methods to detect outliers, both using the median as the indicator instead of the mean. The reason for this is that three problems can occur when using the mean as the central tendency indicator: 1) it supposes that the

distribution of the data, including the outliers, is normal; 2) the mean and standard deviation are highly affected by outliers (Miller, 1991); 3) Cousineau and Chartier (2010) argue that it is very unlikely that this method detects outliers in the case of small samples. Similar to the mean, on the other hand, the median is a measure of central tendency but has an advantage over the mean as it is very insensitive to the presence of outliers (Leys et al., 2013).

The 'breakdown point' is one of the indicators of this insensitivity (see for example Donoho and Huber, 1983). "The estimator's breakdown point is the maximum proportion of observations that can be contaminated (i.e., set to infinity) without forcing the estimator to result in a false value (infinite or null in the case of an estimator of scale)" (Leys et al. 2013, p.765). A single observation with an infinite value, for example, causes the mean of all other observations to be infinite as well, and consequently makes the mean's breakdown point 0. The median value, by contrast, remains unaffected. Only when more than 50% of observations are infinite does the median become absurd. A breakdown point of 0.5 makes the median the location estimator with the highest breakdown point. The exact same thing applies to the Median Absolute Deviation (MAD), an estimator of scale. In addition, the sample size does not in any way affect the MAD (Leys et al., 2013). Based on these two properties, Huber (1981, p. 107) describes the MAD as the "single most useful ancillary estimate of scale". For example, compared to the classical interquartile range – which was also used in the current study (to be explained shortly) – it is more robust, having a breakdown point of only 25% (Leys et al., 2013).

The present study uses Tukey's interquartile range (IQR) (1977) and Median Absolute Deviation (MAD) (Leys et al., 2013) to detect outliers. IQR is a measure of statistical dispersion which uses the median and lower and upper quartiles (25^{th} and 75^{th} percentiles). The interquartile range, or IQ, is the difference between the lower quartile (Q1) and the upper quartile (Q3), namely (Q3 – Q1). In Tukey's (1977) method, potential outliers are identified as those data beyond the upper quartile + 1.5 – IQR and lower quartile -1.5 – IQR. Leys et al. (2013) described a robust and easy to conduct method of detecting outliers using the Median Absolute Deviation. The procedure for

calculating the MAD is 1) computing the median, 2) subtracting the obtained value from all observations in the statistical series, 3) computing the median of the resulting new variables, and 4) multiplying the obtained value by 1.4826. The authors strongly recommended the median plus or minus 2.5 times the MAD method for outlier detection. Both methods were used separately for each tooth and each set of measurements to detect outlaying values in the data sets.

5.3.3.5. One-way ANOVA

When determining whether any statistically important differences exist between the means of two or more independent groups, the one-way analysis of variance (ANOVA) is used. Comparing only two groups, a one-way ANOVA provides the same results as an independent t-test. The null hypothesis in this technique is that all population means are equal. In this study, a one-way ANOVA was used to compare the mean differences between males and females.

5.3.3.6. Discriminant Function Analysis

Discriminant function classification was carried out to determine the relationship between osteologically estimated sex and dental measurements. One of the most frequently used techniques to develop sex assessment formulae is the *discriminant* function analysis, which is based on using one or more measurements from the skeleton. Discriminant function analysis is a statistical technique that researchers use in order to be able to investigate the relations among two or more groups by using any number of variables simultaneously. An analysis in which a single measurement is independently used for sex assessment is termed a univariate discriminant function analysis. When the researcher uses a combination of measurements, however, the method is referred to as multivariate discriminant function analysis. This method can either be direct or stepwise. In direct analysis, all variables are entered into the analysis simultaneously, while in stepwise analysis the variables that are not statistically significant are removed from the analysis. Stepwise discriminant function analysis is used to determine which variables best discriminate between males and females. In

this study, separate discriminant analysis was conducted for the 2D and 3D cervical measurements as well as the tooth root volume measurements, separately by tooth class (incisor, canine, premolar, and molar) and position (maxillary and mandibular). Many studies have shown that canines are the most sexually dimorphic teeth, therefore canines were added to each function to indicate whether classification success would increase. In addition, in order to increase the applicability of the technique where dentition is not well preserved, the analysis was also conducted for each tooth and measurement separately. 2D cervical measurements were also combined with 3D root volume measurements to see whether classification accuracy was improved. In the present study, the discriminant function analysis was carried out for samples > 20 individuals that had relatively equal male/female size groups.

A leave-one-out classification procedure was also used to demonstrate the accuracy rate of the original sample and the sample created by cross-validation, a technique that is used to assess the performance of a predictive model. One of the most common forms of cross-validation, leave-one-out is a method in which "the model is repeatedly refit leaving out a single observation and then used to derive a prediction for the left-out observation" (Lopez-Yanez et al. 2013, p.22). The results of cross-validation are usually lower than the results obtained in the original classification, but are more reliable.

5.3.3.7. Posterior Probabilities

In this study, the posterior probabilities of each individual for 2D cervical, 3D cervical, and root volume measurements were calculated, "since they reflect the affinity of each case to be reassigned to the original group according to the values of the discriminant score" (Kranioti and Apostol, 2014, p. 358). The posterior probability refers to the likelihood that an unknown case belongs to a particular group. This probability is calculated from the Mahalanobis' distances, measuring the distance to the centre or centroid of each group. The evaluation of how likely it is that the unknown case belongs to a group based on the average variability within all groups is referred to as the typicality probability (Mardia et al., 2000). For example, those discriminant scores

that are approximately zero fall in the zone that indicates overlap between the two groups, which makes sex estimation uncertain. Using posterior probabilities, the researchers are able to calculate how probable it is for a case to belong to the male or the female group. In the current study, a discriminant subprogram of SPSS was used to produce the posterior probability values for each function, and the data was plotted using the Excel programme for Windows.

5.3.3.8. The Pearson Correlation Coefficient

In multivariate analysis, when two predictor variables correlate or associate with one another, some common underlying factors or traits are shared among them that lead to some equality in the way that they vary on the scores in the data set. As a result of that underlying trait, the two variables co-vary with each other. This, in other words, causes similar variations in scores measured as variance. As mentioned earlier, the present study used the combination of 2D cervical measurements and tooth root volumes for sex estimation. However, according to some researchers there is a positive and systematic correlation between root length and crown size for both mesiodistal and buccolingual crown diameters (Garn et al., 1978; Harris and Couch, 2008). They have also determined that the correlations of mesiodistal crown size with root length are higher than its correlations with buccolingual crown size (Garn et al., 1978). Harris and Couch (2008) also reported a strong positive correlation between different crown measurements (length, width, and height) and root length. Therefore, Pearson's correlation was performed separately for each tooth measurement, in order to determine whether there was a statistically significant relationship between 2D cervical measurements and root volume measurements. When measuring the statistical relationship or association that exists between two continuous variables, Pearson's correlation coefficient is used. It is a test statistics that is considered to be the best method for the measurement of the association between variables, due to it being based on the method of covariance (Hunter and Schmidt, 2004). The range of values in the Pearson correlation coefficient (r) is from +1 to -1. When there is no correlation between the two variables, the value is indicated as 0. When there is a positive correlation, the value is greater than 0; that is, an increase in the value of one variable

results in an increase in the other variable. Where there is a negative correlation, the value is less than 0; that is, a decrease in the value of one variable results in a decrease in the value of the other variable. Pearson correlation method was also used to provide an indication of the degree of association of 2D and 3D cervical measurements and whether the values were significantly different from zero at the $p < 0.05$ level.

The relationship between 2D cervical and RV measurements, and between 2D and 3D cervical measurements, was also examined using least squares linear regression: y = ax + b, where y = dependent variable, x = independent variable, a = a constant which defines the intercept on the Y axis, and b = a constant which defines the slope of the line. Regression analysis is frequently "used to predict the value of one variable from the value of another variable" (Reckase, 2009, p.43). The key output of a regression analysis is R squared (R^2), which determines how well a regression line fits the actual data. R^2 values between 0% and 100% show the extent to which the dependent variable can be predicted from the independent variable (Albright and Winston, 2014), with 0% showing that the dependent variables cannot be predicted from the independent variables (no linear relationship), and 100% showing that the dependent variables can be predicted with no error from the independent variables (perfect linear relationship). R^2 values between 0% and 100% show the extent to which the dependent variable can be predicted from the independent variable (Albright and Winston, 2014). For example, an R^2 value of 0.84 shows that 84% of the variation in the y variable can be explained by the x variable.

5.3.3.9. Bootstrapping

The present study uses bootstrapping to account for possible biases due to small sample size, particularly in the 3D measurements. Bootstrapping is a statistical "technique for estimating the variance and the bias of an estimator by repeatedly drawing random samples with replacement from the observations at hand. One applies the estimator to each sample drawn, thus obtaining a set of estimates" (Last, 1995, p. 18). The main assumption on which bootstrapping is based is that sample distribution is a good estimate of population distribution. In other words, the sample accurately

reflects the entire population. Bootstrap computes a confidence interval which provides an estimate for the population mean. A confidence interval is a range of values computed from the sample observations that are considered, with a particular confidence level, to include the true parameter value. For example, when there is a 95% confidence interval, it means that when the estimate process is repeated over and over again, it is expected that 95% of the computed intervals will include the true parameter value. In the biological sciences bootstrapping is regularly used to estimate classification error rates and is comparable to cross-validation, because they both decrease classification bias and error classification variability (Fox et al., 1996; McBride et al., 2001; Ponsting et al., 2001; Plochocki, 2011). In the present study, the bootstrapping was used in cases with sample size < 60.

5.3.3.10. Percentage of Sexual Dimorphism

The present study uses the percentage of sexual dimorphism as an indicator to describe the differences between males and females. To calculate this index, Garn et al.'s formula (1967) [(male mean _ female mean)/female mean] _ 100) was used. The percentage of sexual dimorphism shows the difference between male and female mean values. When there is a positive value, it means larger male tooth dimension, and when there is a negative value, it means larger female tooth dimension. When the value is approximately zero, it indicates that the degree of sexual dimorphism will be lower. The statistical results, together with age and morphological sex estimation results, will be discussed in detail in the next chapter.

CHAPTER 6 RESULTS

6.1. Introduction

The present study aims to determine the reliability of dental measurements in sex estimation in Hasanlu and Dinkha Tepe archaeological samples. To achieve this goal the sex of the skeletons was first estimated using morphological features of the skull and pelvis, and then these data were compared with the results obtained from 2D and 3D cervical and RV measurements. This chapter presents the results produced from different sexing and ageing methods used on the Hasanlu and Dinkha Tepe collections, and also the results of the statistical analysis which was used for sex estimation using dental measurements.

6.2. Age Estimation

In total 263 skeletons from the Hasanlu Iron Age levels (n = 212) and Dinkha Tepe (n = 51) collections were studied. Of these, 26 individuals did not have any teeth preserved and were thus excluded from the analysis, therefore age estimation was conducted on 237 individuals from the Hasanlu and Dinkha Tepe collections. In total, 64 individuals from Hasanlu and 5 individuals from Dinkha Tepe were classified as subadults using tooth formation and eruption (Buikstra and Ubelaker, 1994; Scheuer and Black, 2004) and epiphyseal formation and union (Scheuer and Black, 2004). Since sex estimation was conducted only on adult individuals, the subadults were excluded from the analysis. Table 6.1 shows the distribution of subadults by age category developed by Buikstra and Ubelaker (1994).

Table 6.1. Age distribution of subadult skeletons

Age	N	
	Hasanlu	**Dinkha Tepe**
Fetus (before birth)	1	0
Infant (0-3 years)	16	2
Child (3-12 years)	24	1
Adolescent (12-20 years)	23	2
Total	**64**	**5**

Using multiple methods based on dental wear (Buikstra and Ubelaker, 1994; Miles, 2001) and morphological changes in the skull (Meindl and Lovejoy, 1985) and pelvis (Brooks and Suchey, 1990; Buckberry and Chamberlain, 2002) the age of the adult individuals was estimated. The age distribution of the 168 remaining individuals from the Hasanlu (n = 128) and Dinkha Tepe (n = 40) collections is presented in Table 6.2. The most frequently used method was dental wear (n = 149), as well as cranial sutures (n = 84), and pelvic features (n = 78). The majority of the individuals were grouped into the middle age category (35-50 years), making up 46% of the sample, followed by young adults and old adults, 32% and 19% respectively. Five individuals were also added to the category of general adult, due to them being clearly adult despite the inability to be reliably recognized as young, middle or old adult (Table 6.2).

Table 6.2. Age distribution of adult skeletons

Age	**N**	
	Hasanlu	**Dinkha Tepe**
Young adult (20-35 years)	45	10
Middle adults (35-50 years)	57	21
Old adults (50+ years)	23	7
General adult	3	2
Total	**128**	**40**

6.3. Morphological Sex Estimation

In total, 168 adult individuals from the Hasanlu (n = 128) and Dinkha Tepe (n = 40) collections were used for sex estimation. A number of images showing the level of tooth preservation are presented in Appendix B.

Multiple methods were employed for estimating sex of Hasanlu and Dinkhah Tepe specimens. The most reliable indicators were pelvic (Phenice, 1969; Presorius et al., 2006) followed by cranial (Walker, 2005, 2008) arid then metric traits of long bones which has been conducted by Selinsky (2009).

Sexing in the Hasanlu and Dinkha Tepe samples was relatively successful. Individuals were classified as male, probable male, female, probable female, indeterminate and unobservable. Crania and mandibles were present nearly twice as often as pelves. Pelvic morphological features were used in the sexing of 76 individuals, cranial features in 117 individuals and mandibular features in 104 individuals.

In general, there was an excellent agreement between methods. If there were differences in sexing, it was a one-step change (e.g. from female to indeterminate). In total, sex was estimated for 143 individuals in the Hasanlu (n=105) and Dinkha Tepe (n=38) samples. To increase the sample size, the two categories within each sex were combined. In addition, those individuals which were grouped as unobservable were also combined with indeterminate individuals (Table 6.3). Table 6.3 presents the distribution of final sex estimates for each collection.

As mentioned in the previous chapter, the sex estimation results of this study were compared with Selinsky's (2009) results for each individual separately. In general, there was great agreement between the two studies. There were differences in sexing in only five individuals, which the present study determined as indeterminate, while Selinsky classified them as males or females. However, to avoid bias in the analysis these individuals were excluded from the data.

As shown in Tables 6.3, and 6.2, the greatest number of individuals in both the Hasanlu and Dinkha Tepe collections are males aged between 35-50 years old. Most of the females were also grouped in the middle adult age category. The distribution of adult individuals by sex and age is shown in Figure 6.1.

Table 6.3. Sex distribution of adult skeletons

Sex	**N**	
	Hasanlu	**Dinkha Tepe**
Male	67	23
Female	38	15
Indeterminate	18	5
Total	**123**	**43**

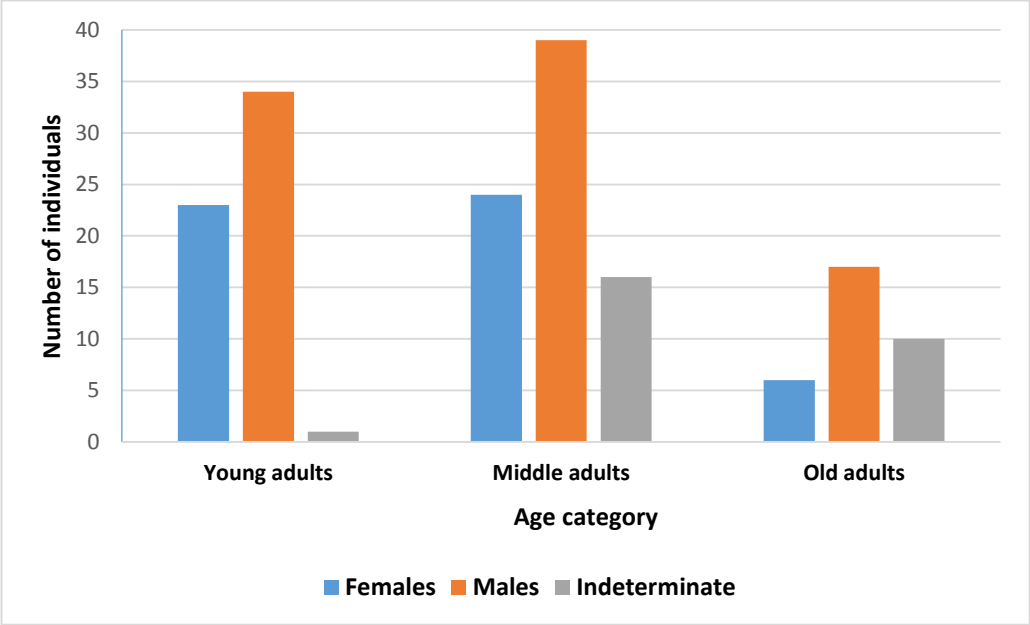

Fig. 6.1. The distribution of adult individuals by sex and age.

2D cervical measurements were collected from all 143 adults from the Hasanlu and Dinkha Tepe collections. However, due to ORSA's inability to provide CT scan images, the 3D analysis was performed on less than half of the individuals. A total number of 51 adults of the main data sample (n = 143) were used for 3D cervical and RV analysis. Similar to the main data, the greatest number of the individuals in these two subsamples are males (Table 6.4) aged between 35-50 years old (Table 6.2). The distribution of adult individuals by sex and age for 3D data is shown in Figure 6.2. Detailed information about the age and sex of each skeleton can be found in Appendix C-A. The sex of the skeletons was estimated based on conventional morphological analysis.

Table 6.4. Sex distribution of adult skeletons for 3D data

Sex	**N**			
	Hasanlu		**Dinkha Tepe**	
	3D cervical	RV	3D cervical	RV
Male	18	18	12	13
Female	11	10	10	10
Total	**29**	**28**	**22**	**23**

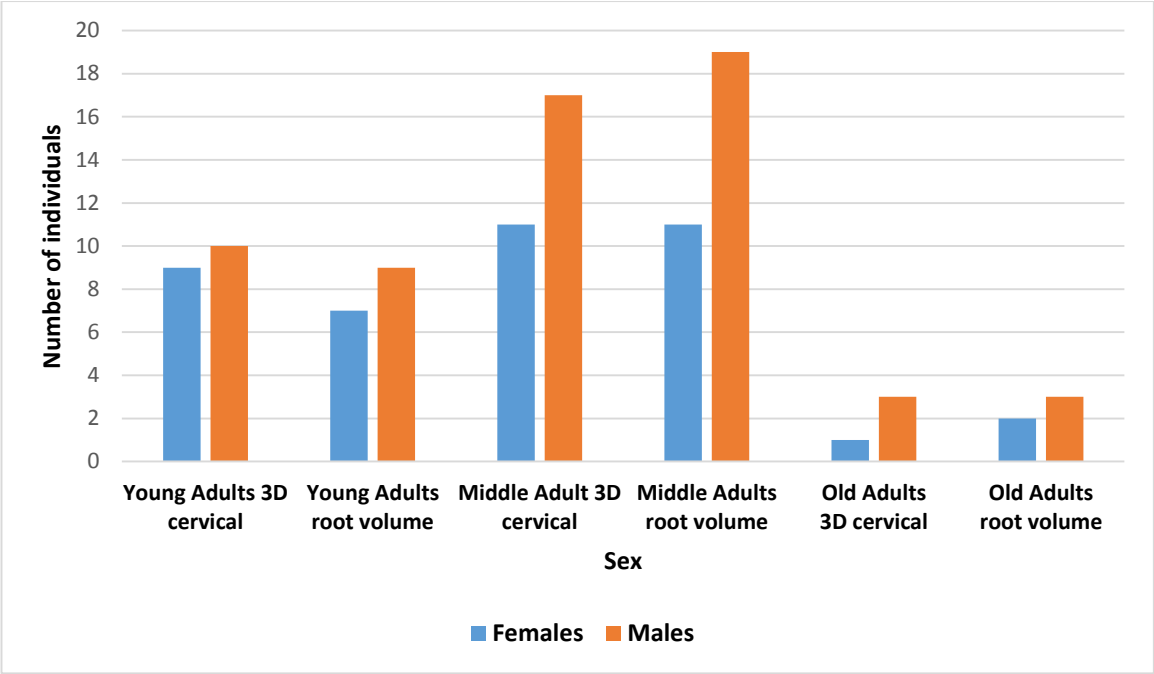

Fig. 6.2. The distribution of adult individuals by sex and age for 3D data.

6.4. Odontometric Sex Estimation

6.4.1. Dental Collection

The preservation of dental remains was much better than skeletal elements, and dental measurements were collected from all adults whose sex was osteologically estimated.

Of the 143 individuals analysed for dental completeness, 2,143 (46.8%) (Hasanlu= 1,608, Dinkha Tepe= 535) teeth were present out of a possible 4576. Among the teeth analysed, the number of mandibular teeth (58%) was more than maxillary (42%) ones. In comparison with anterior teeth (incisors and canines, 36%), posterior teeth (molars and premolars) were much better (64%) represented (Table 6.5). The same pattern might also be attributed to numbers, because in a single dental arcade there is a total of 20 posterior teeth, in comparison with 12 anterior teeth. Nevertheless, the survival and recovery of premolars and molars with larger and more complex root systems are also influential. Dental measurements were taken for the entire arcade, right and left side. However, the majority of the teeth belonged to the right side (1,241 > 902), therefore the right-side measurements were used for sex estimation. In the case of a

missing value from the right side, the left antimere was substituted. A total number of 65 teeth were also excluded from the analysis due to pathology and glue preventing the collection of accurate measurements. In total 1,327 maxillary and mandibular teeth from the Hasanlu (n = 1,010) and Dinkha Tepe (n = 317) collections were used for statistical analysis (Table 6.6). The 2D cervical measurements were taken from all 1,327 teeth. Similar to the main tooth data, there were slightly more mandibular teeth (57%) than maxillary teeth (43%), and many more posterior teeth (65%) than anterior teeth (35%) (Table 6.6, Fig. 6.3).

Table 6.5. Total number of teeth in the Hasanlu and Dinkha Tepe collections

Collections	**Maxillary**	**Mandibular**	**Anterior**	**Posterior**
Hasanlu	688 (32%)	920 (43%)	589 (27%)	1,019 (48%)
Dinkha Tepe	208 (10%)	327 (15%)	193 (9%)	342 (16%)
Total	896 (42%)	1,247 (58%)	782 (36%)	1,361 (64%)

In the 3D cervical and RV measurements, a very small number of left-side teeth were available, which did not allow the author to test the statistical differences between left- and right-side teeth. Therefore, dental measurements were taken only from right-side teeth. In total, 457 and 480 3D tooth models were used for 3D cervical and RV analysis respectively. In these two subsamples, there were also more mandibular and posterior teeth than maxillary and anterior teeth (Table 6.6, Fig. 6.3).

Table 6.6. Number of teeth used for statistical analysis

Diameter	**Maxillary**		**Mandibular**		**Anterior**		**Posterior**	
	HAS	DIN	HAS	DIN	HAS	DIN	HAS	DIN
2D cervical	448 (34%)	125 (9%)	562 (42%)	192 (14%)	349 (26%)	110 (8%)	661 (50%)	207 (16%)
3D cervical	138 (30%)	82 (18%)	112 (25%)	125 (27%)	87 (19%)	75 (16%)	163 (36%)	132 (29%)
RV	139 (29%)	93 (19%)	123 (26%)	125 (26%)	94 (20%)	77 (16%)	168 (35%)	141 (29%)

HAS = Hasanlu, DIN = Dinkha Tepe

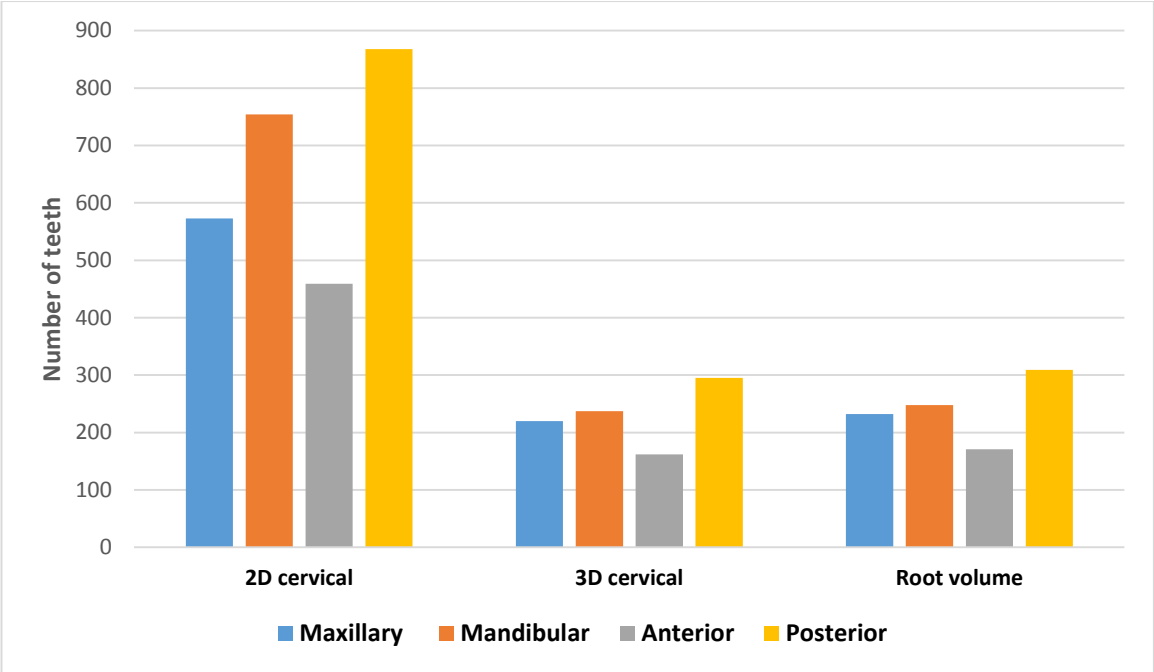

Fig. 6.3. The distribution of the maxillary, mandibular, anterior and posterior teeth for 2D and 3D data.

6.4.2. 2D/3D MD Cervical Measurements

As Table 6.7 shows taking the 2D MD cervical measurements from the buccal or lingual side greatly affected the resultant measurements. The differences in average measurements varying from 0.08mm to 0.24mm. The lowest and highest degree of difference was observed in LM2 (0.08mm) and LP4 (0.24mm) respectively. The degree of differences between labial and lingual sides was significantly lower for 3D cervical MD measurements when compared to 2D cervical MD measurements. As shown in Table 6.8, The maximum average difference between 3D MD measurements was 0.05, which was significantly less than the results obtained from 2D measurements (>0.24).

Table 6.7. Comparison of the mean MD cervical measurement from lingual and buccal positions (measurements are in mm).

Teeth	N	Average measurement from lingual position	Average measurement from buccal position	Differences in average measurements
UI1	18	6.21	6.40	0.19
UI2	19	4.65	4.87	0.22
UC	22	5.41	5.59	0.18
UP3	25	4.62	4.83	0.21
UP4	27	4.84	4.99	0.15
UM1	23	7.65	7.74	0.09
UM2	24	7.15	7.23	0.08
UM3	15	6.64	6.74	0.10
LI1	17	3.42	3.60	0.18
LI2	16	3.91	4.07	0.16
LC	24	5.22	5.39	0.17
LP3	26	4.55	4.76	0.21
LP4	24	4.73	4.97	0.24
LM1	22	8.51	8.61	0.10
LM2	23	8.47	8.55	0.08
LM3	20	8.29	8.41	0.12

Table 6.8. Comparison of the mean 3D MD cervical measurement from lingual and buccal positions (measurements are in mm).

Teeth	N	Average measurement from lingual position	Average measurement from buccal position	Differences in average measurements
UI1	18	6.18	6.20	0.02
UI2	19	4.60	4.56	0.04
UC	19	5.40	5.38	0.02
UP3	20	4.79	4.83	0.04
UP4	21	4.75	4.71	0.04
UM1	18	7.56	7.58	0.02
UM2	18	7.23	7.24	0.01
UM3	12	6.70	6.75	0.05
LI1	17	3.37	3.42	0.05
LI2	16	3.80	3.82	0.02
LC	20	5.16	5.19	0.03
LP3	21	4.68	4.66	0.02
LP4	20	4.76	4.80	0.04
LM1	19	8.48	8.50	0.02
LM2	18	8.67	8.68	0.01
LM3	14	8.30	8.35	0.05

6.4.3. Statistical Analysis

6.4.3.1. Intra- and inter-observer Error

Intra- and inter-observer error were calculated for each set of data to check the reliability of the methods. TEM, rTEM and the coefficient of reliability (R) (Ulijaszek and Kerr, 1999) were used to determine the differences between the two sets of measurements. Intra-observer error was assessed using a random subset of 50 individuals for 2D cervical measurements, and 35 individuals for both 3D cervical and RV measurements, while a random subset of 30 individuals was used to assess inter-observer error for each set of data.

Tables 6.9 and 6.10 show the mean difference between the two sets of measurements, TEM, rTEM, and the coefficient of reliability results, evaluating intra-observer error for 2D cervical, 3D cervical and RV measurements. The mean differences take into account whether the values obtained from the first measurement are consistently higher or lower than those taken from the second measurement, and therefore vary from negative to positive. The mean difference in all teeth was between −0.02 and +0.01mm for 2D cervical measurements, −0.01 and +0.01mm for 3D cervical measurements (Table 6.9), and −2.02 and +1.89mm for RV measurements (Table 6.10); the amount to which they were positive or negative was not consistent enough to suggest a strong methodological difference between the two repeated measurements. The TEM values were very low for both 2D and 3D cervical measurements, varying from 0.02-0.04mm (Table 6.9). These values were significantly higher for RV measurements, varying from 1.94-4.65mm (Table 6.10). This difference is due to the positive association between the size of the TEM and the size of the measurements (see Chapter 3). To solve this problem, the TEM was converted to relative TEM. This conversion provided very low rTEM percentages (Tables 6.9 and 6.8). The mean rTEM for 2D and 3D cervical measurements was 0.45% and 0.46% respectively, and for RV measurements it was 1.54%. The R for all variables found to be > 99%, which represents almost complete reliability (Ulijaszek and Kerr, 1999). The variables with the highest value for intra-observer error were the

MD measurement of LI2 for both 2D and 3D cervical measurements, and LP4 for RV measurements (Tables 6.9 and 6.10).

Inter-observer error was slightly higher than intra-observer error for all sets of data. The mean difference for 2D cervical, 3D cervical and RV measurements was between −0.02 and +0.06mm, −0.03 and +0.03mm, and −1.14 and +1.97mm, respectively (Tables 6.10 and 6.11). The TEM values for both cervical measurements varied from 0.03-0.05mm, and for RV measurements varied from 2.21-4.98mm. The mean rTEM was 0.62% for 2D cervical measurements, 0.60% for 3D cervical measurements and 1.75% for RV measurements, with R values > 0.98 for all measurements (Tables 6.10 and 6.11). The variable with the highest inter-observer error for all three sets of data was LI2.

In general, inter- and intra-observer error values for 2D cervical measurements were very similar to those obtained for 3D cervical measurements, and they were higher for RV measurements. The rTEM and R values for all the measurements were below the 5% rTEM and above the 0.95 R standards for anthropometric studies (Franklin et al., 2013).

Mean and standard deviation values of repeated measurements for 2D cervical, 3D cervical and RV measurements are summarized in Appendix A.

Table 6.9. Mean difference, TEM, rTEM, and coefficient of reliability results evaluating intra-observer error in 2D and 3D cervical measurements (measurements are in mm).

Measurements	2D cervical					3D cervical				
MD	**N**	**Diff**	**TEM**	**rTEM**	**R**	**N**	**Diff**	**TEM**	**rTEM**	**R**
UI1	36	−0.01	0.03	0.45	1	22	0.00	0.03	0.46	1
LI1	25	0.00	0.02	0.58	0.99	26	−0.01	0.02	0.7	0.99
UI2	36	0.00	0.03	0.61	1	21	−0.01	0.03	0.56	1
LI2	39	−0.01	0.04	0.78	0.99	26	0.00	0.03	0.76	0.99
UC	37	0.00	0.03	0.53	1	34	0.00	0.03	0.6	1
LC	48	−0.01	0.03	0.49	1	29	0.00	0.02	0.44	1
UP3	38	−0.01	0.04	0.72	0.99	34	−0.01	0.03	0.6	1
LP3	50	−0.01	0.03	0.55	0.99	32	0.01	0.03	0.62	1
UP4	42	−0.01	0.03	0.65	1	31	0.01	0.03	0.57	1
LP4	38	0.00	0.04	0.47	1	30	0.01	0.02	0.5	1
UM1	48	0.00	0.04	0.39	1	29	0.00	0.03	0.38	1
LM1	31	−0.01	0.03	0.26	1	29	−0.01	0.03	0.32	1
UM2	42	−0.01	0.04	0.45	1	29	0.00	0.03	0.38	1
LM2	22	−0.02	0.03	0.36	1	34	−0.01	0.03	0.37	1
UM3	18	0.00	0.04	0.54	1	14	0.00	0.03	0.39	1
LM3	31	0.00	0.03	0.36	1	21	0.00	0.03	0.29	1
BL										
UI1	36	−0.01	0.03	0.48	1	22	0.00	0.03	0.46	1
LI1	22	0.00	0.03	0.49	0.99	26	0.01	0.03	0.58	0.99
UI2	36	0.00	0.02	0.44	1	21	0.01	0.03	0.6	0.99
LI2	39	−0.01	0.03	0.47	0.99	26	0.01	0.02	0.43	1
UC	37	0.00	0.03	0.33	1	34	0.00	0.03	0.35	1
LC	48	0.00	0.02	0.31	1	29	0.00	0.03	0.45	1
UP3	38	−0.01	0.03	0.38	1	34	−0.01	0.03	0.41	1
LP3	50	0.00	0.03	0.45	0.99	32	0.00	0.03	0.42	1
UP4	42	0.01	0.03	0.39	1	31	0.00	0.03	0.37	1
LP4	38	0.00	0.03	0.35	1	30	0.00	0.04	0.56	1
UM1	41	−0.01	0.03	0.29	1	29	0.00	0.03	0.28	1
LM1	40	0.00	0.03	0.33	1	29	0.00	0.03	0.3	1
UM2	39	−0.01	0.03	0.32	1	29	0.01	0.03	0.29	1
LM2	37	0.01	0.03	0.38	1	34	0.00	0.04	0.51	0.99
UM3	25	0.01	0.03	0.36	1	14	0.00	0.03	0.32	1
LM3	31	−0.01	0.03	0.39	1	21	−0.01	0.03	0.33	1

Table 6.10. Mean difference, TEM, rTEM, and coefficient of reliability results evaluating intra- and inter-observer error in RV measurements (measurements are in mm^3).

Measurements	Intra-observer error					Inter-observer error				
RV	**N**	**Diff**	**TEM**	**rTEM**	**R**	**N**	**Diff**	**TEM**	**rTEM**	**R**
UI1	22	1.5	3.61	1.66	1	20	1.82	4.8	2.12	0.99
LI1	26	0.73	1.94	1.97	0.99	21	−0.16	2.21	2.2	0.98
UI2	26	0.80	2.6	1.93	1	23	1.41	3.33	2.27	0.99
LI2	24	−0.62	2.4	1.87	0.99	20	1.30	2.77	2.18	0.99
UC	34	0.03	3.89	1.57	1	25	0.36	4.63	1.86	1
LC	26	1.89	2.96	1.26	1	22	0.91	3.69	1.5	1
UP3	34	0.95	3.09	1.88	1	22	0.32	3.05	2.01	0.99
LP3	31	−0.26	2.81	1.83	0.99	24	−1.14	3.2	1.98	0.99
UP4	32	0.73	3.32	1.94	1	24	1.12	3.9	2.24	0.99
LP4	30	−0.30	3.8	2.06	0.99	23	0.43	4.13	2.22	0.99
UM1	28	0.92	4.16	0.97	1	25	0.07	4.56	1.06	1
LM1	29	0.73	3.77	0.91	1	23	−0.27	4.24	0.99	1
UM2	31	−0.63	4.59	1.15	1	24	0.46	4.98	1.21	1
LM2	32	0.09	3.76	1.02	1	22	−0.83	4.23	1.1	1
UM3	10	−2.02	4.65	1.49	1	6	−0.97	4.71	1.69	1
LM3	20	0.71	3.66	1.11	1	12	1.97	4.46	1.39	1

Table 6.11. Mean difference, TEM, rTEM, and coefficient of reliability results evaluating inter-observer error in 2D and 3D cervical measurements (measurements are in mm).

Measurements	2D cervical					3D cervical				
MD	**N**	**Diff**	**TEM**	**rTEM**	**R**	**N**	**Diff**	**TEM**	**rTEM**	**R**
UI1	26	−0.01	0.04	0.57	1	19	0.01	0.04	0.61	1
LI1	21	0.01	0.03	0.75	0.98	21	−0.01	0.03	0.9	0.98
UI2	28	0.01	0.05	0.75	1	20	−0.01	0.04	0.78	1
LI2	27	−0.01	0.03	0.87	0.99	20	0.00	0.03	0.88	0.99
UC	30	0.01	0.04	0.68	1	24	0.00	0.04	0.77	1
LC	31	0.01	0.04	0.69	1	23	0.02	0.03	0.59	1
UP3	29	−0.01	0.04	0.76	1	24	−0.01	0.04	0.8	0.99
LP3	28	0.01	0.03	0.76	0.99	22	0.02	0.04	0.79	0.99
UP4	30	0	0.04	0.75	0.99	22	0.03	0.04	0.81	0.99
LP4	27	0.01	0.04	0.83	0.99	23	0.02	0.04	0.77	0.99
UM1	27	0	0.05	0.56	0.99	24	0.01	0.04	0.5	0.99
LM1	29	0	0.04	0.52	1	23	0.00	0.04	0.44	1
UM2	28	−0.02	0.05	0.62	0.99	24	0.02	0.03	0.46	1
LM2	25	0.02	0.05	0.57	0.99	24	0.01	0.04	0.43	1
UM3	14	−0.02	0.04	0.61	1	8	0.01	0.04	0.7	1
LM3	20	0.02	0.05	0.54	1	13	0.02	0.05	0.51	1
BL										
UI1	26	0.01	0.04	0.58	1	19	0.00	0.04	0.61	0.99
LI1	21	−0.01	0.04	0.68	0.99	21	0.02	0.04	0.66	0.99
UI2	28	0.00	0.03	0.61	1	20	0.02	0.04	0.75	0.99
LI2	27	0.00	0.04	0.65	0.99	20	0.02	0.03	0.6	0.99
UC	30	0.00	0.04	0.49	1	24	0.00	0.03	0.45	0.99
LC	31	−0.01	0.03	0.44	1	23	0.01	0.04	0.62	1
UP3	29	0.00	0.04	0.56	0.99	24	0.00	0.04	0.49	1
LP3	28	0.02	0.04	0.69	0.99	22	0.00	0.04	0.54	1
UP4	30	−0.01	0.04	0.55	1	22	0.02	0.04	0.5	1
LP4	27	0.00	0.05	0.71	1	23	0.01	0.03	0.5	1
UM1	27	−0.02	0.04	0.46	0.99	24	0.01	0.03	0.34	1
LM1	29	0.01	0.04	0.53	1	23	0.01	0.03	0.4	1
UM2	28	0.00	0.04	0.52	1	24	0.01	0.04	0.36	1
LM2	25	0.01	0.04	0.49	1	24	0.00	0.05	0.62	0.99
UM3	14	0.06	0.04	0.62	1	8	0.03	0.04	0.44	1
LM3	20	−0.02	0.04	0.48	1	13	−0.03	0.04	0.57	0.99

6.4.3.2. Normality and Homogeneity of Variances Tests

The Kolmogorov-Smirnov and Shapiro-Wilk tests were applied for each sex and measurement separately to check the normality of the data. There was an excellent agreement between the two tests, and the *p-values* of all measurements were higher than 0.05. The results showed that all measurements were normally distributed within each sex. The results of both tests for cervical measurements are presented in Tables 6.12 and 6.13, and for RV measurements in Table 6.114.

Table 6.12. Normality test results for 2D and 3D cervical measurements (maxillary teeth)

Tooth	Sex	Measurements	2D cervical			3D cervical		
			N	Kolmogorov-Smirnov	Shapiro-Wilk	N	Kolmogorov-Smirnov	Shapiro-Wilk
UI1	Males	MD	30	0.19	0.42	15	0.20	0.98
		BL	30	0.20	0.78	15	0.20	0.54
	Females	MD	22	0.20	0.59	7	0.20	0.88
		BL	22	0.20	0.36	7	0.20	0.92
UI2	Males	MD	34	0.20	0.85	14	0.20	0.31
		BL	34	0.20	0.26	14	0.20	0.57
	Females	MD	21	0.20	0.60	8	0.20	0.99
		BL	21	0.20	0.19	8	0.20	0.27
UC	Males	MD	50	0.20	0.09	20	0.20	0.16
		BL	50	0.20	0.21	20	0.20	0.88
	Females	MD	34	0.09	0.19	15	0.20	0.34
		BL	34	0.20	0.56	15	0.20	0.34
UP3	Males	MD	52	0.09	0.27	21	0.20	0.31
		BL	52	0.20	0.44	21	0.20	0.44
	Females	MD	35	0.20	0.46	14	0.20	0.62
		BL	35	0.06	0.73	14	0.20	0.53
UP4	Males	MD	49	0.20	0.71	16	0.20	0.86
		BL	49	0.20	0.49	16	0.20	0.77
	Females	MD	34	0.20	0.40	15	0.17	0.45
		BL	34	0.20	0.53	15	0.20	0.28
UM1	Males	MD	51	0.20	0.85	17	0.20	0.91
		BL	51	0.20	0.54	17	0.20	0.70
	Females	MD	33	0.20	0.92	13	0.20	0.36
		BL	33	0.20	0.42	13	0.20	0.91
UM2	Males	MD	52	0.20	0.59	21	0.20	0.57
		BL	52	0.20	0.38	21	0.20	0.84
	Females	MD	30	0.20	0.51	9	0.20	0.22
		BL	30	0.20	0.95	9	0.20	0.77
UM3	Males	MD	30	0.20	0.92	8	0.20	0.94
		BL	30	0.17	0.46	8	0.20	0.81
	Females	MD	16	0.17	0.63	6	0.20	0.37
		BL	16	0.20	0.95	6	0.20	0.29

Table 6.13. Normality test results for 2D and 3D cervical measurements (mandibular teeth)

Tooth	Sex	Measurements	2D cervical			3D cervical		
			N	Kolmogorov -Smirnov	Shapiro-Wilk	N	Kolmogorov -Smirnov	Shapiro-Wilk
LI1	Males	MD	48	0.20	0.10	15	0.20	0.66
		BL	48	0.07	0.28	15	0.20	0.75
	Females	MD	27	0.20	0.09	12	0.20	0.73
		BL	27	0.20	0.78	12	0.20	0.99
LI2	Males	MD	59	0.07	0.06	15	0.20	1.00
		BL	59	0.20	0.69	15	0.06	0.21
	Females	MD	32	0.15	0.12	11	0.20	0.62
		BL	32	0.11	0.25	11	0.20	0.12
LC	Males	MD	66	0.20	0.33	19	0.20	0.93
		BL	66	0.20	0.84	19	0.20	0.89
	Females	MD	36	0.20	0.87	12	0.20	0.22
		BL	36	0.20	0.53	12	0.20	0.92
LP3	Males	MD	69	0.20	0.29	20	0.06	0.17
		BL	69	0.20	0.20	20	0.20	0.15
	Females	MD	42	0.20	0.99	14	0.20	0.1
		BL	42	0.20	0.15	14	0.19	0.1
LP4	Males	MD	68	0.20	0.79	20	0.13	0.13
		BL	68	0.07	0.13	20	0.46	0.46
	Females	MD	36	0.20	0.21	12	0.20	0.55
		BL	36	0.20	0.50	12	0.20	0.12
LM1	Males	MD	62	0.20	0.83	17	0.17	0.2
		BL	62	0.20	0.15	17	0.04	0.12
	Females	MD	34	0.20	0.27	13	0.20	0.96
		BL	34	0.20	0.81	13	0.20	0.9
LM2	Males	MD	69	0.20	0.18	21	0.20	0.94
		BL	69	0.20	0.62	21	0.20	0.46
	Females	MD	38	0.19	0.53	15	0.20	0.27
		BL	38	0.20	0.55	15	0.20	1.00
LM3	Males	MD	45	0.20	0.34	14	0.20	0.81
		BL	45	0.20	0.81	14	0.20	0.81
	Females	MD	24	0.18	0.30	8	0.20	0.81
		BL	24	0.14	0.15	8	0.20	0.19

The assumption of homogeneity of variance was tested using Levene's Test of Equality of Variances. As can be seen in Table 6.15, the *p-values* of all measurements were greater than 0.05, indicating that the sample is statistically homogenous in all measurements.

Table 6.14. Normality test results for RV measurements (maxillary and mandibular teeth)

Tooth	Males			Females		
	N	Kolmogorov	Shapiro-	N	Kolmogorov	Shapiro-
UI1	14	0.20	0.97	7	0.20	0.22
UI2	17	0.20	0.29	8	0.20	0.12
UC	19	0.20	0.66	16	0.20	0.14
UP3	25	0.20	0.84	17	0.18	0.23
UP4	18	0.20	0.99	16	0.11	0.43
UM1	18	0.09	0.30	12	0.11	0.09
UM2	20	0.20	0.83	11	0.20	0.67
UM3	6	0.20	0.72	8	0.20	0.82
LI1	17	0.14	0.10	11	0.17	0.16
LI2	18	0.20	0.77	11	0.20	0.41
LC	20	0.09	0.36	12	0.20	0.69
LP3	22	0.20	0.10	15	0.12	0.13
LP4	21	0.20	0.93	11	0.14	0.10
LM1	19	0.20	0.69	11	0.20	0.15
LM2	22	0.19	0.16	14	0.20	0.32
LM3	15	0.20	0.71	9	0.06	0.15

Table 6.15. Levene's test results for 2D cervical, 3D cervical and RV measurements

Tooth	2D cervical			3D cervical			RV	
		p-value			*p-value*			*p-value*
	N	**MD**	**BL**	**N**	**MD**	**BL**	**N**	**Volume**
UI1	52	0.74	0.12	15	0.53	0.31	14	0.62
UI2	55	0.06	0.22	14	0.74	0.65	17	0.08
UC	84	0.58	0.98	20	0.07	0.75	19	0.10
UP3	87	0.53	0.93	21	0.14	0.07	24	0.28
UP4	83	0.27	0.90	16	0.14	0.12	17	0.29
UM1	84	0.67	0.23	17	0.10	0.08	18	0.37
UM2	82	0.97	0.48	21	0.63	0.12	20	0.25
UM3	45	0.20	0.10	8	0.56	0.13	6	0.07
LI1	75	0.72	0.08	15	0.41	0.21	17	0.53
LI2	91	0.08	0.81	15	0.06	0.08	18	0.61
LC	102	0.38	0.55	19	0.33	0.24	20	0.18
LP3	110	0.73	0.41	20	0.41	0.43	22	0.10
LP4	103	0.86	0.45	20	0.88	0.13	21	0.12
LM1	95	0.45	0.19	17	0.78	0.21	19	0.43
LM2	106	0.31	0.65	21	0.52	0.26	22	0.28
LM3	68	0.19	0.45	14	0.48	0.62	15	0.53

6.4.3.3. Student t-test

6.4.3.3.1. Differences between Hasanlu and Dinkha Tepe Skeletons

An independent student t-test was performed to check the mean differences between Hasanlu and Dinkha Tepe skeletons. In all three sets of data, both maxillary and mandibular teeth showed no statistically significant differences between the mean values of Hasanlu and Dinkha Tepe skeletons ($p > 0.05$). Accordingly, the two samples were subsequently pooled to increase sample size for analysis. The only exceptions were the 2D and 3D cervical MD measurements of UM3, which showed a significant difference between the two collections and was therefore removed from the analysis (Table 6.16). Bootstrapping was also used in all measurements. SPSS was used to generate around 1,000 bootstrap samples for each measurement to obtain the *p-values*. The results produced by bootstrap samples also showed no significant difference between the measurements, except the cervical MD measurements of UM3. Tables 6.16 and 6.15 present the *t-values*, and the *p-values* for both the original sample and the bootstrap sample. The difference in the means and variances of the two populations were used to calculate the *t-value*. The greater the *t-value*, the more certain it is that the means are different. Mean and standard deviation for each measurement are presented in Appendix A.

Table 6.16. Independent student t-test comparing the means between Hasanlu and Dinkha Tepe collections, including original and bootstrap samples: 2D and 3D cervical measurements

Measurements	**2D cervical**					**3D cervical**				
	N		*t-value*	*p-value*	Bootstrap *p-value*	N		*t-value*	*p-value*	Bootstrap *p-value*
MD	Hasanlu	Dinkha				Hasanlu	Dinkha			
UI1	44	8	1.21	0.23	0.13	15	7	0.65	0.53	0.49
UI2	55	20	0.32	0.75	0.72	12	15	0.46	0.65	0.66
UC	43	12	1.64	0.10	0.14	13	9	1.84	0.08	0.09
UP3	68	23	−1.48	0.14	0.17	12	14	−0.05	0.96	0.96
UP4	64	20	0.55	0.58	0.59	21	14	0.95	0.35	0.35
UM1	75	27	−0.99	0.32	0.34	14	16	−0.25	0.81	0.80
UM2	71	16	−0.20	0.84	0.86	23	12	0.03	0.98	0.98
UM3	84	27	−1.41	0.16	0.16	17	17	−1.33	0.19	0.19
LI1	64	19	−0.71	0.48	0.48	19	12	−0.33	0.75	0.75
LI2	80	24	−1.69	0.09	0.08	17	15	−1.12	0.27	0.28
LC	67	17	−0.14	0.88	0.87	20	10	−0.23	0.82	0.8
LP3	73	22	−0.75	0.46	0.43	16	14	0.74	0.47	0.45
LP4	62	20	−1.30	0.20	0.18	20	10	−0.57	0.57	0.52
LM1	79	28	−0.45	0.65	0.62	18	18	−0.81	0.42	0.42
LM2	33	13	−2.99	0.00[a]	0.00[a]	7	7	−2.33	0.04[b]	0.05
LM3	47	21	−1.63	0.11	0.10	6	16	−0.13	0.90	0.91
BL										
UI1	44	8	1.32	0.19	0.28	15	7	0.23	0.82	0.86
UI2	55	20	0.90	0.37	0.36	12	15	1.14	0.26	0.28
UC	43	12	1.41	0.16	0.16	13	9	1.49	0.15	0.17
UP3	68	23	0.30	0.77	0.80	12	14	0.16	0.88	0.87
UP4	63	20	1.33	0.19	0.12	21	14	1.30	0.20	0.16
UM1	74	27	0.00	1.00	1.00	14	16	−0.03	0.97	0.97
UM2	71	16	1.47	0.15	0.15	23	12	1.97	0.07	0.06
UM3	84	26	−0.87	0.39	0.41	17	17	−0.86	0.40	0.42
LI1	64	19	1.14	0.26	0.16	19	12	1.05	0.30	0.24
LI2	80	23	−1.61	0.11	0.08	16	15	0.19	0.84	0.84
LC	66	17	0.54	0.59	0.53	20	10	0.95	0.35	0.29
LP3	74	22	−0.45	0.65	0.66	16	14	−0.19	0.85	0.84
LP4	62	20	−1.11	0.27	0.22	20	10	−0.10	0.92	0.92
LM1	79	27	−0.24	0.81	0.80	18	18	−1.13	0.27	0.29
LM2	32	13	0.71	0.48	0.49	7	7	0.60	0.56	0.54
LM3	47	21	−0.55	0.59	0.59	6	16	−1.16	0.26	0.28

[a] $p < 0.05$
[b] $P < 0.05$

Table 6.17. Independent student t-test comparing the means between Hasanlu and Dinkha Tepe collections, including original and bootstrap samples: RV measurements

Tooth	**N**		***t-value***	***p-value***	**Bootstrap *p-value***
	Hasanlu	Dinkha			
UI1	14	7	1.02	0.32	0.35
UI2	14	15	0.30	0.76	0.79
UC	14	11	0.32	0.16	0.16
UP3	15	14	0.05	0.96	0.97
UP4	20	15	1.03	0.31	0.32
UM1	16	16	−0.87	0.39	0.42
UM2	23	18	1.26	0.21	0.22
UM3	19	18	−0.75	0.46	0.47
LI1	19	14	−0.16	0.88	0.88
LI2	17	15	−0.63	0.53	0.53
LC	19	11	0.77	0.45	0.44
LP3	15	15	−0.94	0.36	0.36
LP4	21	10	0.02	0.99	0.98
LM1	18	18	−1.16	0.25	0.25
LM2	7	7	−0.69	0.50	0.53
LM3	9	15	0.22	0.83	0.83

6.4.3.3.2. Differences between right- and left-side teeth

Paired student t-test showed no statistically significant differences between right- and left-side teeth for both maxillary and mandibular dentition ($p > 0.05$) (Table 6.18). Mean and standard deviations for each measurement are presented in Appendix A.

Table 6.18. Paired student t-test comparing the means between right- and left-side teeth: 2D cervical measurements

Measurements	Males			Females		
MD	**N**	***t-value****	***p-value***	**N**	***t-value***	***p-value***
UI1	17	−0.35	0.73	12	−0.65	0.53
LI1	27	−0.19	0.85	14	0.27	0.79
UI2	15	−0.77	0.45	11	1.71	0.12
LI2	35	−0.93	0.36	20	0.10	0.92
UC	34	−0.15	0.89	15	−1.12	0.25
LC	42	−1.57	0.12	22	0.67	0.51
UP3	32	−0.63	0.53	17	−1.31	0.21
LP3	48	−0.93	0.36	24	1.20	0.24
UP4	25	−1.20	0.24	14	1.17	0.26
LP4	50	0.83	0.41	19	0.11	0.91
UM1	28	0.76	0.46	16	1.18	0.26
LM1	49	−0.70	0.49	18	0.81	0.43
UM2	26	1.89	0.07	13	1.09	0.30
LM2	49	−0.63	0.53	16	0.99	0.34
UM3	13	−1.62	0.13	5	0.46	0.67
LM3	19	1.55	0.14	6	−0.24	0.82
BL						
UI1	17	−0.91	0.38	12	−0.71	0.49
LI1	27	1.00	0.33	14	−1.00	0.34
UI2	15	0.50	0.62	11	−1.14	0.28
LI2	35	1.44	0.16	20	1.21	0.24
UC	34	−0.03	0.98	15	−0.90	0.38
LC	42	1.23	0.23	22	0.50	0.62
UP3	32	−0.34	0.73	17	0.61	0.55
LP3	48	1.48	0.15	24	1.33	0.20
UP4	25	0.09	0.93	14	1.32	0.21
LP4	50	1.66	0.10	19	−0.11	0.91
UM1	28	−0.30	0.76	16	0.71	0.49
LM1	49	−1.00	0.32	18	0.86	0.40
UM2	26	0.95	0.35	13	1.06	0.31
LM2	49	−1.75	0.09	16	−1.89	0.08
UM3	13	0.16	0.88	5	1.18	0.30
LM3	19	−1.60	0.13	6	−1.55	0.18

6.4.3.3.3. 2D and 3D Cervical Measurements Comparison

A paired student t-test was performed to compare the cervical measurements obtained by dental callipers with those obtained by the AMIRA software. In total, 2D and 3D cervical MD and BL measurements of 427 maxillary and mandibular teeth were compared. As Table 6.19 shows, no statistically significant differences were found between the two sets of data ($p > 0.05$), except for the MD measurement of LM2 and the BL measurement of UM2 ($p < 0.05$). As can be seen in Figure 6.4, the highest level of significance (> 0.90) was observed in MD measurements of UI1, and BL measurements of UP3 and LP3. In general, when compared to cervical BL measurements, cervical MD measurements showed a higher level of significance, similar to that found in mandibular teeth when compared to maxillary teeth. UP3 and LP3 were the only teeth which provided a very high level of significance (> 0.70) for both cervical MD and BL measurements (Table 6.19, Fig. 6.4). On average, the 3D cervical MD measurements were 0.02mm smaller than the 2D cervical MD measurements, while the 3D cervical BL measurements were 0.01mm smaller than 2D cervical BL measurements (Table 9, Appendix A).

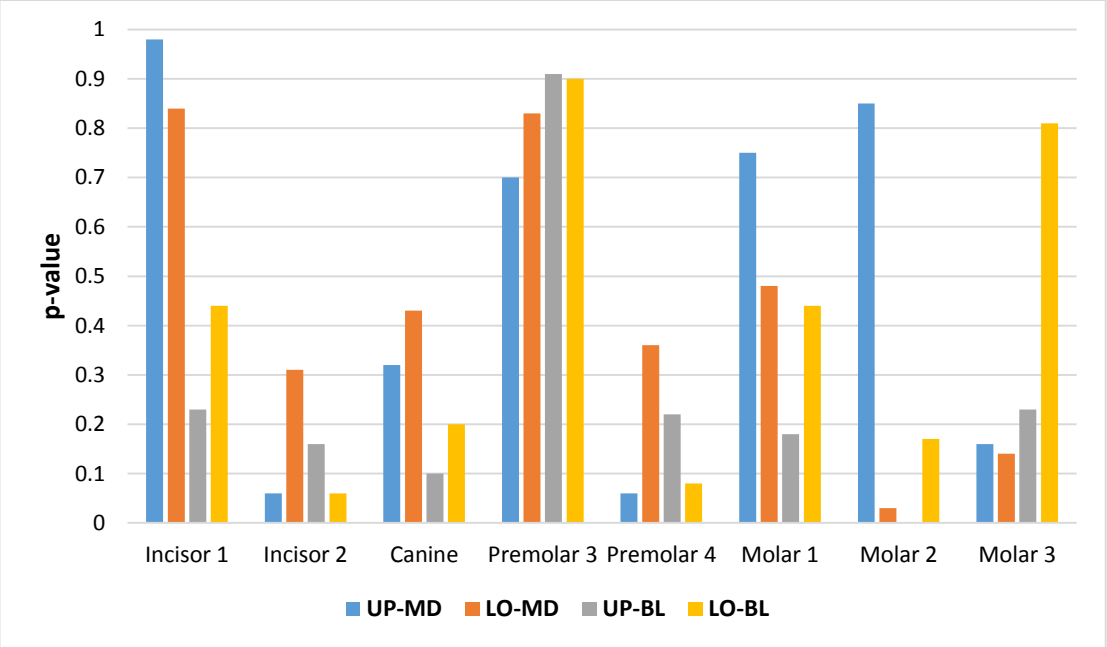

Fig. 6.4. Mean differences between 2D and 3D cervical measurements for all teeth.

The bootstrap sample (n = 1,000) also provided results very close to the original sample (Table 6.19). Mean and standard deviations for each measurement are presented in Appendix A.

Table 6.19. Paired student t-test comparing the means between 2D and 3D cervical measurements, including original and bootstrap samples

Measurements	N	Mean Diff (mm)	*t-value*	*p-value*	Bootstrap p-value
MD					
UI1	21	0.00	0.03	0.98	0.98
LI1	23	0.00	−0.19	0.84	0.84
UI2	20	0.09	1.97	0.06	0.06
LI2	24	0.02	1.03	0.31	0.31
UC	33	0.02	1.02	0.32	0.32
LC	30	0.01	0.81	0.43	0.43
UP3	30	0.01	−0.39	0.70	0.71
LP3	34	0.00	−0.22	0.83	0.82
UP4	29	0.04	2.00	0.06	0.06
LP4	32	0.02	0.94	0.36	0.33
UM1	25	0.01	−0.32	0.75	0.75
LM1	28	0.02	0.71	0.48	0.46
UM2	28	0.00	0.19	0.85	0.84
LM2	35	0.05	2.24	0.03*	0.03*
UM3	14	0.03	1.51	0.16	0.16
LM3	21	0.03	1.53	0.14	0.12
BL					
UI1	21	0.02	1.10	0.23	0.28
LI1	23	0.02	0.79	0.44	0.43
UI2	20	0.04	1.45	0.16	0.16
LI2	24	0.05	1.99	0.06	0.07
UC	33	0.04	1.68	0.10	0.10
LC	29	0.06	2.42	0.20	0.03
UP3	30	0.00	−0.11	0.91	0.91
LP3	34	0.01	0.13	0.90	0.90
UP4	29	0.03	1.25	0.22	0.22
LP4	31	0.05	1.81	0.08	0.08
UM1	25	0.04	−1.38	0.18	0.17
LM1	28	0.01	−0.80	0.44	0.44
UM2	28	0.07	−3.07	0.00*	0.02*
LM2	35	0.03	−1.40	0.17	0.17
UM3	14	0.04	1.11	0.23	0.31
LM3	21	0.01	0.24	0.81	0.82

*$p < 0.05$

6.4.3.4. Outlier Detection

Tukey's interquartile range (IQR) (1977) and Median Absolute Deviation (MAD) (Leys et al., 2013) were used to search for possible outliers. The IQR method identified seven outliers in the 2D cervical data, two outliers in the 3D cervical data and one outlier in the RV data. In addition to those data, the MAD method also detected three more outliers in the 2D cervical data, and one more outlier each in the 3D cervical and RV data. In total, ten measurements were shown to be outliers in the 2D cervical data, three measurements in the 3D cervical data and two measurements in the RV data. As Table 6.20 shows, the majority of the outliers were males (n = 11) and BL measurements (n = 10). In total, seven outliers in the 2D cervical measurements, and one outlier in each of the other two data sets were unusually high compared to the other measurements, which shows that these outliers were probably due to a typo or data entry error. Since outliers can affect reliability statistics, the outliers were excluded from each group of measurements.

Table 6.20. Detected outliers in each set of data

2D cervical			3D cervical			RV		
Tooth	**N**	**Sex**	**Tooth**	**N**	**Sex**	**Tooth**	**N**	**Sex**
BL UC	1	Female	BL LP4	1	Female	UP3	1	Male
BL UM1	1	Male	BL LM1	1	Male	UP4	1	Male
BL UM3	1	Male	MD LM1	1	Male	**Total**	**2**	
BL LC	1	Female	**Total**	**3**				
BL LP3	1	Male						
BL LP4	1	Male						
BL LM2	1	Male						
BL LM3	1	Male						
MD LM1	1	Female						
MD LM3	1	Male						
Total	**10**							

6.4.3.5. One-way ANOVA

6.4.3.5.1. Univariate Sex Dimorphism

A one-way ANOVA was used to compare the mean differences between males and females. The results of the one-way ANOVA indicated that the differences between male and female mean values were significant for all measurements ($p < 0.000$), except for MD UM3 in 2D cervical measurements, and MD and BL UM3 and MD LM3 in 3D cervical measurements, which were excluded from the analysis. Due to the small number of UM3 in each set of data, as well as their high degree of variation in size (Townsend et al., 2016), measurements for this tooth were excluded from the discriminant function analysis. Tables 6.21, 6.22 and 6.23 show the sample size, descriptive statistics, *p-value* and associated univariate *F*-ratio of the differences between male and female individuals' means. "The *F*-ratio reflects the variation among the means of several groups in relation to the variation within the groups" (Rubin, 2013, p.187). As Tables 6.21, 6.22 and 6.23 show, in both maxillary and mandibular teeth all measurements showed a higher value in males compared with females, particularly in RV measurements. The greatest sex dimorphism was observed in MD, BL and RV measurements of canines and M2 for all three sets of data (Tables 6.21, 6.22, 6.23). The distribution of the mean differences between male and female tooth measurements for each set of data are presented in Figures 6.5 and 6.6.

Table 6.21. One-way ANOVA comparing the means between males and females: 2D cervical measurements

Measurements	Females			Males			Mean Diff. (mm)	*p-value*	*F* ratio
	N	Mean (mm)	SD	N	Mean (mm)	SD			
MD									
UI1	22	5.99	0.49	30	6. 47	0.48	0.48	0.00[a]	12.25
LI1	27	3.31	0.19	48	3.62	0.20	0.31	0.00	45.43
UI2	21	4.53	0.50	34	4.97	0.33	0.44	0.00	14.91
LI2	32	3.62	0.20	59	4.02	0.29	0.40	0.00	46.18
UC	34	5.16	0.36	50	5.88	0.36	0.72	0.00	79.23
LC	36	4.87	0.37	66	5.60	0.41	0.73	0.00	77.96
UP3	35	4.27	0.35	52	4.76	0.32	0.49	0.00	44.87
LP3	42	4.46	0.29	69	4.93	0.30	0.47	0.00	69.06
UP4	34	4.43	0.29	49	4.89	0.36	0.46	0.00	39.38
LP4	36	4.70	0.35	68	5.17	0.34	0.47	0.00	44.86
UM1	33	7.43	0.33	51	7.91	0.38	0.48	0.00	35.14
LM1	33	8.54	0.44	62	9.10	0.50	0.56	0.00	28.96
UM2	30	6.94	0.56	52	7.87	0.54	0.93	0.00	54.76
LM2	38	8.35	0.53	69	9.20	0.59	0.85	0.00	54.51
UM3*	16	6.87	0.75	30	7.00	0.58	0.13	0.49[b]	0.49
LM3	24	8.25	1.00	44	8.94	0.77	0.69	0.00[c]	10.05
BL									
UI1	22	5.96	0.27	30	6.47	0.40	0.51	0.00	27.14
LI1	27	5.27	0.27	48	5.66	0.34	0.39	0.00	26.17
UI2	21	5.36	0.43	34	5.88	0.34	0.52	0.00	23.66
LI2	32	5.76	0.34	59	6.12	0.31	0.36	0.00	26.47
UC	33	7.32	0.48	50	8.14	0.48	0.82	0.00	59.25
LC	35	6.91	0.54	66	7.75	0.46	0.84	0.00	60.91
UP3	35	7.68	0.55	52	8.12	0.54	0.44	0.00	13.45
LP3	42	6.31	0.42	68	6.90	0.48	0.59	0.00	43.26
UP4	34	7.76	0.60	49	8.42	0.59	0.66	0.00	24.81
LP4	36	6.76	0.60	67	7.33	0.56	0.57	0.00	23.04
UM1	33	9.53	0.43	50	10.21	0.52	0.68	0.00	38.94
LM1	34	8.27	0.46	62	8.97	0.56	0.70	0.00	39.29
UM2	30	9.19	0.57	52	10.28	0.61	1.09	0.00	62.11
LM2	38	7.73	0.56	69	8.65	0.58	0.92	0.00	62.15
UM3*	16	8.94	0.59	29	9.61	0.99	0.67	0.02	6.27
LM3	24	7.59	0.50	44	8.19	0.48	0.60	0.00	23.16

[a] Significant at $p < 0.01$, [b] $p < 0.05$, [c] $p < 0.002$, all others significant at $p < 0.000$

* Excluded from the discriminant function analysis.

Table 6.22. One-way ANOVA comparing the means between males and females: 3D cervical measurements

Measurements	Females			Males			Mean Diff. (mm)	*p-value*	*F* ratio
	N	Mean (mm)	SD	N	Mean (mm)	SD			
MD									
UI1	7	5.79	0.42	15	6.52	0.47	0.73	0.00[a]	12.17
LI1	12	3.30	0.11	15	3.69	0.15	0.39	0.00	58.87
UI2	8	4.05	0.28	14	4.98	0.31	0.93	0.00	49.13
LI2	11	3.50	0.14	15	4.06	0.30	0.56	0.00	32.58
UC	15	4.92	0.20	20	5.84	0.34	0.92	0.00	88.39
LC	11	4.58	0.25	19	5.54	0.34	0.96	0.00	66.04
UP3	14	4.14	0.19	21	4.86	0.33	0.72	0.00	55.18
LP3	14	4.36	0.31	20	4.99	0.26	0.63	0.00	41.43
UP4	15	4.29	0.20	16	4.81	0.31	0.52	0.00	30.28
LP4	12	4.51	0.35	20	5.18	0.34	0.67	0.00	28.68
UM1	13	7.38	0.20	17	8.07	0.33	0.69	0.00	44.92
LM1	13	8.48	0.45	17	9.09	0.43	0.61	0.00[b]	14.19
UM2	9	7.04	0.44	21	7.96	0.57	0.92	0.00	18.33
LM2	15	8.36	0.45	21	9.23	0.53	0.87	0.00	26.63
UM3*	6	6.77	0.71	8	6.90	0.96	0.13	0.78[c]	0.08
LM3*	8	8.82	0.58	14	9.04	0.81	0.22	0.50[c]	0.47
BL									
UI1	7	5.75	0.26	15	6.54	0.36	0.79	0.00	26.04
LI1	12	5.09	0.21	15	5.57	0.30	0.48	0.00	21.86
UI2	8	5.17	0.30	14	5.76	0.29	0.59	0.00	21.11
LI2	11	5.43	1.00	15	5.99	0.27	0.56	0.00	41.18
UC	15	6.99	0.44	20	7.95	0.47	0.96	0.00	37.07
LC	11	6.42	0.37	19	7.61	0.54	1.19	0.00	41.90
UP3	14	7.43	0.39	21	8.15	0.60	0.72	0.00	15.80
LP3	14	6.20	0.39	20	6.84	0.30	0.64	0.00	29.47
UP4	15	7.42	0.42	16	8.37	0.67	0.95	0.00	21.94
LP4	11	6.78	0.24	20	7.28	0.59	0.50	0.00	6.97
UM1	13	9.39	0.32	17	10.11	0.58	0.72	0.00	16.01
LM1	13	8.22	0.34	17	8.88	0.44	0.66	0.01[d]	19.77
UM2	9	9.22	0.22	21	10.33	0.65	1.11	0.00	24.67
LM2	15	7.80	0.41	21	8.54	0.49	0.74	0.00	22.15
UM3*	6	9.02	0.51	8	9.20	1.03	0.18	0.70[c]	0.16
LM3	8	7.61	0.34	14	8.10	0.43	0.49	0.01[e]	7.72

[a] Significant at $p < 0.002$, [b] $p < 0.001$, [c] $p < 0.05$, [d] $p < 0.013$, [e] $p < 0.012$, all others significant at $p < 0.00$
*Excluded from the discriminant function analysis

Table 6.23. One-way ANOVA comparing the means between males and females: RV measurements

Measurements	Females			Males			Mean Diff. (mm^3)	*p-value* [a]	*F* ratio
	N	Mean (mm^3)	SD	N	Mean (mm^3)	SD			
UI1	7	139.64	29.82	14	245.44	24.26	105.80	0.00	76.43
LI1	11	83.64	12.22	17	113.15	10.88	29.51	0.00	44.61
UI2	8	82.63	10.71	17	170.49	20.83	87.86	0.00	124.67
LI2	11	95.59	16.33	18	149.69	12.74	54.10	0.00	99.43
UC	16	161.47	23.51	19	317.18	43.12	155.71	0.00	166.43
LC	12	170.71	25.11	20	271.82	43.63	101.11	0.00	53.38
UP3	17	115.76	20.70	24	182.19	26.32	66.43	0.00	75.16
LP3	15	123.61	21.69	22	180.15	15.41	56.54	0.00	86.20
UP4	16	135.34	20.15	17	198.34	26.87	63.00	0.00	61.97
LP4	11	138.31	31.57	21	211.43	24.74	73.12	0.00	52.14
UM1	12	363.96	62.46	18	483.44	51.40	119.48	0.00	32.76
LM1	11	349.19	35.49	19	473.82	46.34	124.63	0.00	59.11
UM2	11	305.93	48.88	20	461.90	68.09	155.97	0.00	44.71
LM2	14	307.57	49.00	22	429.09	58.85	121.52	0.00	41.33
UM3*	8	237.66	15.16	6	311.53	33.59	73.87	0.00	30.96
LM3	9	252.67	45.14	15	359.65	48.79	106.98	0.00	28.54

[a] All significant at p<0.00.
*Excluded from the discriminant function analysis.

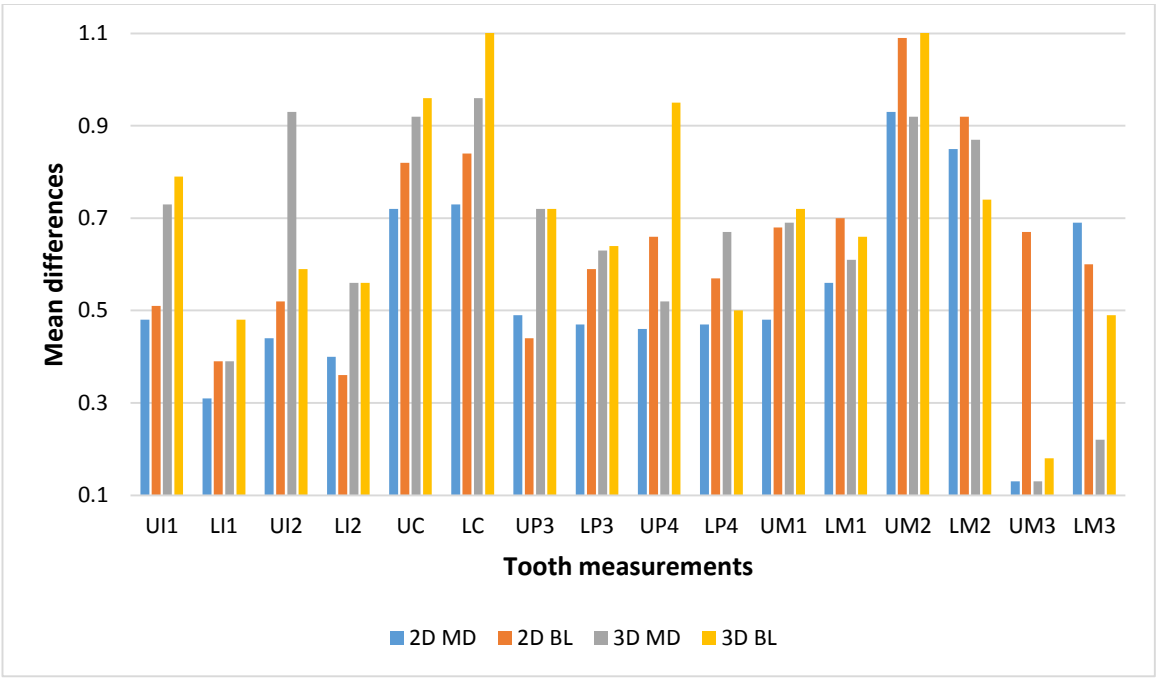

Fig. 6.5. Mean differences between males and females: cervical measurements. All statistically significant at p<0.00.

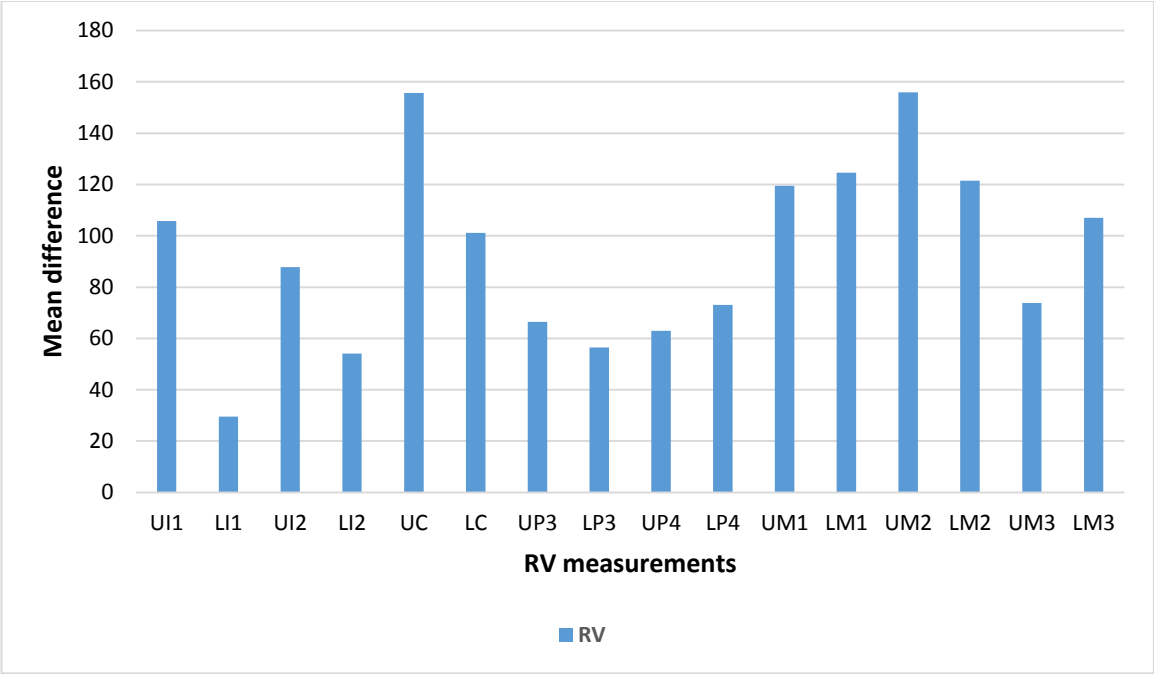

Fig. 6.6. Mean differences between males and females: RV measurements. All statistically significant at $p<0.00$.

6.4.3.6. Sexual Dimorphism

Table 6.24 presents the percentage of sexual dimorphism for 2D cervical MD, BL, 3D cervical MD, BL, and RV measurements for each tooth separately.

It was observed that the most sexually dimorphic 2D cervical measurements were the MD diameter of LC, with a 14.99 percentage of dimorphism, followed by the MD diameter of UC and UM2, with a 13.93 and 13.40 percentage of dimorphism, respectively (Table 6.24). The MD diameter of UI2, with a 22.96 percentage of sexual dimorphism, was the most sexually dimorphic 3D cervical measurement, followed by the MD diameter of LC (20.96%) and the BL diameter of LC (18.54%) (Table 6.24). The most sexually dimorphic RV measurement was also UI2, with a 106.33 percentage of dimorphism, followed by the UC and UI1, each with a 96.43 and 75.77 percentage of dimorphism, respectively (Table 6.24). These measurements also showed a statistically significant difference between male and female measurements for all dimensions (Figs 6.5, 6.6). Figures 6.7 and 6.8 show the percentage of sexual dimorphism in each tooth for all maxillary and mandibular teeth. As the figures show, canines are the most dimorphic teeth for all dimensions and, in general, anterior teeth

are more sexually dimorphic than posterior teeth. A comparison between the maxillary and mandibular and the mesiodistal and buccolingual measurements shows that maxillary teeth are more sexually dimorphic than those of the mandible for 3D dimensions, and mandibular teeth are more sexually dimorphic than maxillary teeth for 2D dimensions, and also that MD measurements are more sexually dimorphic than BL measurements for both 2D and 3D cervical dimensions. The smallest sexual dimorphism was observed in M3 (particularly maxillary) for all diameters.

Table 6.24. Sexual dimorphism percentages for all teeth and all dimensions

Measurements	2D cervical		3D cervical		Tooth	RV	
	N	SD %	N	SD %		N	SD %
MD							
UI1	52	8.01	22	12.61	UI1	21	75.77
LI1	75	9.37	27	11.82	LI1	28	32.58
UI2	55	9.70	22	**22.96**	UI2	25	**106.33**
LI2	91	11.05	26	16.00	LI2	29	56.60
UC	84	13.93	35	18.70	UC	35	96.43
LC	102	**14.99**	30	20.96	LC	32	59.23
UP3	87	11.48	35	17.39	UP3	41	57.39
LP3	111	10.54	34	14.45	LP3	37	45.74
UP4	83	10.38	31	12.12	UP4	33	46.55
LP4	104	10.16	32	14.86	LP4	32	52.87
UM1	84	6.42	30	9.35	UM1	30	32.83
LM1	95	6.56	30	7.19	LM1	30	35.69
UM2	82	13.40	30	13.07	UM2	31	50.98
LM2	107	10.18	36	10.41	LM2	36	39.51
UM3	46	1.89	14	1.92	UM3	14	31.08
LM3	68	8.36	22	2.49	LM3	24	42.34
BL							
UI1	52	8.56	22	13.74			
LI1	75	7.37	27	9.43			
UI2	55	9.60	22	11.41			
LI2	91	6.25	26	10.31			
UC	83	11.20	35	13.73			
LC	101	**12.16**	30	**18.54**			
UP3	87	5.73	35	9.69			
LP3	110	9.35	34	10.32			
UP4	83	8.51	31	12.80			
LP4	103	8.38	31	7.37			
UM1	83	7.11	30	7.67			
LM1	96	7.06	30	8.03			
UM2	82	11.86	30	11.93			
LM2	107	11.90	36	9.49			
UM3	45	7.53	14	2.00			
LM3	68	7.91	22	6.44			

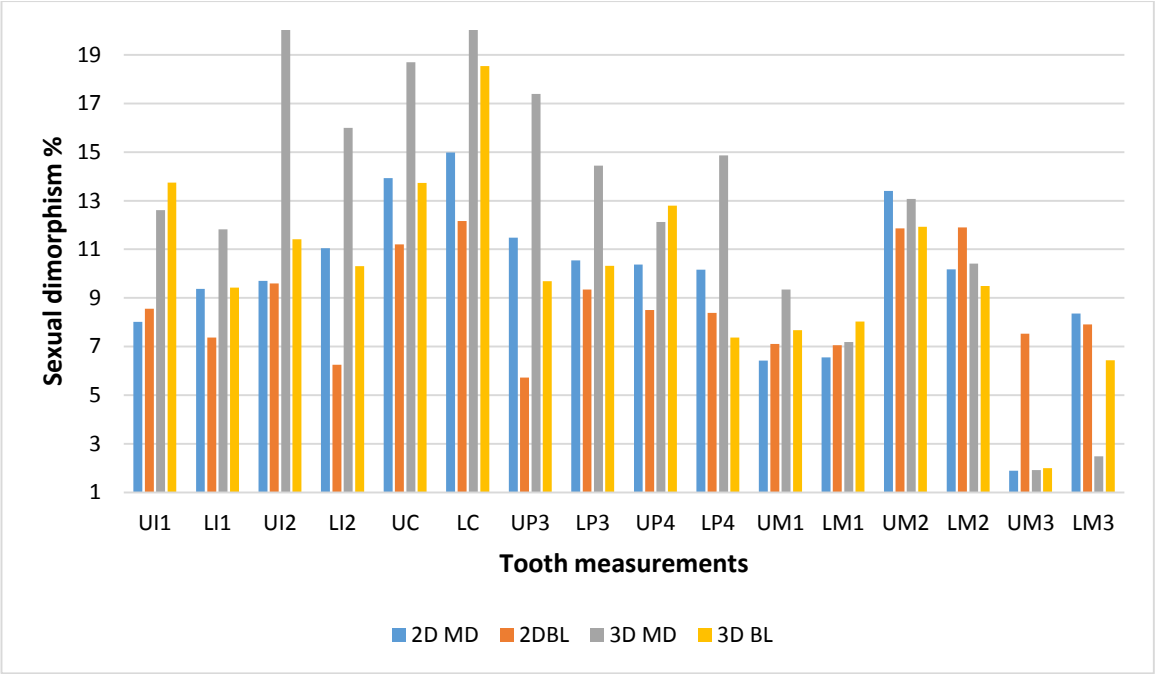

Fig. 6.7. Percentage of sexual dimorphism in maxillary and mandibular teeth: cervical measurements.

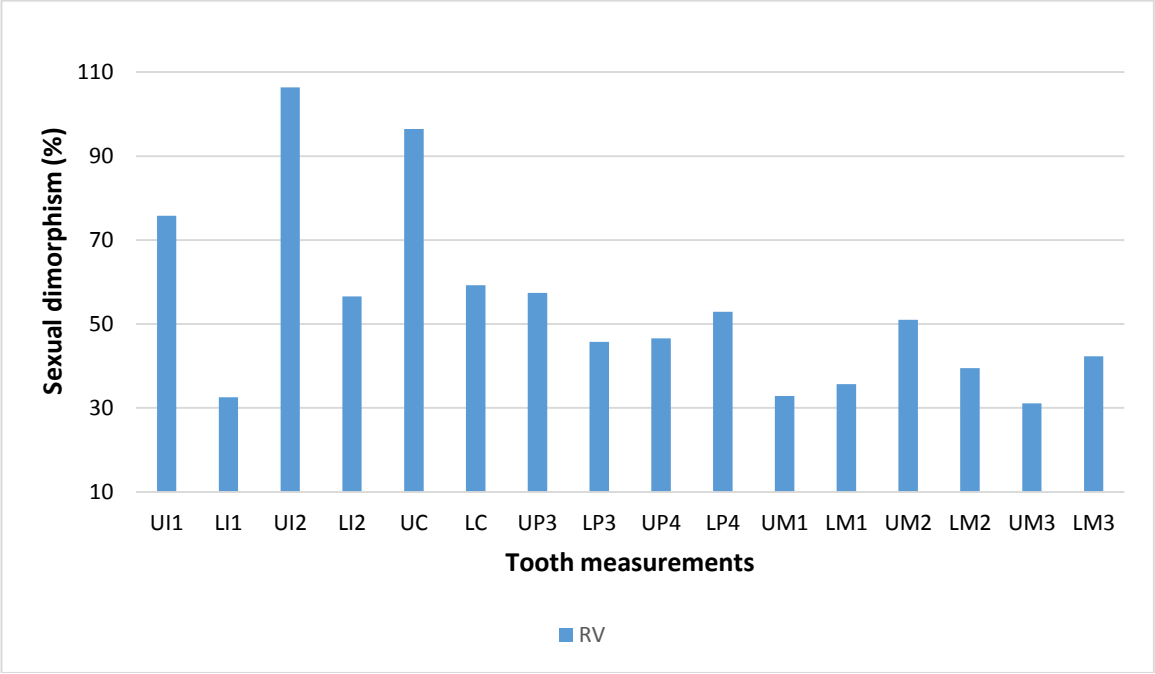

Fig. 6.8. Percentage of sexual dimorphism in maxillary and mandibular teeth: RV measurements.

6.4.3.7. The Pearson Correlation Coefficient

The present study used the Pearson correlation coefficient to analyse the relationship between 2D cervical and RV measurements. Table 6.25 shows the coefficient and the *p-value* for each tooth measurement. The results show that all positively correlated variables with a correlation above 0.40 are significant ($p < 0.05$), and those above 0.50 are highly significant ($p < 0.01$). These results are in accordance with those reported for crown and root length measurements (Garn et al., 1978; Harris and Couch, 2006).

The scatterplots (Figs 6.8, 6.9) also suggest a positive correlation between both MD and RV measurements and BL and RV measurements, with the larger values of MD and BL tending to be related to the larger values of RV measurements. The correlation between cervical MD and RV measurements ranged from 0.44 to 0.82; with the 95% confidence interval ranging from 0.11 to 0.91. The correlation between cervical BL and RV measurements ranged from 0.43 to 0.76; with the 95% confidence interval ranging from 0.10 to 0.88 (Table 6.25). The weakest correlation was observed between the BL measurement of UP4 and its RV measurement, and also between the MD measurement of LM1 and its RV measurement (Table 6.25). The strongest correlation was observed between the MD measurement of UC and its RV measurement, followed by the MD measurement of LI2 and its RV measurement (Table 6.25). The regression analysis also showed a significant linear relationship between 2D MD and BL cervical and RV measurements. The R^2 values indicated that 75% and 66% of the RV measurements were predictable from 2D MD and 2D BL cervical measurements, respectively (Fig. 6.9).

It is normally preferable to find axes of variation that are statistically independent. In this way, the sexual dimorphism that some tooth dimensions exhibit is not duplicative of that of other dimensions. A greater statistical power to discriminate between the sexes based on multiple tooth dimensions could be provided by using separate "axes" of variation. Taking into account the consistently positive results, the high correlations shown in Table 6.25 generally imply the presence of effectively only a single statistical, and inferentially biological, axis of sexual dimorphism. In order to

determine the most significant variable contributing to sex estimation, stepwise discriminant function analysis was carried out between the 2D cervical and RV measurements. The results of the stepwise analysis (Table 6.25) show that the RV measurements that were variable made the most significant contribution to discrimination.

Table 6.25: Matrix of Pearson correlation coefficient between 2D cervical and RV measurements for all teeth: original and bootstrap samples

Toot		Original sample				Bootstrap sample					
	N*	Coefficient		*p-value*		Confidence limits (95%)				Bias	
		MD	BL	MD	BL	MD		BL		MD	BL
						Lower	Uppe	Lower	Upper		
LI1	23	0.62	0.56	0.00	0.00	0.39	0.82	0.21	0.80	0.00	0.00
LI2	23	0.78	0.69	0.00	0.00	0.57	0.91	0.45	0.87	0.00	0.00
UC	30	0.82	0.71	0.00	0.00	0.72	0.91	0.53	0.85	0.00	0.00
LC	29	0.70	0.72	0.00	0.00	0.48	0.88	0.50	0.86	0.00	0.00
UP3	30	0.71	0.67	0.00	0.00	0.49	0.87	0.50	0.80	0.00	0.00
LP3	33	0.70	0.65	0.00	0.00	0.48	0.85	0.39	0.82	0.00	0.00
UP4	27	0.52	0.43[a]	0.00	0.03	0.19	0.80	0.10	0.67	0.00	0.00
LP4	30	0.66	0.64	0.00	0.00	0.48	0.82	0.38	0.82	0.00	0.00
UM1	25	0.66	0.72	0.00	0.00	0.35	0.86	0.52	0.88	0.00	0.00
LM1	26	0.44[a]	0.67	0.02	0.00	0.11	0.69	0.47	0.85	0.00	0.00
UM2	27	0.72	0.76	0.00	0.00	0.54	0.87	0.61	0.88	0.00	0.00
LM2	30	0.71	0.74	0.00	0.00	0.44	0.85	0.55	0.87	0.00	0.00

*Pearson coefficient test was performed for samples > 20

[a] Correlation is significant at $p > 0.05$, all others at $p > 0.001$

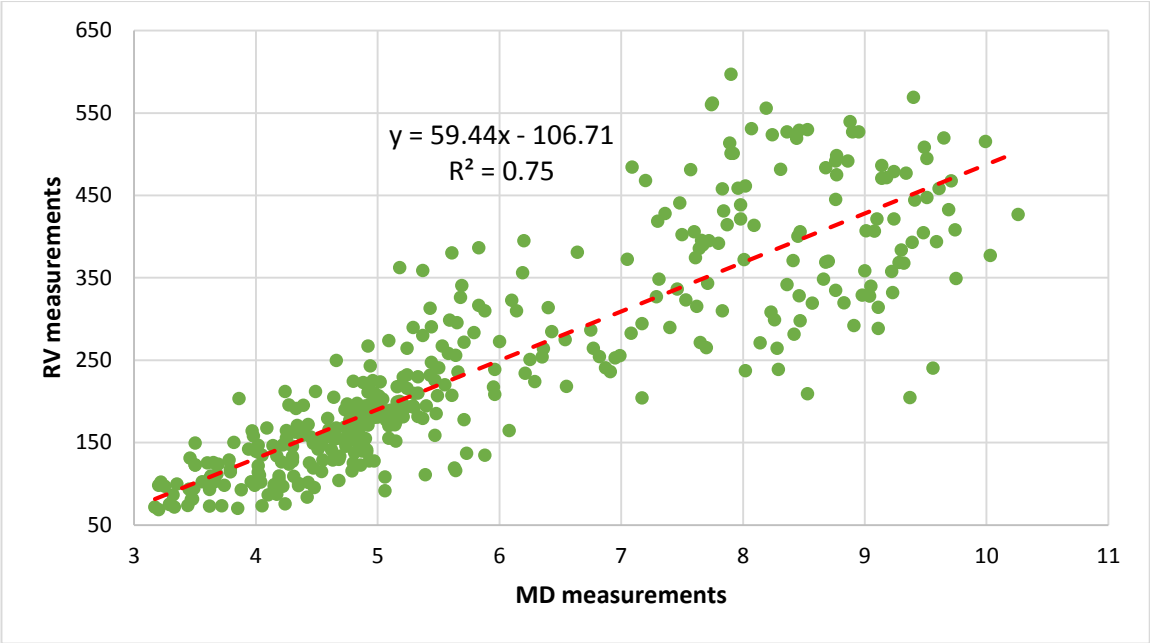

Fig. 6.9. Scatterplot suggesting a positive linear relationship between MD and RV measurements. The linear regression line, its equation, and R^2 value are shown. The regression analysis shows that 75% of RV measurements can be predicted from the 2D MD cervical measurements ($R^2 = 0.75$).

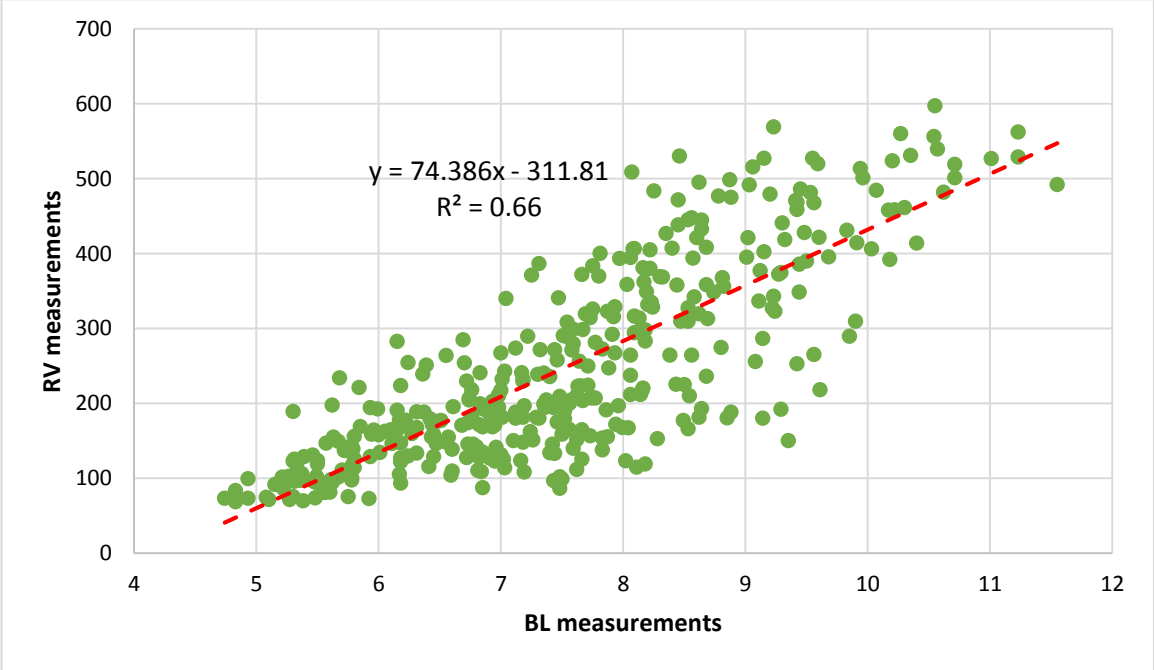

Fig. 6.10. Scatterplot suggesting a positive linear relation between BL and RV measurements. The linear regression line, its equation, and R^2 value are shown. The regression analysis shows that 66% of RV measurements can be predicted from 2D BL cervical measurements ($R^2 = 0.75$).

Pearson correlation results and scatter plots also showed a very high positive correlation between 2D and 3D MD and BL cervical measurements (Table 6.26, Fig 6.11, 6.12). The correlation between MD measurements ranged from 0.92 to 0.99; with 95% confidence interval ranging from 0.84 to 1.00. The correlation between BL measurements also ranged from 0.92 to 0.99; with the 95% confidence interval ranging from 0.81 to 1.00.

The regression analysis also showed a perfect linear relationship between 2D and 3D cervical measurements. The R^2 values of 1 and 0.99 for MD and BL measurements showed that 100% and 99% of the 3D MD and BL measurements could be predicted from the 2D MD and BL measurements, respectively (Fig. 6.8).

Table 6.26. Matrix of Pearson correlation coefficient between 2D cervical and 3D cervical measurements for all teeth: original and bootstrap samples.

Toot		Original sample				Bootstrap sample					
	N*	Coefficient		*p-value***		Confidence limits (95%)				Bias	
		MD	BL	MD	BL	MD		BL		MD	BL
						Lower	Uppe	Lower	Upper		
UI1	21	0.97	0.98	0.00	0.00	0.94	0.99	0.95	0.99	0.00	0.00
LI1	23	0.92	0.92	0.00	0.00	0.85	0.97	0.86	0.96	0.00	0.00
UI2	20	0.94	0.96	0.00	0.00	084	0.99	0.93	098	0.00	0.00
LI2	24	0.96	0.92	0.00	0.00	0.92	0.98	0.81	0.97	0.00	0.00
UC	33	0.98	0.98	0.00	0.00	0.97	0.99	0.97	0.99	0.00	0.00
LC	30	0.96	0.98	0.00	0.00	0.92	0.98	0.97	0.99	0.00	0.00
UP3	30	0.96	0.99	0.00	0.00	0.93	0.98	0.97	0.99	0.00	0.00
LP3	34	0.95	0.96	0.00	0.00	0.90	0.98	0.92	0.98	0.00	0.00
UP4	29	0.95	0.99	0.00	0.00	0.90	0.97	0.98	1.00	0.00	0.00
LP4	32	0.95	0.97	0.00	0.00	0.91	0.98	0.94	0.99	0.00	0.00
UM1	25	0.96	0.98	0.00	0.00	0.93	0.98	0.96	0.99	0.00	0.00
LM1	28	0.96	0.98	0.00	0.00	0.92	0.98	0.94	0.99	0.00	0.00
UM2	28	0.99	0.99	0.00	0.00	0.97	0.99	0.97	1.00	0.00	0.00
LM2	35	0.98	0.98	0.00	0.00	0.97	0.99	0.96	0.99	0.00	0.00
LM3	21	0.99	0.98	0.00	0.00	0.97	1.00	0.96	0.99	0.00	0.00

*Pearson coefficient test was performed for samples > 20.
** Correlation is significant at $p > 0.01$ for all measurements.

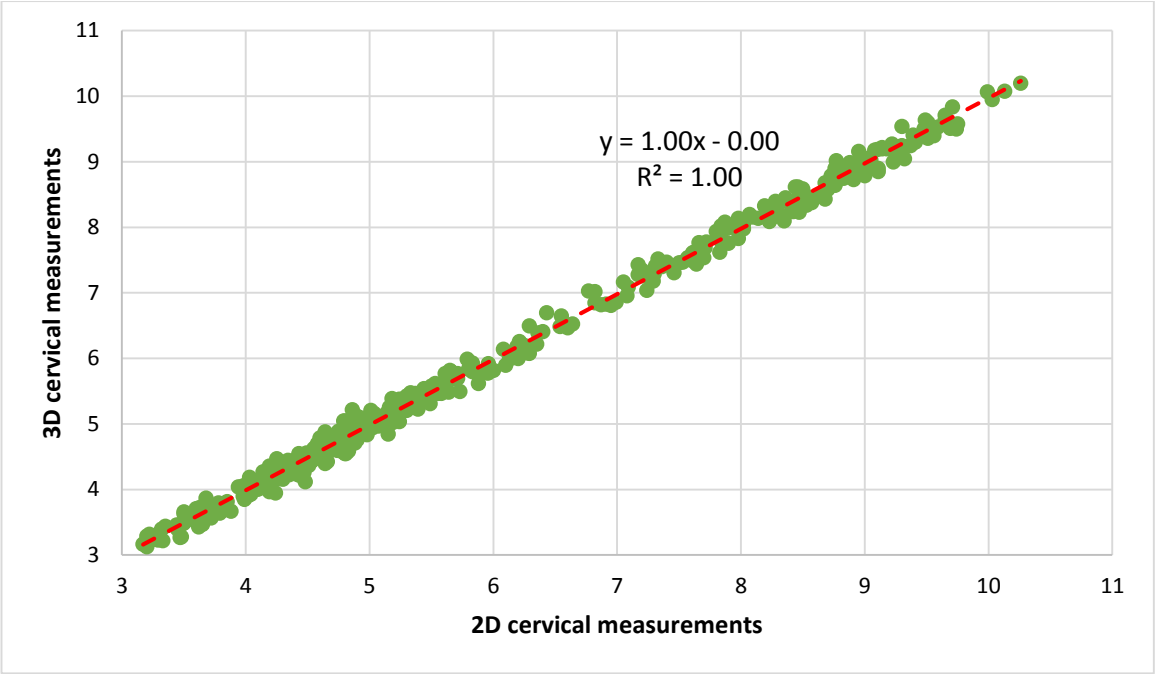

Fig. 6.11. Scatterplot suggesting a very high positive linear relation between 2D and 3D cervical MD measurements. The linear regression line, its equation, and R^2 value are shown. The regression analysis shows that 100% of the 3D MD measurements can be predicted from 2D MD cervical measurements ($R^2 = 1.00$).

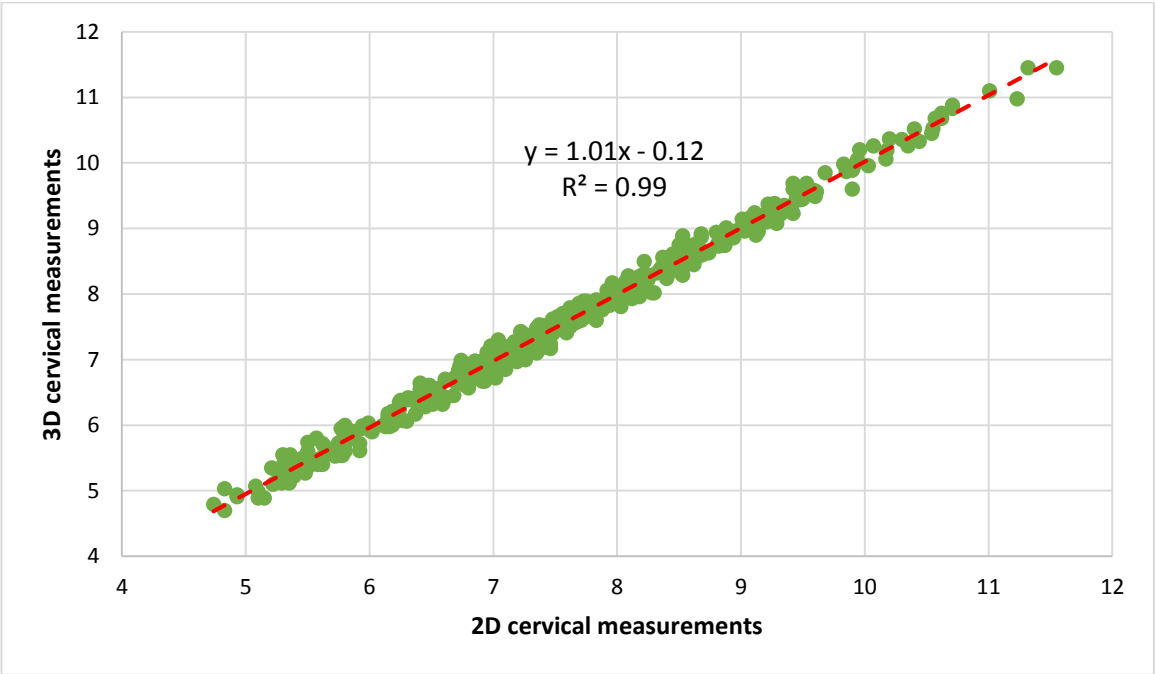

Fig. 6.12. Scatterplot suggesting a very high positive linear relation between 2D and 3D cervical BL measurements. The linear regression line, its equation, and R^2 value are shown. The regression analysis shows that 99% of the 3D BL measurements can be predicted from 2D BL cervical measurements ($R^2 = 0.99$).

6.4.3.8. Discriminant Function Analysis

Direct and stepwise discriminant function analysis was used to assess the applicability of 2D cervical, 3D cervical and RV measurements in sex estimation, and also to create population-specific functions. The analysis was also carried out separately for each measurement (univariate discriminant function analysis), so that the applicability of the technique is increased where dentition is not well preserved. Measurements that showed no significant differences between males and females, including UM3 for both 2D and 3D cervical measurements and LM3 for 3D cervical measurements, were removed from the discriminant function analysis, as they did not improve the discrimination power of the analysis. UM3 RV measurements were also removed from the discriminant function analysis due to the very small sample size and their high degree of variation in size.

6.4.3.8.1. Direct Discriminant Analysis

Direct discriminant analysis was performed separately for each tooth using 2D and 3D cervical MD and BL measurements. Tables 6.27 and 6.28 show the tooth variables, Wilks's lambda, *F*-value, degree of freedom (df), and unstandardized coefficient for each function. Wilks's lambda indicates which variable contribute significantly to discriminant analysis and determines the order in which the variables entered the analysis. Wilks's lambda ranges from the values 0 to 1, and the closer the Wilks's lambda value is to 0, the contribution of the variable is more to the discriminant function. The *F*-value gives an indication of the contribution of variables entered in the equation to separate sexes (Mukhopadhyay, 2009). Degree of freedom (df) is "the number of independent pieces of information that go into the estimate of a parameter" (Cardinal and Aitken, 2006, p. 416). Unstandardized coefficient is used to calculate the discriminant score which is assigned to each sex. The scores vary from one case to another, determined by the single variable or the combination of variables in the function. Group centroids are the mean discriminant scores for each sex, and can be used to calculate the degree of separation between males and females. A sectioning point is the average of two group centroids and separates the two sexes. The sex of an

individual can be estimated by multiplying the tooth measurement with its respective unstandardized coefficient and adding it to the constant. In the present study, the sectioning point was set to zero for all the functions, therefore if the value obtained is greater than the sectioning point of zero, the individual is considered male, and if less than zero, the individual is considered female (Klepinger, 2006). Depending on how close the individual is to the sectioning point and which information the centroids provide, the reliability of sex assessment is determined. In the classification function, it is more likely for the male group to have positive scores and the female group to have negative scores (see Tables 6.27, 6.28). The discriminant function thus shows that when tooth dimension increases (above the mean) it means that the individual will most probably get a positive score, and therefore will fit the male group pattern. On the contrary, when tooth dimension decreases (below the mean), it indicates the female group. Therefore, the closer the dimension value is to one of the centroids, the greater the reliability of the sex assignment. The probability of correct classification of an individual is lower when the dimension value is close to the sectioning point, because it is an area in which the two groups overlap.

F 1 to 15 (Table 6.27) demonstrate the results of direct discriminant function analysis using 2D cervical measurements of each tooth separately, and F 16 to 29 demonstrate the results of 3D cervical measurements (Table 6.28). Classification accuracy of each function for 2D and 3D cervical measurements is presented in Table 6.29.

Table 6.27. Direct discriminant function analysis of 2D cervical MD and BL measurements of all teeth

Variables [a]	Wilks's lambda *	*F* [b]	df	Unstandardized coefficient
F1: UI1				
MD	0.80	12.25[c]	1,50	0.82
BL	0.65	27.14	1,50	2.33
Constant				−19.74
F2: LI1				
MD	0.62	45.43	1,73	4.2
BL	0.74	26.17	1,73	0.99
Constant				−20.21
F3: UI2				
MD	0.78	14.91	1,53	0.95
BL	0.69	23.66	1,53	1.99
Constant				−15.84
F4: LI2				
MD	0.66	46.18	1,89	2.91
BL	0.77	26.47	1,89	1.54
Constant				−20.51
F5: UC				
MD	0.52	75.45	1,81	1.88
BL	0.58	59.26	1,81	0.95
Constant				−17.93
F6: LC				
MD	0.57	74.08	1,99	1.69
BL	0.62	60.91	1,99	0.86
Constant				−15.42
F7: UP3				
MD	0.66	44.87	1,85	3.05
BL	0.86	13.46	1,85	−0.04
Constant				−13.57
F8: LP3				
MD	0.61	68.53	1,108	2.89
BL	0.71	43.26	1,108	0.45
Constant				−16.74
F9: UP4				
MD	0.67	39.39	1,81	2.44
BL	0.77	24.81	1,81	0.46
Constant				−15.2
F10: LP4				
MD	0.70	43.69	1,101	2.37
BL	0.81	23.04	1,101	0.56
Constant				−15.86
F11: UM1				
MD	0.71	33.83	1,81	1.32
BL	0.68	38.94	1,81	1.32
Constant				−23.27

Continued

Table 6.27 continued

Variables [a]	Wilks's lambda *	*F* [b]	df	Unstandardized coefficient
F12: LM1				
MD	0.76	28.99	1,93	0.96
BL	0.71	37.28	1,93	1.29
Constant				−19.79
F13: UM2				
MD	0.59	54.76	1,80	0.96
BL	0.56	62.11	1,80	1.05
Constant				−17.61
F14: LM2				
MD	0.64	59.35	1,104	0.99
BL	0.61	65.46	1,104	1.15
Constant				−18.33
F15: LM3 [d]				
MD	0.87	10.05	1,66	0.54
BL	0.74	23.16	1,66	1.69
Constant				−18.12

*Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove
[a] The sectioning point for all the functions is zero
[b] *F* values statistically significant at $p \leq 0.000$
[c] *F* value statistically significant at $p \leq 0.001$
[d] UM3 was excluded from the discriminant function analysis

Table 6.28. Direct discriminant function analysis of 3D cervical MD and BL measurements of all teeth

Variables [a]	Wilks's lambda* *	*F* [b]	df	Unstandardized coefficient
F16: UI1				
MD	0.62	12.17[c]	1,20	0.85
BL	0.43	26.04	1,20	2.4
Constant				−20.45
F17: LI1				
MD	0.30	58.87	1,25	7.71
BL	0.53	21.86	1,25	−0.15
Constant				−26.3
F18: UI2				
MD	0.29	49.13	1,20	2.76
BL	0.49	21.11	1,20	1.33
Constant				−20.15
F19: LI2				
MD	0.42	32.58	1,24	1.68
BL	0.37	41.18	1,24	3.16
Constant				−24.62
F20: UC				
MD	0.27	88.39	1,33	2.97
BL	0.47	37.07	1,33	0.63
Constant				−20.94
F21: LC				
MD	0.30	66.04	1,28	2.5
BL	0.40	41.9	1,28	0.67
Constant				−17.8
F22: UP3				
MD	0.37	55.18	1,33	3.25
BL	0.68	15.8	1,33	0.4
Constant				−18.02
F23: LP3				
MD	0.44	41.43	1,32	2.51
BL	0.52	29.47	1,32	1.4
Constant				−21.06
F24: UP4				
MD	0.49	30.28	1,29	2.73
BL	0.57	21.94	1,29	0.75
Constant				−18.41
F25: LP4				
MD	0.54	24.88	1,29	2.72
BL	0.81	6.97[d]	1,29	0.26
Constant				−15.3
F26: UM1				
MD	0.38	44.92	1,28	3.16
BL	0.64	16.01	1,28	0.53
Constant				−29.68
F27: LM1				
MD	0.66	14.19[e]	1,28	1.14
BL	0.59	19.77	1,28	1.77
Constant				−25.21

Continued

Table 6.28 continued

Variables [a]	Wilks's lambda* *	*F* [b]	df	Unstandardized coefficient
F28: UM2				
MD	0.60	18.33	1,28	0.77
BL	0.53	24.67	1,28	1.26
Constant				−18.46
F29: LM2[f]				
MD	0.56	26.63	1,34	1.33
BL	0.61	22.15	1,34	0.95
Constant				−19.57

*Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove
[a] The sectioning point for all the functions is zero
[b] *F* values statistically significant at $p \leq 0.000$ for all variables
[c] *F* value statistically significant at $p \leq 0.002$, [d] $p \leq 0.013$, [e] $p \leq 0.001$
[f] UM3 and LM3 were excluded from the discriminant function analysis

As can be seen in Table 6.29, accuracy ranges from 80% to 94.1% in males, and 58.3% to 81.8% in females, and total classification accuracy ranges from 75.9% to 87.9% for 2D cervical measurements. The best classification accuracy was achieved with F4 (87.9%) and F6 (86.1%), which used MD and BL measurements of LI2 and LC respectively. LI2 (F4: 87.9%) provided the highest accuracy among anterior teeth, while LM2 (F14: 83%) provided the highest accuracy rate among posterior teeth. In all functions the accuracy in males was significantly greater than in females. Canines and M2 also showed a very high percentage of sexual dimorphism, and significant differences between male and female measurements (Tables 6.21, 6.23).

3D cervical measurements provided significantly better sex classification percentages, particularly in females. For these measurements, accuracy ranges from 81.3% to 100% in males, and 71.4% to 100% in females, and total classification accuracy ranges from 82.4% to 100%. The functions with the highest classification accuracy were F18 (100%) and F20 (97.1%), which used the 3D cervical MD and BL measurements of UI2 and UC, respectively (Table 6.29). These two teeth also showed the highest sexual dimorphism percentages among all teeth (Table 6.22). In both 2D and 3D cervical measurements I2 and canines achieved the highest accuracy rates, however for 2D cervical measurements the mandibular teeth were used in the analysis, and in the 3D cervical measurements the maxillary teeth were used. UI2 (F18: 100%) achieved the

best classification results among anterior teeth and UM1 (F26: 93.3%) achieved the best classification results among posterior teeth. In contrast to the 2D cervical measurements, in most 3D cervical functions the accuracy in females was greater than in males (Table 6.29).

Table 6.29: Classification accuracy of original and cross validated samples: 2D and 3D cervical measurements – direct discriminant analysis

Functions	Predicted Group Membership						N
	2D cervical measurements						
	Original %			Cross-validated %			
	Male	Female	Total	Male	Female	Total	
F1:UI1	80	72.7	76.9	80	72.7	76.9	52
F2:LI1	89.6	77.8	85.3	89.6	77.8	85.3	75
F3:UI2	94.1	66.7	83.6	91.2	66.7	81.8	55
F4:LI2	91.5	81.3	87.9	91.5	78.1	86.8	91
F5:UC	88	81.8	85.5	88	81.8	85.5	83
F6:LC	90.9	77.1	86.1	90.9	77.1	86.1	101
F7:UP3	82.7	65.7	75.9	82.7	62.9	74.7	87
F8:LP3	83.8	69	78.2	83.8	69	78.2	110
F9:UP4	81.6	70.6	77.1	81.6	67.6	75.9	83
F10:LP4	86.6	63.9	78.6	86.6	61.1	77.7	103
F11:UM1	86	72.7	80.7	84	69.7	78.3	83
F12:LM1	87.1	60.6	77.9	87.1	60.6	77.9	95
F13UM2	86.5	76.7	82.9	86.5	73.3	81.7	82
F14:LM2	86.8	76.3	83	86.8	73.7	82.1	106
F15:LM3	86.4	58.3	76.5	84.1	54.2	73.5	68
	3D cervical measurements						
F16:UI1	100	71.4	90.9	93.3	71.4	86.4	22
F17:LI1	86.7	100	92.6	86.7	100	92.6	27
F18:UI2	100	100	100	100	100	100	22
F19:LI2	86.7	100	92.3	86.7	100	92.3	26
F20:UC	95	100	97.1	95	100	97.1	35
F21:LC	94.7	100	96.7	94.7	100	96.7	30
F22:UP3	85.7	92.9	88.6	85.7	92.9	88.6	35
F23:LP3	85	78.6	82.4	85	78.6	82.4	34
F24:UP4	81.3	86.7	83.9	81.3	86.7	83.9	31
F25:LP4	90	72.7	83.9	85	72.7	80.6	31
F26:UM1	88.2	100	93.3	88.2	100	93.3	30
F27:LM1	82.4	84.6	83.3	82.4	76.9	80	30
F28:UM2	90.5	88.9	90	90.5	88.9	90	30
F29:LM2	85.7	86.7	86.1	85.7	80	83.3	36

Cross-validation classification rates were close to the original accuracy in all cases for both 2D and 3D cervical measurements (Table 6.29). The bootstrap sample (n = 1,000) provided results similar to the original sample for 2D cervical measurements and very

close to the original sample for 3D cervical measurements (see Table 10, Appendix A).

6.4.3.8.2. Stepwise Discriminant Analysis

After the direct discriminant function analysis, a stepwise analysis was performed to determine which variables best discriminated between males and females. Different combinations of variables were used for each set of measurements.

F 30 to 38 (Table 6.30) demonstrate the results of stepwise discriminant function analysis using 2D cervical measurements. As mentioned above, UM3 was removed from the discriminant analysis and LM3 was also excluded from F34 and F38 to increase the sample size. F 30-34 show the results of stepwise discriminant analysis using the cervical measurements of each tooth type separately. UC and LC were also added to F 35-38 to determine if the accuracy rate would increase (Table 6.30).

Table 6.30. Stepwise discriminant function analysis of 2D cervical MD and BL measurements of all teeth

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F30: Incisors				
MDLI2	0.53	22.05	1,25	5.25
BLLI2	0.25	36.74	2,24	2.97
BLUI1	0.19	32.10	3,23	1.75
Constant				−49.04
F31: Canines				
MDUC	0.48	67.47	1,63	1.9
BLUC	0.45	51.70	2,62	0.85
Constant				−17.26
F32: Premolars				
MDUP3	0.65	26.92	1,50	3.13
Constant				−14.25
F33: Molars [c]				
MDUM2	0.69	15.42	1,34	1.69
Constant				−12.61
F34: Molars – LM3[c]				
MDUM2	0.64	27.29	1,49	1.20
BLUM1	0.55	19.92	2,48	1.29
Constant				−22

Continued

Table 6.30 continued

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F35: Incisors + Canines				
MDLI2	0.25	28.50	2,19	3.98
BLLC	0.18	28.13	3,18	2.14
BLUI1	0.14	36.09	3,18	2.05
Constant				−44.29
F36: Premolars + Canines				
MDUC	0.56	27.30	1,35	1.68
MDUP3	0.50	16.86	2,34	1.81
Constant				−17.88
F37: Molars [c] + Canines				
MDUC	0.58	17.94	1,25	2.60
Constant				−14.9
F38: Molars – LM3 + Canines				
MDUC	0.52	32.67	1,36	2.82
Constant				−16.20

*Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove
[a] The sectioning point for all the functions is zero
[b] *F* values statistically significant at $p \leq 0.000$ for all variables
[c] UM3 was excluded from the discriminant function analysis

Classification accuracy of stepwise discriminant functions for 2D cervical measurements is presented in Table 6.31. Accuracy ranges from 79.3% to 100% in males and 45.4% to 100% in females, and the total accuracy rate ranges from 75-100%. Similar to the direct discriminant analysis, in all functions accuracy was greater in males than in females. The best classification accuracy (100%) was achieved with F30 and F35, which used the anterior teeth. The combination of maxillary and mandibular molars (excluding M3) with maxillary and mandibular canines (F38) gave the next best classification (92.1%), followed by maxillary and mandibular canines (F31: 87.7%). The canines, which showed the highest percentage of sexual dimorphism (Table 6.24), were added to F 35 to 38. Classification accuracy significantly improved in all functions, particularly in F37 (Table 6.31). Mandibular M3 was removed from the analysis, which increased the sample size to 51 and 38, and the classification accuracy to 82.4% and 92.1% for F 34 and 38, respectively. As can be seen in Table 6.30, UC figured in 3 of the 4 functions combined with canines. Of these 3, 2 of them utilised MDUC measurements alone (F37, F38), and in the other function (F36), MDUC entered into the analysis first.

Cross-validation accuracy was not significantly different from the original accuracy (Table 6.31). The bootstrap sample (n = 1,000) also provided results similar to the original sample.

F 39 to 48 (Table 6.32) demonstrate the results of stepwise discriminant function analysis using 3D cervical measurements. As mentioned above, M3 was removed from the sex estimation analysis. F 39 to 44 show the results of stepwise discriminant analysis using the cervical measurements of each tooth type separately. The variables were selected based on tooth type and their position in the dental arcade (maxillary/mandibular). As mentioned above, discriminant analysis was performed for samples larger than 20 individuals, therefore it was not possible to use a combination of maxillary and mandibular teeth of every tooth type for sex estimation, as was done in the 3D measurements. In addition, due to a larger sample size, only UC was added to F 45 to 48 to determine if the accuracy rate would increase (Table 6.32).

Table 6.31: Classification accuracy of original and cross validated samples: 2D cervical, 3D cervical, and RV measurements – stepwise discriminant analysis

Functions	Predicted Group Membership						N
	2D cervical measurements						
	Original %			Cross-validated %			
	Male	Female	Total	Male	Female	Total	
F30: Incisors	100	100	100	100	100	100	27
F31: Canines	92.5	80	87.7	90	76.9	84.6	65
F32: Premolars	79.3	69.6	75	79.3	69.6	75	52
F33: Molars	88	45.4	75	88	45.5	75	36
F34: Molars – LM3	85.3	76.5	82.4	85.3	76.5	82.4	51
F35: Incisors + Canines	100	100	100	100	100	100	22
F36: Premolars + Canines	87.5	76.9	83.8	83.3	76.9	81.1	37
F37: Molars + Canines	95	71.4	88.9	95	71.4	88.9	27
F38 :Molars – LM3 + Canines	96.4	80	92.1	96.4	80	92.1	38
	3D cervical measurements						
F39: L Incisors	100	100	100	100	100	100	23
F40: Canines	100	100	100	100	100	100	20
F41: U Premolars	100	100	100	100	100	100	23
F42: L Premolars	88.2	72.7	82.1	88.2	72.7	82.1	28
F43: U Molars	92.3	100	95.2	92.3	100	95.2	21
F44: L Molars	86.7	76.9	82.1	80	76.9	78.6	28
F45: U Premolars + U Canine	100	100	100	100	100	100	21
F46: L Premolars + U Canines	91.7	100	95	91.7	100	95	20
F47: U Molars + U Canine	100	100	100	100	100	100	20
F48: L Molars + U Canine	90.9	90	90.5	81.8	90	85.7	21
	RV measurements						
F49: L Incisors	100	90	96.3	100	90	96.3	27
F50: Canines	100	100	100	100	100	100	24
F51: All Premolars	100	100	100	100	100	100	22
F52: U Premolars	94.1	93.3	93.8	94.1	93.3	93.8	32
F53: L Premolars	95	80	90	95	80	90	30
F54: U Molars	100	87.5	95.7	100	87.5	95.7	23
F55: L Molars	94.7	81.8	90	94.7	81.8	90	30
F56: L Incisors + U Canine	100	100	100	100	100	100	22
F57: U Premolars + U Canine	93.3	100	96.6	93.3	100	96.6	29
F58: L Premolars + U Canine	100	100	100	100	100	100	21
F59: U Molars + U Canine	100	100	100	100	100	100	22
F60: L Molars + U Canine	100	100	100	100	100	100	22

Classification accuracy of stepwise discriminant functions for 3D cervical measurements is presented in Table 6.31. Accuracy ranges from 88.2% to 100% in males and 72.7% to 100% in females, and the total accuracy rate ranges from 82.1% to 100%. F 39-41, 45 and 47 display the highest overall accuracy rate (100%) for both original and cross-validated data. The next best classification accuracy was achieved with F43 (95.2%) and F46 (95%), which used a combination of maxillary and mandibular M1 and M2, and a combination of LP3, LP4 and UC for sex estimation, respectively. Similar to the 2D cervical measurements, adding UC to F 45-48 significantly improved the classification accuracy, particularly for F46 (Table 5.31). Similar to the 2D cervical measurements, UC was also entered in all these functions (Table 6.32). In general, half of the functions provided an accuracy rate of 100%, for both original and cross-validated data, in 3 of which UC was used. Except for the functions with 100% total accuracy rates, males provided greater accuracy rates in 3 functions (42, 44, 48), while females provided greater accuracy rates (100%) in 2 functions (46, 43) (Table 6.31).

Cross-validation accuracy was not significantly different from the original accuracy (Table 6.31). The bootstrap sample (n = 1,000) also provided results similar to the original sample.

Table 6.32. Stepwise discriminant function analysis of 3D cervical MD and BL measurements of all teeth

Variables [a]	Wilks's lambda* *	*F* [b]	Df	Unstandardized coefficient
F39: L Incisors				
MDLI1	0.43	28.33	1,21	5.29
MDLI2	0.21	38.48	2,20	3.36
Constant				−31.43
F40: Canines				
MDLC	0.21	68.71	1,18	2.50
MDUC	0.17	56.58	2.17	1.80
Constant				−22.84
F41: U Premolars				
MDUP3	0.25	62.85	1,21	4.70
Constant				−21.70
F42: L Premolars				
MDLP3	0.43	34.98	1,26	3.37
Constant				−15.92
F43: U Molars [c]				
MDUM1	0.34	36.74	1,19	4.17
Constant				−32.90
F44: L Molars [d]				
MDLM2	0.47	29.56	1,26	2.10
Constant				−18.58
F45: U Premolars + U Canine				
MDUP3	0.26	53.72	1,19	2.81
MDUC	0.19	38.45	2,18	2.21
Constant				−25.14
F46: L Premolars + U Canine				
MDUC	0.23	59.93	1,18	2.80
MDLP3	0.19	22.47	2,17	1.62
Constant				−22.88
F47: U Molars [c] + U Canines				
MDUC	0.32	37.74	1,18	2.35
MDUM1	0.26	24.48	2,17	2.14
Constant				−30.24
F48: L Molars [d] + U Canine				
MDUC	0.26	55.43	1,19	3.37
Constant				−18.23

*Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove

[a] The sectioning point for all the functions is zero

[b] *F* values statistically significant at $p \leq 0.000$ for all variables

[c] UM3 was excluded from the discriminant function analysis

[d] LM3 was excluded from discriminant function analysis

F 49 to 60 (Table 6.33) demonstrate the results of the stepwise discriminant function analysis using RV measurements. As mentioned above, UM3 was removed from the sex estimation analysis due to the small number of data. F 49-55 show the results of the stepwise discriminant analysis using the RV measurements of each tooth type. Due to the larger number of UC in comparison with LC, UC was added to functions 56-60 to examine whether classification accuracy would increase (Table 6.32).

Table 6.31 shows the classification accuracy of all functions. Accuracy ranges from 93.3% to 100% in males and 80% to 100% in females, and the total accuracy rate ranges from 90-100%. All of the stepwise discriminant functions provided classification accuracy of over 90%, with an accuracy rate of 100% for half of the functions (F 50, 51, 56, 58-60). The combination of UP3 and UP4 with the UC (F57) gave the next best classification (96.6%), followed by the LI1 and LI2 (F49: 96.3%). By adding the UC to F 56 to 60, classification accuracy was significantly improved and all of the functions provided an accuracy rate of 100%, except F57 (96.6%) (Table 6.31). In most functions, accuracy in males was greater than in females. As can be seen in Table 6.33, UC figured in all of the five functions combined with the canine. Of these five, four of them used the RV measurement of UC alone (F57-60) and in the other function, combined with mandibular incisors (F56), UC entered into the analysis first. The same results were observed in the stepwise discriminant function analysis of 2D and 3D cervical measurements. It shows that the canine, especially the UC, is the tooth with the greatest degree of sexual dimorphism.

Cross validation accuracy was close to the original classification accuracy in all cases (Table 6.31). The bootstrap sample (n = 1,000) also provided results similar to the original sample.

Table 6.33. Stepwise discriminant function analysis of RV measurements of all teeth

Variables [a]	Wilks's lambda*	*F* [b]	Df	Unstandardized coefficient
F49: L Incisors				
LI2	0.22	88.64	1,25	0.07
Constant				−9.34
F50: Canines				
UC	0.11	177.85	1,22	0.04
Constant				−8.50
F51: All Premolars				
UP3	0.22	69.55	1,20	0.03
UP4	0.17	59.27	2,19	0.03
Constant				−9.19
F52: U Premolars				
UP4	0.30	68.77	1,30	0.03
UP3	0.32	43.13	2,29	0.02
Constant				−8.15
F53: L				
LP3	0.29	71.45	1,29	0.06
Constant				−9.27
F54: U Molars [c]				
UM2	0.29	51.37	1,21	0.02
Constant				−7.41
F55: L Molars				
LM1	0.32	59.11	1,28	0.02
Constant				−10.00
F56: L Incisors				
UC	0.12	146.17	1,20	0.02
LI2	0.09	97.67	2,19	0.05
Constant				−11.53
F57: U				
UC	0.14	170.61	1,27	0.03
Constant				−7.54
F58: L				
UC	0.07	249.03	1,19	0.04
Constant				−9.82
F59: U Molars [c]				
UC	0.20	81.56	1,20	0.03
Constant				−6.61
F60: L Molars +				
UC	0.09	200.48	1,20	0.04
Constant				−9.04

* Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove

[a] The sectioning point for all functions is zero

[b] *F* values statistically significant at $p \leq 0.000$ for all variables

[c] UM3 was excluded from the discriminant function analysis

As mentioned above, stepwise discriminant analysis was carried out using a combination of 2D cervical and RV measurements to determine the most significant variable in sex estimation, and also to examine whether this would improve classification accuracy. The RV measurements of each tooth were added to the 2D cervical measurements of the same tooth, and were used for sex estimation. Due to the small sample size as well as their high degree of variation in size, M3 was excluded from the analysis. Since the analysis was performed only for samples with more than 20 individuals, maxillary incisors were removed from the analysis. F 61 to 72 demonstrate the results of the stepwise discriminant function analysis using a combination of 2D cervical and RV measurements for each tooth (Table 6.34).

Table 6.34. Stepwise discriminant function analysis of 2D cervical and RV measurements combined

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F61: LI1				
RV	0.34	40.53	1,21	0.09
MD	0.20	39.00	2,20	7.47
BL	0.14	39.30	3,19	−3.61
Constant				−15.7
F62: LI2				
RV	0.18	94.49	1,21	0.07
Constant				−9.09
F63: UC				
RV	0.19	122	1,28	0.03
Constant				−6.41
F64: LC				
RV	0.36	48.65	1,27	0.03
Constant				−6.25
F65: UP3				
RV	0.33	57.25	1,28	0.03
MD	0.28	34.00	2,27	1.43
Constant				−11.36
F66: LP3				
RV	0.25	92.27	1,31	0.08
BL	0.21	57.52	2,30	−1.39
Constant				−2.78
F67: UP4				
RV	0.34	49.44	1,25	0.04
BL	0.27	33.05	2,24	0.91
Constant				−13.49

Continued

Table 6.34 continued

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F68: LP4				
RV	0.36	49.96	1,28	0.04
Constant				−6.86
F69: UM1				
RV	0.41	33.29	1,23	0.02
Constant				−7.66
F70: LM1				
RV	0.25	71.23	1,24	0.03
Constant				−10.79
F71: UM2				
RV	0.37	42.47	1,25	0.02
Constant				−6.4
F72: LM2				
RV	0.37	46.82	1,28	0.02
Constant				−7.3

* Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove
[a] The sectioning point for all functions is zero
[b] *F* values statistically significant at $p \leq 0.000$ for all variables

Table 6.35 shows the classification accuracy of all functions. Accuracy ranged from 88.9% to 100% in males and 63.6% to 100% in females, and the total accuracy rate ranges from 83.3% to 100%. The best classification accuracy (100%) was achieved with F61, which used a combination of 2D cervical and RV measurements of LI1. UC (F63) with 96.7% accuracy rate provided the next best classification, followed by LI2 (F62). The variables used for this stepwise analysis were similar to those used for 2D cervical direct discriminant analysis. As can be seen in Tables 6.29 and 6.35, classification accuracy was significantly improved by adding the RV measurement to the 2D cervical measurement of each tooth. In all 11 functions, RV measurement entered first. Of these 11, 8 of them utilised RV alone for sex estimation (Table 6.34). It shows that RV measurements are very useful for sex estimation and improve classification accuracy. In most functions accuracy in males was greater than in females, similar to the results obtained from 2D cervical and RV measurements.

Cross validation accuracy was close to the original classification accuracy in all cases (Table 6.35). The bootstrap sample (n = 1,000) also provided results similar to the original sample.

Table 6.35: Classification accuracy of original and cross validated samples: 2D cervical and RV measurements combined – stepwise discriminant analysis

Functions	Predicted Group Membership						N
	Original %			Cross-validated %			
	Male	Female	Total	Male	Female	Total	
F61: LI1	100	100	100	100	100	100	23
F62: LI2	100	88.9	95.7	100	88.9	95.7	23
F63: UC	93.8	100	96.7	93.8	100	96.7	30
F64: LC	88.9	90.9	89.7	88.9	90.9	89.7	29
F65: UP3	100	84.6	93.3	100	84.6	93.3	30
F66: LP3	95	92.3	93.9	95	92.3	93.9	33
F67: UP4	92.3	92.9	92.6	92.3	92.9	92.6	27
F68: LP4	94.7	63.6	83.3	94.7	63.6	83.3	30
F69: UM1	92.9	81.8	88	92.9	81.8	88	25
F70: LM1	100	100	100	100	100	100	26
F71: UM2	94.1	80	88.9	88.2	80	85.2	27
F72: LM2	94.1	76.9	86.7	94.1	76.9	86.7	30

6.4.3.8.3. Univariate Discriminant Analysis

Univariate discriminant function analysis was performed for each tooth and measurement separately. As mentioned above, UM3 was removed from the analysis for 2D cervical, 3D cervical and RV measurements. In addition, the 3D MDLM3, which showed no significant differences between the sexes, was also removed from the analysis.

F 73 to 102 demonstrate the results of univariate discriminant function analysis using 2D MD and BL measurements (Table 6.36), F 103 to 131 demonstrate the results of 3D cervical MD and BL measurements (Table 6.38), and finally F132 to 142 demonstrate the results of stepwise discriminant function analysis using RV measurements (Table 6.40).

Classification accuracy of univariate discriminant functions for 2D cervical measurements is presented in Table 6.37. Accuracy ranges from 76.9% to 94.1% in males and 41.7% to 78.1% in females, and the total accuracy rate ranges from 70.7% to 86.8%. Only 11 functions out of 29 used function provided accuracy rate ≥ 80%. The best classification accuracy (86.8%) was achieved with F76, which used the MDLI2 measurement. MDLI1 (F74) gave the next best classification (84%), followed

by MDLC (F78: 83.3%). MDLI2 (F76: 86.8%) provided the highest classification accuracy among anterior teeth, while BLLM3 (F102: 80.9%) provided the highest classification accuracy among posterior teeth. In all functions, accuracy was significantly greater in males than in females. MD measurements provided higher accuracy rates in 24 of the functions. As can be seen in Table 6.37, BL measurements provided better classification results for all molar teeth except for UM1. In general, classification accuracy was higher when both MD and BL variables were used together (Tables 6.29 and 6.37).

Table 6.36. Univariate discriminant function analysis of 2D cervical measurements

Variables [a]	Wilks's lambda*	*F* [b]	Df	Unstandardized coefficient
MD				
F73: UI1	0.80	12.25	1,50	2.06
Constant				−12.88
F74: LI1	0.62	45.43	1,73	5.26
Constant				−18.45
F75: UI2	0.78	14.91	1,53	2.47
Constant				−11.88
F76: LI2	0.66	46.18	1,89	3.79
Constant				−14.71
F77: UC	0.51	79.23	1,82	2.75
Constant				−15.38
F78: LC	0.56	77.96	1,100	−1.18
Constant				0.65
F79: UP3	0.66	44.87	1,85	3.01
Constant				−13.74
F80: LP3	0.61	69.06	1,109	3.42
Constant				−16.25
F81: UP4	0.67	39.39	1,81	3.03
Constant				−14.23
F82: LP4	0.70	44.86	1,102	2.93
Constant				−14.68
F83: UM1	0.70	35.14	1,82	2.77
Constant				−21.36
F84: LM1	0.76	28.99	1,93	2.07
Constant				−18.44

Continued

Table 6.36 continued

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F85: UM2	0.59	54.76	1,80	1.83
Constant				−13.78
F86: LM2	0.66	54.51	1,105	1.76
Constant				−15.62
F87: LM3 [c]	0.87	10.05	1,66	1.16
Constant				−10.12
BL				
F88: UI1	0.65	27.14	1,50	2.86
Constant				−17.9
F89: LI1	0.74	26.17	1,73	3.13
Constant				−17.27
F90: UI2	0.69	23.66	1,53	2.62
Constant				−14.89
F91: LI2	0.77	26.47	1,89	3.15
Constant				−18.88
F92: UC	0.58	59.26	1,81	2.09
Constant				−16.36
F93: LC	0.62	60.91	1,99	2.05
Constant				−15.28
F94: UP3	0.86	13.46	1,85	1.84
Constant				−14.59
F95: LP3	0.71	43.26	1,108	2.21
Constant				−14.74
F96: UP4	0.77	24.81	1,81	1.67
Constant				−13.62
F97: LP4	0.81	23.04	1,101	1.73
Constant				−12.36
F98: UM1	0.68	38.94	1,81	2.07
Constant				−20.59
F99: LM1	0.71	39.29	1,94	1.89
Constant				−16.49
F100: UM2	0.56	62.11	1,80	1.67
Constant				−16.48
F101: LM2	0.61	65.46	1,104	1.83
Constant				−15.19
F102: LM3	0.76	13.16	1,66	2.06
Constant				−16.4

* Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove

[a] The sectioning point for all the functions is zero

[b] *F* values statistically significant at $p \leq 0.000$ for all variables

[c] UM3 was excluded from the discriminant function analysis

Table 6.37: Classification accuracy of original and cross validated samples: univariate discriminant analysis of 2D cervical measurements

Functions	Predicted Group Membership						N
	Original %			Cross-validated %			
MD	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	
F73: UI1	83.3	50	69.2	83.3	50	69.2	52
F74: LI1	89.6	74.1	84	89.6	74.1	84	75
F75: UI2	94.1	61.9	81.8	91.2	61.9	80	55
F76: LI2	91.5	78.1	86.8	91.5	78.1	86.8	91
F77: UC	84	76.5	81	84	76.5	81	84
F78: LC	87.9	75	83.3	87.9	75	83.3	102
F79: UP3	82.7	62.9	74.7	82.7	62.9	74.7	87
F80: LP3	84.1	73.8	80.2	84.1	69	78.4	111
F81: UP4	79.6	70.6	75.9	79.6	70.6	75.9	83
F82: LP4	89.7	55.6	77.9	89.7	55.6	77.9	104
F83: UM1	86.3	63.6	77.4	86.3	63.6	77.4	84
F84: LM1	87.1	57.6	76.8	87.1	57.6	76.8	95
F85: UM2	84.6	66.7	78	84.6	66.7	78	82
F86: LM2	88.4	63.2	79.4	88.4	63.2	79.4	107
F87: LM3	93.2	54.2	79.4	93.2	54.2	79.4	68
BL							
F88: UI1	93.2	54.2	79.4	93.2	54.2	79.4	68
F89: LI1	90.9	62.5	80.9	90.9	62.5	80.9	68
F90: UI2	88.2	66.7	80	88.2	66.7	80	55
F91: LI2	89.8	59.4	79.1	89.8	59.4	79.1	91
F92: UC	80	75.8	78.3	80	75.8	78.3	83
F93: LC	87.9	65.7	80.2	87.9	65.7	80.2	101
F94: UP3	76.9	48.6	65.5	76.9	48.6	65.5	87
F95: LP3	83.8	54.8	72.7	82.4	54.8	71.8	110
F96: UP4	79.6	58.8	71.1	79.6	58.8	71.1	83
F97: LP4	88.1	41.7	71.8	86.6	41.7	70.9	103
F98: UM1	82	60.6	73.5	82	60.6	73.5	83
F99: LM1	91.9	55.9	79.2	91.9	55.9	79.2	96
F100: UM2	82.7	76.7	80.5	82.7	76.7	80.5	82
F101: LM2	89.7	73.7	84	89.7	73.7	84	106
F102: LM3	90.9	62.5	80.9	90.9	62.5	80.9	68

Table 6.38. Univariate discriminant function analysis of 3D cervical measurements

Variables [a]	Wilks's lambda*	F [b]	df	Unstandardized coefficient
MD				
F103: UI1	0.62	12.17	1,20	2.18
Constant				−13.72
F104: LI1	0.30	58.87	1,25	7.53
Constant				−26.46
F105: UI2	0.29	49.13	1,20	3.35
Constant				−15.54
F106: LI2	0.42	32.58	1,24	4.02
Constant				−15.35
F107: UC	0.27	88.39	1,33	3.5
Constant				−19.04
F108: LC	0.30	66.04	1,28	3.22
Constant				−16.7
F109: UP3	0.37	55.18	1,33	3.58
Constant				−16.39
F110: LP3	0.44	41.43	1,32	3.53
Constant				−16.72
F111: UP4	0.49	30.28	1,29	3.83
Constant				−17.47
F112: LP4	0.81	28.68	1,30	2.91
Constant				−14.36
F113: UM1	0.38	45.16	1,28	3.67
Constant				−28.57
F114: LM1	0.66	14.19	1,28	2.29
Constant				−20.18
F115: UM2	0.60	18.33	1,28	1.87
Constant				−14.39
F116: LM2	0.56	26.63	1,34	2
Constant				−17.75
BL				
F117: UI1	0.43	26.04	1,20	2.96
Constant				−18.61
F118: LI1	0.53	21.86	1,25	3.8
Constant				−20.37
F119: UI2	0.49	20.46	1,20	3.41
Constant				−18.9
F120: LI2	0.37	41.18	1,24	4.6
Constant				−26.47
F121: UC	0.47	37.07	1,33	2.17
Constant				−16.34
F122: LC	0.40	41.9	1,28	2.05
Constant				−14.7
F123: UP3	0.68	15.8	1,33	1.9
Constant				−14.92
F124: LP3	0.52	29.47	1,32	2.95
Constant				−19.41
F125: UP4	0.57	21.94	1,29	1.78
Constant				−14.12

Continued

Table 6.38 continued

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F126: LP4	0.81	6.97	1,29	1.1
Constant				−14.17
F127: UM1	0.64	16	1,28	2.05
Constant				−20.09
F128: LM1	0.59	19.77	1,28	2.5
Constant				−21.46
F129: UM2	0.53	24.67	1,28	1.77
Constant				−17.71
F130: LM2	0.61	22.15	1,34	2.17
Constant				−17.82
F131: LM3	0.72	7.72	1,20	2.49
Constant				−19.72

* Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove
[a] The sectioning point for all the functions is zero
[b] *F* values statistically significant at $p \leq 0.000$ for all variables

Classification accuracy of univariate discriminant functions for 3D cervical measurements is presented in Table 6.39. Classification accuracy ranges from 75% to 100% in males and 54.5% to 100% in females, and the total accuracy rate ranges from 77.4% to 95.5%. In general, 3D cervical measurements provided better classification accuracy rates compared to 2D cervical measurements. 24 functions out of the 28 used provided an accuracy rate ≥ 80%. MDUM1 (F123: 96.7%) displayed the highest overall accuracy. MDUI2 provided the next best classification accuracy (F107: 95.5%), followed by MDUC (F111: 94.3%). MDUI2 (F107: 95.5%) showed the greatest classification accuracy among anterior teeth, while MDUM1 (F123: 96.7%) showed the greatest classification accuracy among posterior teeth. Males showed greater classification accuracy in a majority of functions (n = 19). Similar to the 2D cervical measurements, the highest accuracy rates were provided by MD measurements, however all molar teeth (except for UM1) showed higher accuracy rates in BL measurements. In general, classification accuracy was relatively higher when both MD and BL variables were used together (Tables 6.29 and 6.39). The bootstrap sample (n = 1,000) provided results very close to the original sample for both 3D mesiodistal and buccolingual measurements (Table 11 and 12, Appendix A).

Table 6.39: Classification accuracy of original and cross validated samples: univariate discriminant analysis of 3D cervical measurements

Functions	Predicted Group Membership						N
	Original %			Cross-validated %			
MD	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	
F103: UI1	86.7	71.4	81.8	86.7	71.4	81.8	22
F104: LI1	86.7	100	92.6	86.7	100	92.6	27
F105: UI2	100	87.5	95.5	100	87.5	95.5	22
F106: LI2	86.7	100	92.3	86.7	100	92.3	26
F107: UC	95	93.3	94.3	95	93.3	94.3	35
F108: LC	94.7	90	93.3	89.5	90.9	90	30
F109: UP3	85.7	92.9	88.6	85.7	92.9	88.6	35
F110: LP3	85	92.9	88.2	85	85.7	85.3	34
F111: UP4	81.3	80	80.6	81.3	80	80.6	31
F112: LP4	90	75	84.4	90	75	84.4	32
F113: UM1	94.1	100	96.7	94.1	100	96.7	30
F114: LM1	82.4	69.2	76.7	82.4	69.2	76.7	30
F115: UM2	85.7	66.7	80	81	66.7	76.7	30
F116: LM2	85.7	66.7	77.8	85.7	66.7	77.8	36
BL							
F117: UI1	93.3	85.7	90.9	93.3	85.7	90.9	22
F118: LI1	86.7	91.7	88.9	86.7	91.7	88.9	27
F119: UI2	85.7	75	81.8	85.7	75	81.8	22
F120: LI2	80	100	88.5	80	100	88.5	26
F121: UC	85	73.3	80	85	73.3	80	35
F122: LC	89.5	90.9	90	89.5	90.9	90	30
F123: UP3	90.5	78.6	85.7	90.5	78.6	85.7	35
F124: LP3	85	71.4	79.4	85	71.4	79.4	34
F125: UP4	75	80	77.4	75	80	77.4	31
F126: LP4	90	54.5	77.4	90	54.5	77.4	31
F127: UM1	76.5	84.6	80	76.5	84.6	80	30
F128: LM1	88.2	76.9	83.3	88.2	76.9	83.3	30
F129: UM2	90.5	88.9	90	90.5	88.9	90	30
F130: LM2	81	80	80.6	81	80	80.6	36
F131: LM3	85.7	75	81.8	78.6	75	77.3	22

Table 6.40. Univariate discriminant function analysis of RV measurements

Variables [a]	Wilks's lambda*	*F* [b]	df	Unstandardized coefficient
F132: UI1	0.20	76.43	1,19	0.04
Constant				−8.04
F133: LI1	0.37	44.61	1,26	0.09
Constant				−8.90
F134: UI2	0.43	124.67	1,23	0.05
Constant				−7.76
F135: LI2	0.21	100.04	1,27	0.07
Constant				−9.15
F136: UC	0.17	166.43	1,33	0.03
Constant				−6.91
F137: LC	0.36	53.38	1,30	0.03
Constant				−6.17
F138: UP3	0.34	75.16	1,39	0.04
Constant				−6.40
F139: LP3	0.29	86.09	1,35	0.06
Constant				−8.64
F140: UP4	0.33	61.97	1,31	0.04
Constant				−7.30
F141: LP4	0.37	52.14	1,30	0.04
Constant				−6.85
F142: UM1	0.46	32.76	1,28	0.02
Constant				−7.78
F143: LM1	0.32	59.11	1,28	0.02
Constant				−10.00
F144: UM2	0.39	44.71	1,29	0.02
Constant				0.89
F145: LM2	0.45	41.33	1,34	0.02
Constant				−6.91
F146: LM3 [c]	0.44	28.54	1,22	0.02
Constant				−6.73

* Method: Wilks's lambda with F: 3.84 to enter and F: 2.71 to remove
[a] The sectioning point for all the functions is zero
[b] *F* values statistically significant at $p \leq 0.000$ for all variables
[c] UM3 was excluded from the discriminant function analysis

Classification accuracy of univariate discriminant functions for RV measurements is presented in Table 6.41. Classification accuracy ranges from 86.4% to 100% in males and 71.4% to 100% in females, and the total accuracy rate ranges from 86.4% to 100%. All of the functions provided an accuracy rate ≥ 80%. The best classification accuracy was obtained using RV measurements of UI2 (F134: 100%), followed by UC (F136) and LI2 (F135), with 97.1% and 96.6% classification accuracy, respectively. Among anterior teeth, UI2 (F134: 100%) achieved the highest accuracy rate, while among the posterior teeth UP4 (F138: 90.9) achieved the highest accuracy rate. MDUI2 (F107:

95.5%) showed the greatest classification accuracy among anterior teeth, while MDUM1 (F123: 96.7%) showed the greatest classification accuracy among posterior teeth. In most functions, males showed better classification accuracy (n = 14) than females (Table 6.41). In general, classification accuracy was significantly higher in RV measurements compared to cervical measurements.

Cross validation accuracy was close to the original classification accuracy in all cases (Tables 6.37, 6.39, and 6.41). The bootstrap sample (n = 1,000) also provided results similar to the original sample for 2D cervical and RV measurements.

Appendix C-B, compares the sex estimation results using morphological features of the skull and pelvis, with the sex estimation results using RV measurements. Due to the high number of equations used for each tooth and each individual, only the RV measurements, as the most effective parameter for sex estimation, are presented in Appendix C-B.

Table 6.41: Classification accuracy of original and cross validated samples: univariate discriminant analysis of RV measurements

Functions	Predicted Group Membership						N
	Original %			Cross-validated %			
MD	Male	Female	Total	Male	Female	Total	
F132: UI1	100	85.7	95.2	100	86.7	95.2	21
F133: LI1	100	72.7	89.3	100	72.7	89.3	28
F134: UI2	100	100	100	100	100	100	25
F135: LI2	100	90.9	96.6	100	90.9	96.6	29
F136: UC	94.7	100	97.1	94.7	100	97.1	35
F137: LC	90	91.7	90.6	90	91.7	90.6	32
F138: UP3	91.7	88.2	90.2	87.5	82.4	85.4	41
F139: LP3	90.9	86.7	89.2	90.9	86.7	89.2	37
F140: UP4	88.2	93.8	90.9	88.2	93.8	90.9	33
F141: LP4	95.2	63.6	84.4	95.2	63.6	84.4	32
F142: UM1	88.9	75	83.3	88.9	75	83.3	30
F143: LM1	94.7	81.8	90	94.7	81.8	90	30
F144: UM2	95	81.8	90.3	90	81.8	87.1	31
F145: LM2	86.4	71.4	80.6	86.4	71.4	80.6	36
F146: LM3	86.7	88.9	87.5	86.7	88.9	87.5	24

6.4.3.9. Posterior Probabilities

Figures 6.13-6.23 demonstrate the probability levels of correct group assessment according to the discriminant scores of each individual for each dimension. The applicability of discriminant functions increases if one includes the posterior probability of the discriminant scores that they produce in the analysis.

Posterior probability scores show the effectiveness of the classification of an individual that a function provides by demonstrating the probability of the association of the score with a correct classification. Due to the fact that, in this study, the selection point was set to zero for all functions, the value of the scores close to zero would prove to be small, because of the nearly 50% chance of the classification being wrong. Similarly, the scores that are farther from zero would therefore be associated with a more dependable estimate.

A discriminant subprogram of SPSS was used to produce the posterior probability values for each function. Then the cases that were misclassified were removed and the probabilities of correct classification were merged for both sexes. As a result of plotting the data using the Excel program for Windows, the following diagrams were produced. Graphs of the posterior probability for the discriminant scores of univariate and multivariate functions are presented in Figs 6.13-6.23 for each dimension separately. The x-axis shows discriminant score values and the y-axis indicates the probability of correct sex classification. For example, if a discriminant score based on the stepwise analysis of the RV measurement of the LI1 (F61) is 3.39 (x coordinate), the posterior probability of that individual coming from the male group is 100% (y coordinate) (Fig 6.22).

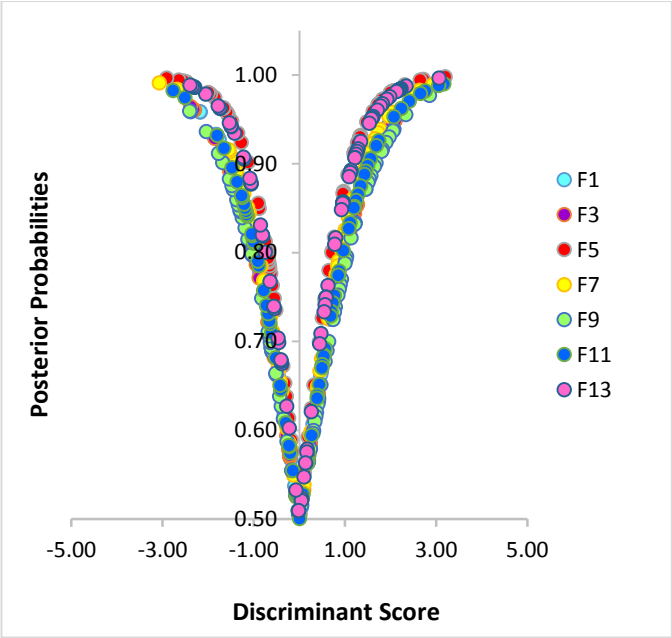

Fig 6.13. Probability levels of correct sexing for each individual, (2D maxillary teeth).

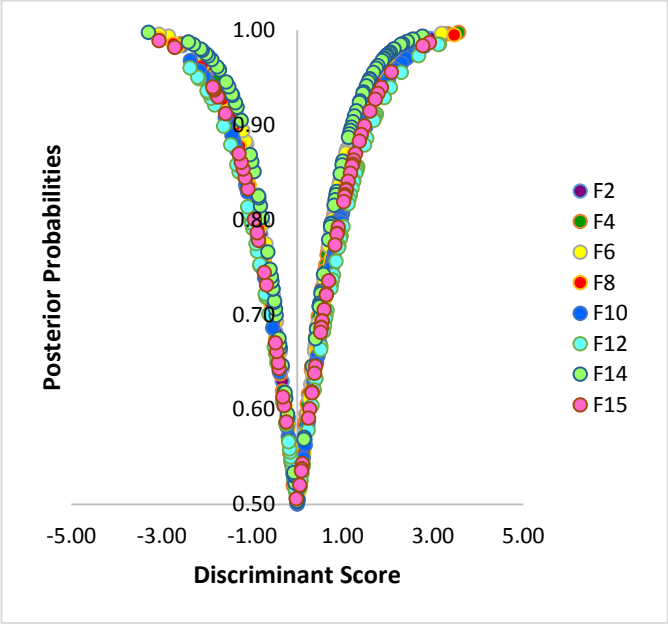

Fig 6.14. Probability levels of correct sexing for each individual, (2D mandibular teeth).

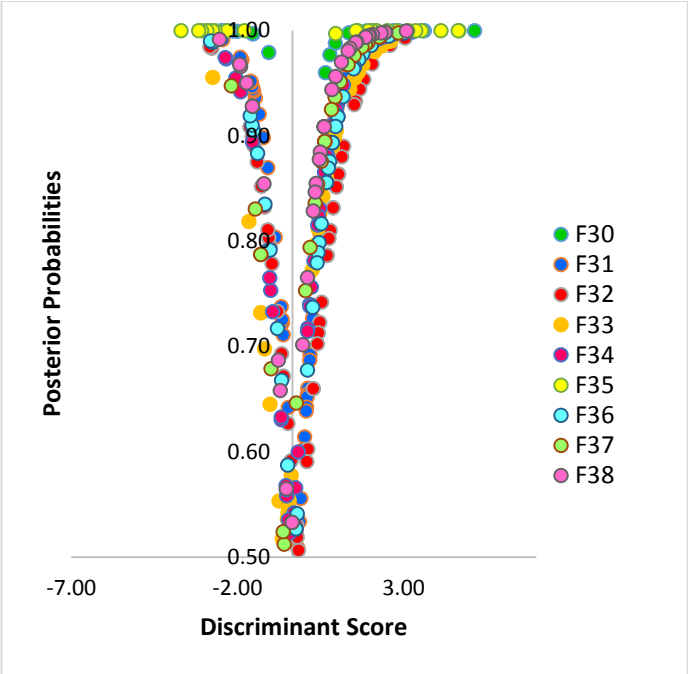

Fig 6.15. Probability levels of correct sexing for each individual (2D stepwise analysis).

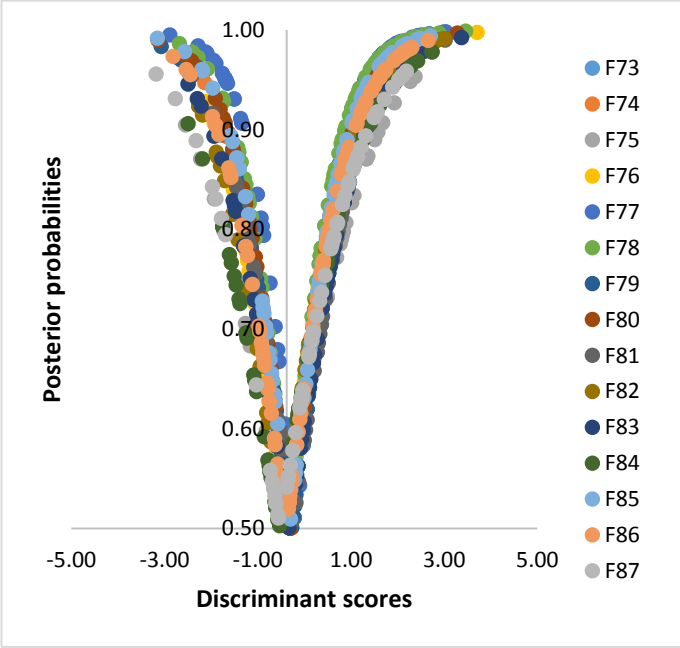

Fig 6.16. Probability levels of correct sexing for each individual - univariate analysis (2D MD measurements)

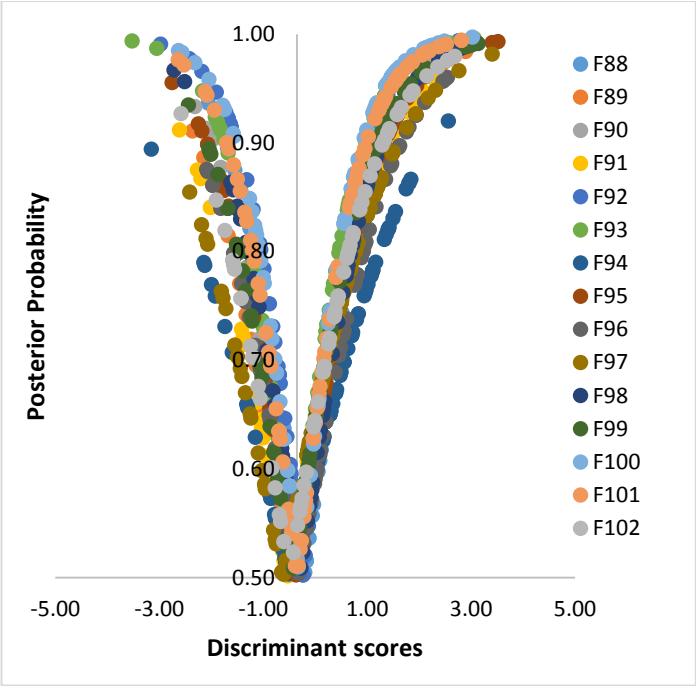

Fig 6.17. Probability levels of correct sexing for each individual - univariate analysis (2D BL measurements).

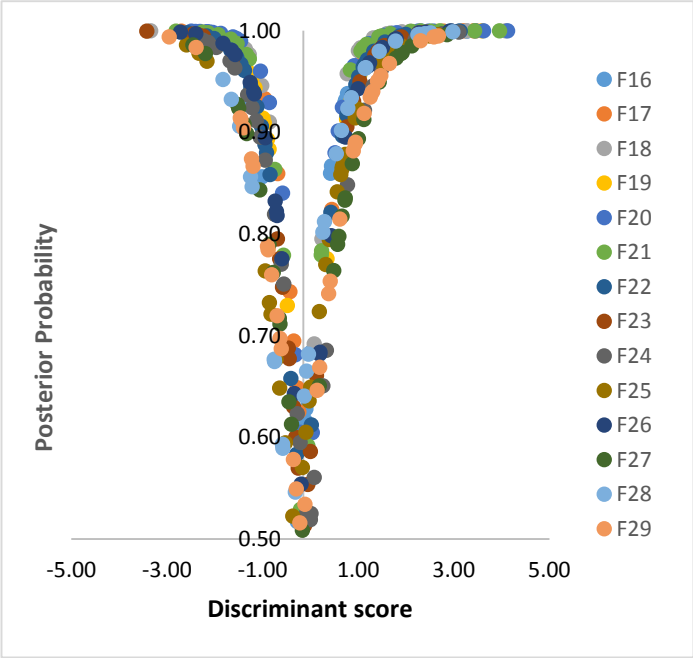

Fig 6.18. Probability levels of correct sexing for each individual – direct analysis (3D cervical measurements).

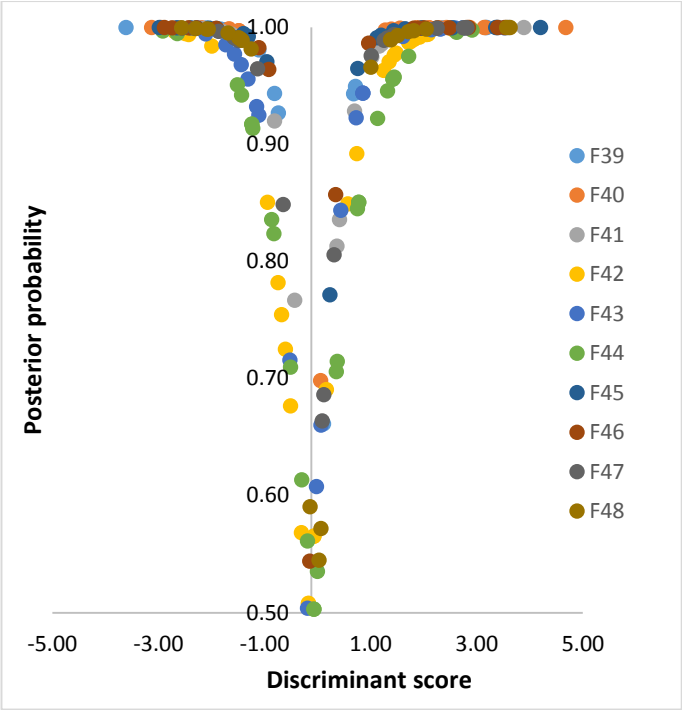

Fig 6.19. Probability levels of correct sexing for each individual – stepwise analysis (3D cervical measurements).

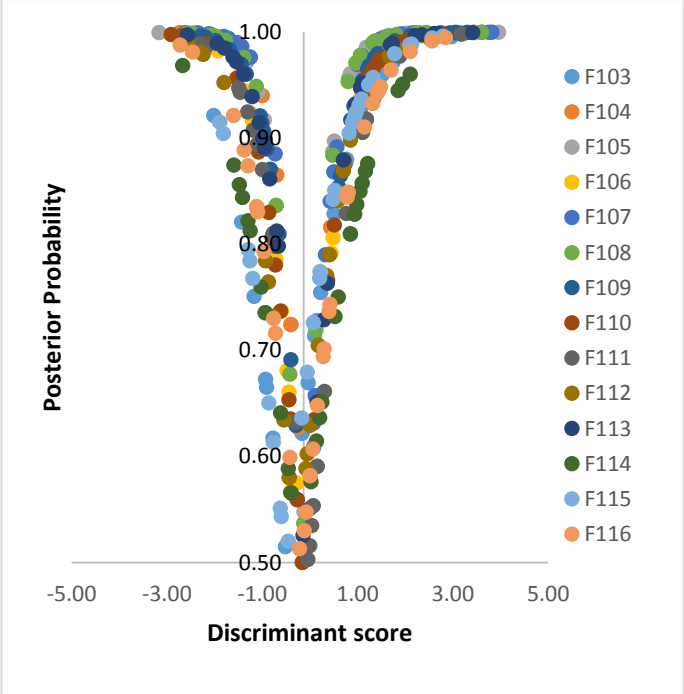

Fig 6.20. Probability levels of correct sexing for each individual – Univariate analysis (3D cervical MD measurement).

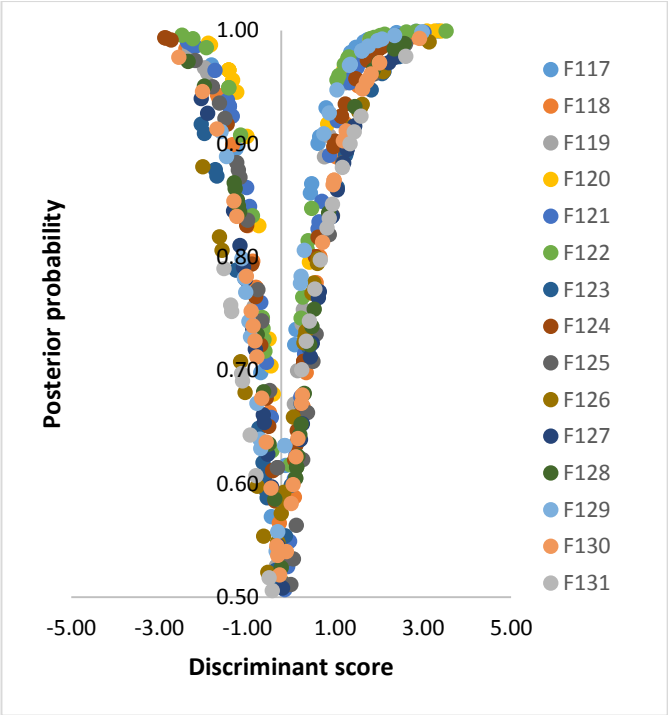

Fig 6.21. Probability levels of correct sexing for each individual – Univariate analysis (3D cervical BL measurement).

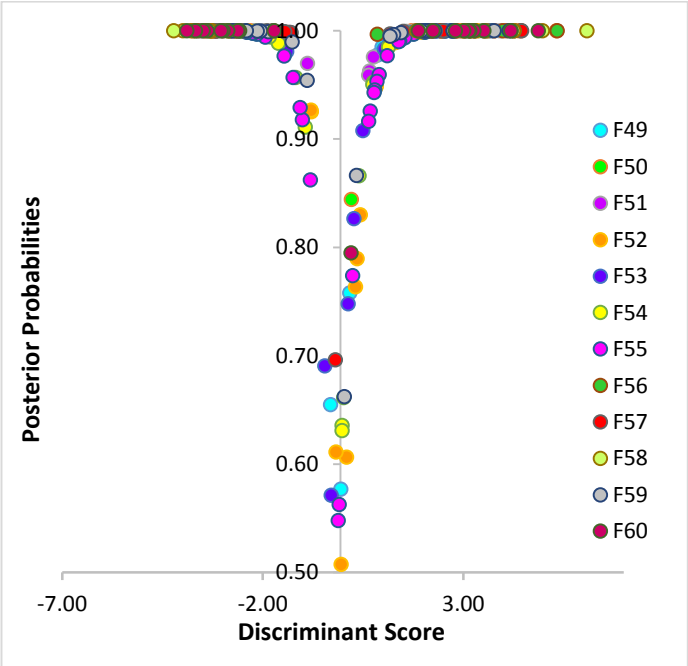

Fig 6.22. Probability levels of correct sexing for each individual (3D stepwise analysis).

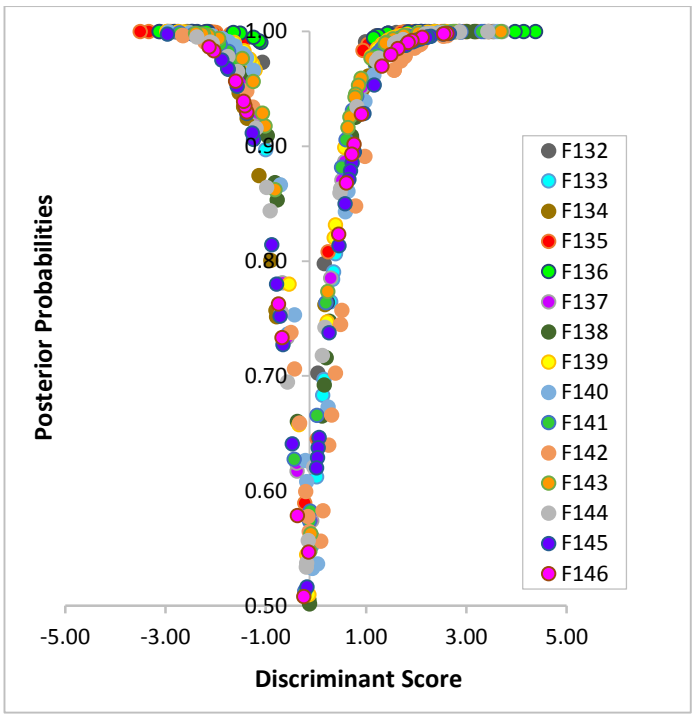

Fig 6.23. Probability levels of correct sexing for each individual – Univariate analysis (RV measurements).

CHAPTER 7 LIMITATIONS OF THE CURRENT STUDY

7.1. Introduction

Before and during the research a set of problems presented themselves to the researcher that imposed limitations on the knowledge that could be obtained from the study. It is important to emphasize the limitations of the study, particularly in regards to attempts at gaining access to the collection, collecting data from archaeological specimens that are usually incomplete compared to modern specimens, and in determining how representative the skeletons were of the overall population. Limitations of the current study, and how these were minimized or taken into account during the project, are outlined below.

7.2. Access to the Collections

One of the main problems that the researcher encountered at a very early stage of the research was access to the collection. As mentioned previously, the Hasanlu and Dinkha Tepe collections are housed at the University of Pennsylvania Museum of Archaeology and Anthropology (UPM) in the United States. To have access to the collection, it was therefore necessary for one researcher to travel to the United States, meaning she had to apply for a visa, a time-consuming and expensive process. In addition, it was not possible to stay more than three months in the United States due to their visa policies, not to mention high accommodation and living costs. As a result, the researcher had only a short time to collect all the available morphometric data for sex estimation, such as long bone measurements. As mentioned earlier, however, all the osteological sex estimation results obtained by the current study were compared with Selinsky's (2009) results, in which long bone measurements were also used for sex estimation.

Access to the CT scans of the skeletons created another problem. There were no CT scans available at UPM for loose teeth or for those in situ teeth with extremely fragmented maxillae and mandibles, which forced the researcher to use these only for

2D analysis and to exclude them from the 3D analysis. Moreover, the researcher was not provided with all the available CT scans, despite regular contact with ORSA. She therefore had access to CT scans of only 80 individuals, which limited the scope of the analysis. However, due to technical problems that occurred during the scanning process, 29 of the 80 CT scans could not be used for 3D analysis, which is much less than the number of samples used for 2D analysis.

7.3. Sample-Related Limitations

Based on existing osteoarchaeological studies of the Hasanlu skeletal collections, it was initially expected that the study would have 212 Iron Age individuals available for analysis at UPM. The current study confirmed the same number of skeletons; however, many of them were in a state that prevented the researcher from using them for analysis. Problems included poor preservation of the pelvis and skull, the absence of teeth in some of the individuals, and other tooth-related problems (mentioned in Chapter 5). In addition, 64 of the skeletons belonged to subadults, which were also excluded from the analysis. As a result, in total, 105 adult individuals from the Hasanlu collection were used for sex estimation analysis. Since the small sample size would limit the conclusions that could be drawn from the analysis, the researcher decided to increase the sample size by pooling another Iron Age population in close temporal and geographic proximity in the Solduz Valley. As discussed above, since Hasanlu is one of the few well-preserved Iranian collections, there was not a wide range of options available. The researcher, therefore, decided to expand the study to Dinkha Tepe, as the only available option, which increased the sample size to 143 individuals. In addition, bootstrapping was used to account for possible statistical biases which might have been caused by the small sample size.

Much of the Hasanlu Tepe remains are still unexcavated and remain for future generations to investigate. As a result, only a sample of the Hasanlu population was available for analysis, not a complete set of remains from the site. In addition, as mentioned earlier, the expression of sexual dimorphism in this study was calculated based on those individuals for which sex could be accurately estimated. This means

that the sample may not be totally representative of the population, which introduces a bias into the analysis. The researcher aims to further examine the proposed methods in other studies on larger archaeological collections from different periods and regions, to check the applicability of these methods in sex estimation in other populations.

As mentioned in previous chapters, there is also the possibility that skeletons of invaders may be mixed with those of locals in the Hasanlu Citadel (High Mound) sample. This might affect the results for sex estimation as a population-specific method. DNA analysis could be conducted to distinguish invaders from native inhabitants, but this was beyond the resources of the current study. However, other studies that have used craniofacial measurements (Dulik, 2005) and isotope analysis (Toebbe, 2005) to address this issue have demonstrated that none of the individuals were truly non-residents at Hasanlu. Dulik et al. (2011) extracted the DNA from six individuals, but unfortunately no aDNA was found in the samples analysed. Nevertheless, in the case of violent conflict, the possibility of the bodies of the invaders being mixed with the victims cannot be ruled out. As mentioned in Chapter 5, the current study used outlier detection to minimalize this limitation. In total, 15 outliers were detected among all three sets of measurements, nine of which were typographical errors or data entry errors. In addition, all the detected outliers were either MD or BL measurements of different teeth. In no cases were BL and MD measurements of the same tooth detected as outliers, not even of a single tooth from a single individual, and certainly not the whole dental set of an individual. Thus none of the individuals in the Hasanlu collection were found to have tooth diameters that fell outside the overall pattern of the rest of the data. The following chapter will provide a detailed analysis of the findings of this study.

CHAPTER 8 DISCUSSION

8.1. Introduction

Considering that odontometric methods for sex estimation are population-specific, different scholars have undertaken a variety of studies on tooth measurements in order to determine specific standards of group assessment for various populations (Bishara et al., 1986; Alt et al., 1998; İşcan and Kedici, 2003; Ateş et al., 2006; Acharya and Mainali, 2007; Hassett, 2011; Khamis et al., 2014). The present study is the first reference study for sex estimation using odontometric data in Iranian archaeological populations. From the results of this study, it is clear that dental metric standards can be effectively used to estimate sex in the Hasanlu and Dinkha Tepe populations. This has been achieved using three methods, each obtaining different degrees of reliability. Some of them were clearly more effective compared to others, due to providing better classification rates and offering fewer limitations. In order to be able to accurately interpret all the information obtained from this study, including which method is the most effective and reliable and the reasons why this is so, the data should be discussed at two levels: first, within the context of previous studies and research and, second, within a comparative context that shows which method is potentially the most useful and effective for sex estimation in this particular archaeological sample. The following will discuss the study's objectives with regards to these two levels.

8.2. Objective 1

As already mentioned, the main objective of this research was to develop odontometric standards for sex estimation in Iranian archaeological populations. Discriminant function analysis and a method that relies on previous sex assessment made from morphological features of the pelvis and skull were used to devise population-specific sex prediction equations based on 2D and 3D cervical, and RV measurements, using skeletal samples from the Hasanlu and Dinkha Tepe collections. However, one of the main drawbacks of such methods is that they tend to be population-specific, and standards from one population cannot be used for sex estimation in other populations.

When an odontometric method based on permanent dentition is applied to a population that differs significantly from the population whose metric data were used to develop the method, the discriminant function formulae developed give poor or biased results. For example, Peckman et al. (2015) used the modern Greek discriminant functions for sex estimation in African American populations. The sex classification accuracy results for males was between 93.6% and 100%, however for females it was extremely low, between 0% and 18%. Thus, for sex determination of archaeological skeletal remains using dimensions of permanent dentition, the best way to circumvent the problem of sample specificity is to use dental data from adult individuals whose sex estimates are based on well-established descriptive characteristics of the pelvis and/or the skull, because they provide a greater chance of accurately assessing sex (Viciano et al., 2011). The advantage of these data is that they can be used to develop the methodology for sex determination and then the sample-specific formulae can be applied to other adults without diagnostic elements like the skull and pelvis or whose skeletal morphology is 'intermediate'—i.e. in the same sample (Viciano et al., 2011). This study developed sex estimation discriminant functions for the Hasanlu and Dinkha Tepe collections which are presented in Appendix D. To determine the sex of an individual using the formulae presented here, the value of each dimension in a particular function is multiplied by its respective unstandardized coefficient, and the constant is added to the product. If the result thus obtained is greater than the sectioning point of zero (see chapter six) the individual is considered male; if the result is less, it is considered female. The following will discuss the applicability of these functions for sex estimation using 2D cervical, 3D cervical, and RV measurements in the Hasanlu and Dinkha Tepe collections.

8.3. Objective 2

To assess the applicability of 2D cervical measurements in sex estimation for the Hasanlu and Dinkha Tepe skeletal collections.

This study used 2D cervical MD and BL measurements for sex estimation. All the variables analysed here presented statistically significant differences between males

and females (P < 0.000), with the exception of the UM3 that were excluded from the analysis. A comparison between the two sexes showed that the classification accuracy of all functions was higher for males. This result is in agreement with other studies on cervical tooth measurements conducted on other populations (Vodanovic et al., 2007; Hassett, 2011; Viciano et al., 2011; 2015; Zorba et al., 2011; 2013; Mujib et al., 2014; Peckmann et al., 2015).

The greatest difference in percentage of sexual dimorphism (SD%) was observed in canine MD measurements. There is little comparative data against which the amount of sexual dimorphism in cervical measurements can be compared. Vodanovic et al. (2007) and Tuttösí and Cardoso (2015), however, do provide percentages of sexual dimorphism for cervical tooth measurements in other archaeological samples. Vodanovic et al. (2007), however, reported only the SD% for MD measurements of the UC and LM3. The SD% for UC MD measurement in the present study was 13.93%, which is similar to the Tuttösí and Cardoso (2015) study (13.83%) and about 4% higher compared to the Vodanovic et al. (2007) study (9.55%). The highest percentage of sexual dimorphism was observed in the LC. The SD% for this tooth was 14.99% (MD) and 12.16% (BL), which is significantly higher compared to the Tuttösí and Cardoso (2015) study (4.90% MD and 6.87% BL). In the latter study, the UI2 showed the highest percentage of sexual dimorphism, contradicting the present and other studies (Cardoso, 2008; Zorba et al., 2011). As discussed in chapter three, the high level of sexual dimorphism in canines can be associated with high rates of male violence and polygyny, which has evolutionary significance. For molar teeth, the M2 showed the highest percentage of sexual dimorphism, in accordance with the results of Tuttösí and Cardoso (2015), and also those of crown measurement studies (Cardoso, 2008; Garn et al., 1979; Zorba et al., 2011). Other studies on crown and diagonal measurements of molars, however, reported different results. For example, Prabhu and Acharya (2009) report the LM1 as the most sexually dimorphic tooth in Indian populations, while İşcan and Kedici (2003) observe the highest degree of sexual dimorphism in the UM1 of Turkish populations. A recent study by Peckmann et al. (2015) on African-American populations also reports the UM3 as the most sexually dimorphic tooth. These differences can be attributed to genetic and/or environmental

influences in the expression of the sexual dimorphism of human dentition (Dempsey and Townsend, 2001).

Discriminant function analysis for single tooth measurements also showed that the cervical measurements of the permanent canines and incisors were the most dimorphic, providing classification accuracy of between 76.9% and 87.9%. These results are in accordance with previous studies (Alt et al., 1998; Starp, 1990; Ellendt, 1993; Hassett, 2011; Viciano et al., 2011; 2013; 2015; Mujib et al., 2014). In addition, it was found that M2 dimensions can be a very effective single variable for sex estimation, with a classification accuracy of 83%. A similar result was achieved for a modern Greek population (Zorba et al., 2012), and several archaeological populations also reported a high percentage of correct classification for the second molar (Starp, 1990; Ellendt, 1993; Viciano et al., 2015; Tuttösí and Cardoso, 2015).

Furthermore, several different discriminant functions were created using different combinations of tooth dimensions. The best discriminant functions for sex classification used the maxillary and mandibular incisors, and a combination of maxillary and mandibular incisors and canines. The classification accuracy rates obtained were 100% for both original and cross-validated data; however, this observation was based on a small sample size (n = 27, n = 22), and despite the fact that functions derived from similar size samples are reported (e.g. Viciano et al., 2011), it is recommended that the results be treated with caution. The second-best discriminant function used a combination of canines, M1 and M2, with an accuracy rate of 92.1% for both original and cross-validated data. This was followed by a discriminant function analysis that used maxillary and mandibular canines, providing a correct sex classification rate of 87.7% for the original and 84.6% for the cross-validated data. Although İşcan and Kedici (2003) report that the majority of difference between the sexes appears to come from the canines, Garn et al. (1967) suggest that the teeth located adjacent to the canines are more dimorphic than others; however, some studies of crown MD and BL measurements indicate that incisors are the least sexually dimorphic teeth (Bishara et al., 1986; Ling and Wong, 2007). Acharya and Mainali (2007), however, found that the central and lateral incisors show significant sexual

dimorphism. Considering the dimensions measured, the MD dimension provided better classification rates than the BL dimension. According to Acharya and Mainali (2007), the reason why MD measurements have better sex discriminatory ability might be due to the upper and lower arch dimensions; males exhibited statistically larger measurements of the antero-posterior jaw and also arch size was shown to affect tooth size, which indicate that males' larger jaws result in comparably larger MD dimensions. Regarding the molars, BL measurements provided better classification rates than MD measurements. This finding was consistent with the results from other studies (Garn et al. 1966a; İşcan and Kedici, 2003). Univariate discriminant analysis provided lower classification rates compared to direct and stepwise discriminant analysis. This shows that combining both MD and BL dimensions allows for more discriminatory power compared to using only one measurement. Regarding the posterior probability results, 15.5% of the sample provided over 95% probability of correct classification, while 51% provided between 80-95% posterior probability.

In the present study, one of the main concerns was the reliability of dental measurements, as is common in metric studies. The overall results of the coefficient of reliability suggested that the intra- and inter-observer cervical dental measurements both had high levels of consistency and reliability. The error measurements are comparable to those reported in studies of permanent teeth (Hassett, 2011; Viciano et al., 2011; 2015; Pilloud and Hillson, 2012; Tuttösí and Cardoso, 2015). Intra- and inter-observer error on cervical dental dimensions has been assessed by a few studies (Hassett, 2011; Viciano, 2011; 2013; 2015; Tuttösí and Cardoso, 2015). For comparison, Hillson et al.'s (2005) study is the most appropriate, because the present study uses the same cervical measurements as proposed by Hillson et al. (2005). Their study showed that in comparison with premolars, incisors, and canines, it is slightly more difficult to measure molars consistently for cervical diameters in permanent dentition. The reason being that they provided fewer clear landmarks to base measurements on. The authors also reported slightly larger values for MD measurements compared to BL measurements. Similar results were reported by Aubry (2014). In the present study, the degree of intra-observer error was smaller than that of inter-observer error, which is in agreement with previous investigations (Kieser and

Groeneveld, 1991; Hillson et al., 2005; Acharya and Mainali, 2007; Peckmann et al., 2015).

In conclusion, the overall results of the 2D cervical measurement analysis showed that in the Hasanlu and Dinkha Tepe samples males have significantly larger teeth than females, with incisors and canines as the most sexually dimorphic teeth. Discriminant function analysis showed the high sex classification accuracy rates of 2D cervical measurements in the Hasanlu and Dinkha Tepe collections. In addition, a comparison of these results with previous studies showed that they can be as successfully and effectively applied to archaeological samples as traditional crown and cervical methods used in other populations. In general, 2D cervical measurements were found to be of value for sex assessment. The method presented here is a useful tool for establishing accurate demographic data from the skeletal remains of these Iron Age populations from Iran.

8.4. Objective 3

An examination of the application of Hillson et al.'s (2005) method to archaeological samples.

As mentioned before, when a study involves archaeological samples, the ability to use teeth as a means of assessing sex is very limited, due to attrition of the tooth tissue, very common even in young individuals. In many cases the crowns of the teeth are entirely or almost entirely worn out, which makes measuring crown dimensions nearly impossible. Some recent studies have used dental cervical measurements instead, suggesting that they provide measurement accuracies similar to those of crown measurements (Hillson et al., 2005; Aubry, 2014). The purpose behind devising these cervical dimensions is that they replace crown measurements where the crown is too damaged due to processes such as attrition or breakage. Cervical measurements are therefore ideal replacements for crown measurements in cases such as the Hasanlu and Dinkha Tepe samples, where the tooth crowns are too worn to be measured. This problem is in addition to other problems mentioned in previous chapters, such as non-

metric variations, dental pathologies, and in situ teeth. This study, therefore, used the cervical MD and BL measurements proposed by Hillson et al. (2005) for sex estimation, which allowed a larger dataset to be obtained.

However, Hillson et al.'s (2005) method presents its own set of problems. Depending on the shape and position of the tooth at the cervical margin in cross-section, it can be difficult and time-consuming, for some in situ teeth, to place the calliper tips at the MD landmarks. The slightly higher rate of intra- and inter-observer error could be due to this issue. In addition, as suggested by Hillson et al. (2005), there is a tendency among researchers to measure loose teeth from the lingual side. Depending on the nature of the samples, however, the measurements of some teeth can be taken from the buccal aspect only. Nevertheless, in the case of loose teeth or fragmented jaws, the teeth can be measured from the lingual aspect or by using the backside of the calliper where the tips meet end-to-end. It was observed during the course of collecting the data that measurements differed greatly, depending on the position from which they were taken. The same observation was reported by Aubry (2014), though he did not report the same observation for molars. The present study, however, observed that the degree of difference in molars was significantly lower when compared to anterior and premolar teeth. To overcome this problem, all 2D measurements for both loose and in situ teeth were taken from the labial side. The same solution was also suggested by Aubry (2014).

Aubry (2014) detects two more problems that concern BL measurements of molars to Hillson et al.'s (2005) method. He suggests that the location Hillson et al. (2005) proposed for BL measurements of molars (at points midway along the buccal and lingual sides) is problematic, because it is also a location where enamel extension commonly appears. To solve this problem, Hillson et al. (2005) suggested taking the measurements from one side or the other of the enamel extension, whichever provides the maximum value. According to Aubry (2014), however, this solution is problematic, because "maximum values (whether mesial or distal to the enamel extension) are actually homologous, and […] this measurement is homologous to BL measurements of molars lacking enamel extensions" (Aubry, 2014, p. 160). The

second problem concerns the reduction in the distal component of molars, which causes different diameters between individuals with differential reduction of the distal portion of the tooth. This was not addressed by Hillson et al. (2005) while Aubry (2014) provides a modification that also tackles the first problem. He suggests taking "the maximum breadth of the mesial portion of the tooth in line with the protocone/paracone and the protoconid/entoconid for upper and lower molars, respectively" (Aubry, 2014, p. 163) (Fig. 8.1). This measurement location results in avoiding the enamel extension and also allows researchers to take the same measurements on all molars, whether or not the distal cusp is reduced in size. In the present study, the problem of enamel extension was tackled using Hillson et al.'s (2005) solution. However, since Aubry's (2014) paper was published a few months after data collection in the United States, it was not possible to test the efficacy and applicability of the proposed modifications. Nevertheless, Tuttösí and Cardoso (2015) put Aubry's (2014) modifications of Hillson et al.'s (2005) method to the test, and conclude that they "perhaps" (Tuttösí and Cardoso, 2015, p. 310) increase the reliability of MD measurements of molars, because of more clarity in defining landmarks.

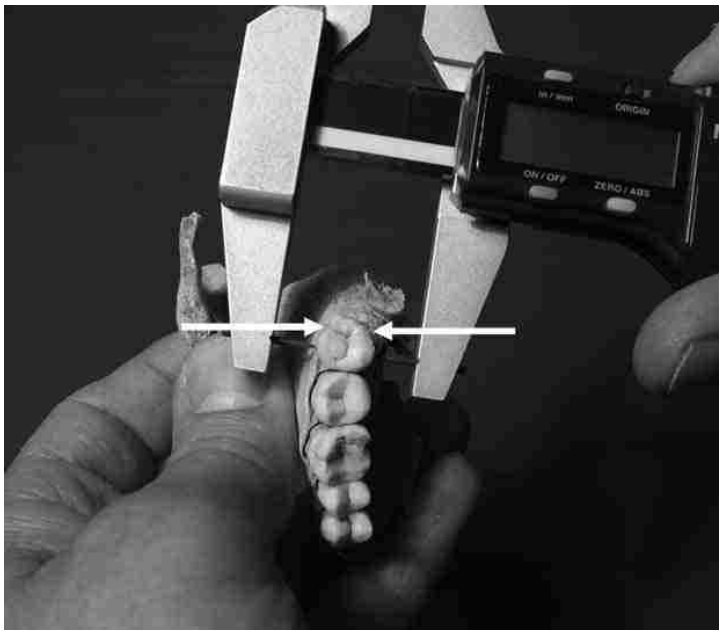

Fig 8.1. BL measurements of molars as defined by Aubry (2014, p. 161).

In addition, during the course of data collection it was observed that callipers could easily damage the tooth crown, particularly in more fragile cases, and could also lead to the removal of the calculus from adjacent teeth. A great deal of care, therefore, needed to be taken during the data collection.

Cervical measurements taken by callipers are considered very effective in sex estimation studies, as they are not affected by dental wear. This is especially important in archaeological samples, in which wear is very common. However, they present their own set of problems, as mentioned above. It is therefore necessary to provide another method with fewer limitations as a complement to 2D cervical measurements. The present study used advances in imaging technologies to introduce a more reliable and effective alternative method of taking cervical measurements for sex estimation.

8.5. Objective 4

In what ways can the 2D cervical measurement method be modified, and how reliable are these modifications for sex estimation in the Hasanlu and Dinkha Tepe collections?

2D odontometric methods are reliable, easy to use, inexpensive, and do not require a lot of time or equipment. 3D technology-based methods, on the other hand, despite being expensive, time-consuming, and requiring more facility and practice, offer a range of advantages, especially in archaeological sample analysis, that have made them very popular with forensic and physical anthropologists. 3D methods are non-invasive and therefore reduce the chances of damaging fragile and delicate archaeological samples. They are also accessible in that they do not require the specimen to be present in order to undertake analysis, meaning they are not limited to use in museums and archaeological sites. 3D technology enables the user to obtain a variety of dental linear and volumetric measurements. As mentioned before, this study collected cervical measurements from 3D models of each tooth. This enabled us to have a better understanding of the differences between 2D and 3D cervical methods.

In addition, this new technique helped us to solve the following issues presented by Hillson et al.'s (2005) methods:

1) In the present study, each tooth was segmented from the jaw using the thresholding tool in the AMIRA software. This enables the user to create a separate 3D model of every single tooth regardless of their situation (loose or in situ). Therefore, in 3D analysis all in situ teeth are changed into loose teeth; this is different from 2D cervical measurements where in situ teeth cannot be rotated or removed from the jaw. This overcomes the limited accessibility of MD measurements in in situ teeth and enables the user to easily identify the MD cervical measurement landmarks.

When taking the MD cervical measurements in loose teeth, it was initially observed that identifying the CEJ line was easier and more accurate using callipers compared to 3D measurements. To increase the reliability and the easiness of the CEJ identification process in 3D analysis, the crown was separated from the root using a second threshold level, and the crown and the root of the same tooth were colour coded. In doing so, the researcher and the second observer responsible for inter-observer error analysis found the process of CEJ line identification using 3D methods much easier and more accurate.

2) As mentioned before, in situ teeth can be measured either from the buccal or lingual sides, depending on the nature of the sample. In 3D analysis, however, the ability to make a separate 3D model of each in situ tooth solved this problem by enabling the user to take measurements from different aspects. In addition, the measurement difference that the position of taking the MD measurement (either buccal or lingual) causes in 2D cervical measurements was not observed using the 3D method.

3) The ability to create 3D models of the tooth using CT scan images significantly reduces the potential damage that might be caused when taking measurements by calliper. Using 3D methods therefore 1) prevents the teeth from being

damaged by the sharpened beaks of the callipers and 2) prevents certain pathological dental conditions such as calculus removal.

Using 3D techniques for odontometric analysis not only resolved the aforementioned limitations of 2D cervical analysis but also provided better sex classification results. A comparison between the 2D and 3D odontometric statistical analyses will provide us with a better understating of the potential effectiveness of 3D methods.

Similar to 2D cervical measurements, male values were significantly ($P < 0.000$) different from female values, except for UM3 and MD measurement of LM3, which were excluded from the analysis. Classification accuracy of 32 functions was higher for males, and higher for females in 21 functions. This is in contrast with 2D cervical measurement results which showed higher classification accuracy of all functions in males.

SD% was higher in all teeth for 3D measurements compared to 2D measurements (except M3 and BLLM2). In contrast to 2D measurements, the highest SD% was observed in the MD measurement of UI2 (22.9%), which was significantly higher than the SD% achieved using 2D measurements (9.7%). This observation is in accordance with other studies on 2D cervical measurements (Cardoso, 2008; Zorba et al., 2011). LC was the most sexually dimorphic tooth, with 20.96 SD% in MD measurement and 18.54 SD% in BL measurement, again much higher than the SD% observed in 2D measurements (14.99% and 12.16%). This difference could be due to the small sample size of the 3D data. The next most sexually dimorphic diameter in both 2D and 3D cervical measurements was the MD measurement of UC, with 13.93 and 18.70 SD% respectively. UM2 showed the highest SD% among 3D measurements of molar teeth, which was in accordance with 2D cervical data. The lowest SD% was also observed in the MD measurement of UM3 for both 2D and 3D data.

In general, 3D cervical measurements provided better sex classification rates compared to 2D cervical measurements. Univariate discriminant function analysis for 3D measurements showed better classification rates in 26 functions out of the total of

29. Total classification rate of single measurements ranged from 65.5% to 86.8% for 2D measurements and 77.4% to 96.7% for 3D measurements. The 3D MD measurement of UM1 provided the best classification rate of 96.7%, followed by the MD measurement of UI2 (95.5%). The accuracy rates of these measurements in 2D cervical analysis were only 77.4% and 81.8% respectively. For the direct discriminant functions, overall accuracy rate of 3D measurements ranged from 82.4% to 100% for both original and cross-validated data, which was significantly higher than 2D measurements (75.9-89.9%). 3D measurements of UI2 provided the best classification rate (100%), followed by UC and LC each with 97.1% and 96.7% correct classification rates respectively. This is in accordance with the results obtained by 2D cervical measurements. In stepwise discriminant analysis, the 3D measurements also showed better classification rates compared to 2D measurements. Half of the analysed functions provided an accuracy rate of 100%. The best classification functions used different combinations of incisors, canines, and maxillary molars. The same combinations were also used in the best stepwise discriminant functions using 2D cervical measurements. Premolars in both direct and stepwise discriminant analysis of 3D measurements provided high classification accuracy rates of between 84% to 100%. This is in contrast with the results obtained by 2D cervical measurements, in which premolars correctly classified sex of only 75.9% to 84% of the skeletons. The variable presented first in all of the 3D measurement stepwise discriminant functions was the MD measurement. Therefore, the 3D cervical MD measurement in all teeth was the most reliable for sex estimation, more than the BL cervical measurement. This is in accordance with the stepwise discriminant analysis of 2D cervical measurements. This significant difference between the 2D cervical and 3D cervical measurement discriminant function analysis results is most likely because, for some of the 2D and 3D functions – particularly the stepwise discriminant functions using measurements of several teeth – the sample sizes were very small. Therefore the results must be interpreted with caution.

Posterior probability analysis also provided better results compared to 2D cervical measurements: 46.74% of the measurements provided over 95% probability of correct

classification, while 70.31% provided between 80-100% probability of correct classification.

The overall intra- and inter-observer error results confirmed that the 3D image system was as reliable and accurate as the 2D system for measuring teeth using callipers. Previous studies have reported similar findings of measurements obtained using 3D methods or direct measurements on plaster models (Smith et al., 2009; El-Zanaty et al., 2010; Ashar et al., 2012). However, these studies are in crown MD and BL measurements, rather than cervical. In the current study, both 2D and 3D measurements generally provided excellent reliability within and between observers. The BL dimension was measured most reliably, whether based on 3D or 2D measurements, whereas MD measurements displayed lower reliability. However, 3D MD measurements showed slightly better consistency and reliability compared to 2D cervical measurements, which could be due to better identification of the CEJ line in 3D analysis. Similar to 2D cervical measurements, slightly larger values were obtained for molar teeth in 3D analysis, especially LM2 and LM3.

The findings of the present study show that dental cervical measurements can be obtained using 2D or 3D methods. This study's comparisons of the two methods highlights the effectiveness and significance of 3D analysis in this field of study, and enables researchers to confidently move from 2D to 3D. This study confirms a very strong correlation and linear relationship between the 2D and 3D measurements obtained using Hillson-Fitzgerald dental callipers and the AMIRA software. Values of Pearson's correlation coefficient were significant at the 0.01 probability level for all variables, confirming that 2D and 3D cervical measurements were comparable. Furthermore, the maximum and minimum differences between 2D and 3D measurements were found to be 0.09 and 0.00 mm, respectively. This range is lower than those reported by other studies comparing dental manual measurements with those obtained by 3D analysis. For example, Lu et al. (2000) compared different 3D dental measurements obtained by a laser scanning 3D digitisation system with manual measurements, and reported a measurement difference of less than 0.10 mm. Hirogaki et al. (2001) in a similar study reported the measurement differences within 0.30 mm.

Smith et al. (2009) compared 2D and 3D crown MD and BL measurements together and reported measurement differences between 0.00 and 0.60 mm. Another study by Ashar et al. (2012) on 2D and 3D crown measurements showed a mean difference of between 0.00 and 0.30 mm.

Similar to the results obtained from 2D cervical measurements, the 3D cervical measurement analysis showed that, in the Hasanlu and Dinkha Tepe collections, males have significantly larger teeth than females. Incisors and canines were also found to be the most sexually dimorphic teeth. In general, discriminant function analysis using 3D cervical measurements provided better classification rates compared to 2D cervical measurements. The high classification rate and excellent inter- and intra-observer error results, as well as this method's ability to overcome the limitations presented by Hillson et al. (2005), make it a reliable and effective technique for sex estimation in these two populations.

8.6. Objective 5

Can the root volume be used as a new parameter for sex estimation and how reliable is it?

As discussed in Chapter 3, tooth root length has a high degree of sexual dimorphism, and in some cases is even more successful in sex estimation than traditional crown measurements (Zorba et al., 2014). The present study therefore investigated whether or not the volume of the tooth root is also sexually dimorphic and whether it can be used for sex estimation. The traditional methods used to collect the physical volume measurements, such as the water displacement method, are highly prone to error and require a highly skilled technician (Trinh et al., 2006). Using the water displacement method in dental volumetric analysis also presents other problems. For example, this method is only useful for taking the volume measurements of loose teeth, and therefore the teeth which are still in the jaw and cannot be rotated or taken out of the jaw cannot be measured by this method. Furthermore, volume measurements of different parts of the tooth, such as the root or crown, cannot be taken separately.

During the last decade, advances in imaging techniques such as computed tomography (CT) have enabled researchers to create highly accurate dental volume rendering models and multiplanar reconstructions. This allows for a better examination of the sexually dimorphic characteristics of the tooth, especially the root, which is usually hidden in the jaw. The ability to make a separate 3D model of each tooth enables the user to treat in situ teeth as loose teeth, similar to 3D cervical measurements. In addition, the segmentation tool in the AMIRA software allows for the separation of different parts of the tooth, so that the volume of each part can be measured separately. This ability significantly decreases the risk of error in dental volumetric analysis, as has also been observed by previous studies (Liu et al., 2010; Forst et al., 2014; Kim et al., 2016). Other studies have also validated the efficacy of CT scans as a tool to measure both root length and volume (Liu et al., 2010; Lund et al., 2012; Kim et al., 2013; Forst et al., 2014). Liu et al. (2010) conducted in vivo volumetric determination using CT scan images and demonstrated small differences (within –4% to +7%) from the actual physical volumes.

The current study is the first study of its kind to use tooth root volume for sex estimation. As mentioned before, Tardivo et al. (2011; 2015) used the volume of the canine teeth for sex estimation and correctly classified sex in 100% of their samples. In their studies the CT scans of modern French people were used to create 3D models of the teeth using the MIMICS-10.01 software. Tardivo et al.'s (2011; 2015) studies used the canine pulp volume and the total volume of the canines for sex estimation. However, while the classification rate of these studies was very high, their method needs to be tested using other tooth types. Moreover, the size of the tooth crown is highly affected by dental pathologies such as caries (particularly occlusal caries) and tooth wear. This, in more severe cases, causes pulp exposure -an opening through the wall of a tooth, produced by pathologic processes, thereby exposing the dental pulp-. (Scully et al., 2010; Van Noort, 2013) and consequently changes the measurements. These issues are overcome in this study by measuring the volume of the root from the apical to the cemento-enamel junction (CEJ). Tooth root volume measurements can be especially effective in the case of samples containing poorly preserved and highly worn teeth. The root volume measuring process was made much easier due to firstly,

segmenting the tooth from the jaw and the crown from the root using two different threshold levels, and secondly, colour coding the crown and the root. In the current study, the quality of the CT images of the mandible was better than that of the maxillae. This might be because of a bigger contrast between the dental alveolus and the cortex that surrounds it, resulting in a better visualization. Nevertheless, during the course of the research, no differences between the segmentation processes of upper and lower teeth were detected. It was noticed that the density of the root in both the upper and lower jaws was closer to cortical bone and easily visualized. A problematic situation occurred when the roots were adjacent to cortical bone in the mandible, making segmentation relatively difficult.

In this study RV measurements demonstrated significant sexual dimorphism, and mean values were considerably higher in males compared with females. A comparison between the two sexes showed that the classification accuracy of most functions was higher for males. This result is in agreement with that of the 2D cervical measurements.

The percentages of sexual dimorphism were also calculated for the RV measurements. There is no comparative data against which the degree of sexual dimorphism in tooth root volume can be compared. However, a provisional comparison with crown, cervical, and root measurements can be performed, which describes the patterns in the sample and which might underline some interesting similarities or differences. It becomes even more important considering that it introduces a new parameter for sex estimation.

In 2D cervical measurements, the greatest difference in percentage of sexual dimorphism was observed in the LC, however analysis of root volume showed the highest percentage of sexual dimorphism in the UI2, which is similar to the results of the 3D cervical analysis. This result is in accordance with the findings of Tuttösí and Cardoso's (2015) study of tooth cervical measurements and Zorba et al.'s (2014) study of root length measurements. The UC showed the next highest percentage of sexual dimorphism; this tooth has also been reported high for sexual dimorphism in crown, cervical, and root length measurements (Garn et al., 1979a; Cardoso, 2008; Zorba et

al., 2011; 2014). These teeth also provided the highest classification accuracy rate for the univariate discriminant function analysis. For molar teeth, the M2 showed the highest percentage of sexual dimorphism, in accordance with the results of Tuttösí and Cardoso (2015) and also those of crown measurement studies (Cardoso, 2008; Garn et al., 1979a; Zorba et al., 2011).

Univariate discriminant function analysis also showed that the root volume of incisors and canines was the most dimorphic, providing classification accuracy of between 89.3 to 100%. These results were in accordance with the 2D cervical measurements and with other studies on crown and cervical measurements (Alt et al., 1998; Hassett, 2011; Viciano et al., 2011; 2013; 2015; Mujib et al., 2014). The root volume of the UI2 reached the highest accuracy rate (100%), followed by the UC, which correctly classified sex in 97.10% of the sample. This result is in accordance with the 3D cervical results and those of Tardivo et al.'s (2015) study on the sexual dimorphism of the total volume of canines. However, 2D cervical measurement results and most previous studies on crown and cervical measurements (Saunders et al., 2007; Angadi et al., 2013; Khamis et al., 2014; Viciano et al., 2015) have demonstrated a greater sexual dimorphism in the dimensions of LC. The RV measurement of the UM2 also provided the highest accuracy rate among molar teeth (90.3%). Similar results were achieved by 2D cervical measurements and by other studies on cervical and crown measurements (Zorba et al., 2012; Viciano et al., 2015; Tuttösí and Cardoso, 2015). In addition, the current study showed that, similar to the 3D cervical measurement, the root volume of premolar teeth can provide very effective variables for sex estimation, with a classification accuracy ranging between 84.4% and 90.9%. However, the analysis of 2D cervical measurements reported a low accuracy rate of 75.9-79.3% for premolars.

Furthermore, several multivariate discriminant functions were created using different combinations of variables. The results of the stepwise discriminant function analysis indicated that the prediction accuracies for estimating sex using the RV measurements ranged from 90 to 100% in Hasanlu and Dinkha Tepe skeletons, with accuracy in males higher than in females. Six out of the twelve functions used in the discriminant

function analysis provided an accuracy rate of 100% for both original and cross-validated data. In general, the classification accuracy rate for both univariate and stepwise discriminant function analysis was better than those obtained from 2D and 3D cervical measurements, showing that the volume of the tooth root can also be useful for sex estimation. The efficacy of RV measurements in sex estimation is supported by another finding of this study: as previously noted, some studies have reported a positive correlation between root length and traditional crown measurements (Garn et al., 1978; Harris and Couch, 2006). However, this positive correlation has been reported for root length and crown size only, and not for RV and cervical measurements. The Pearson correlation and regression analysis in this study also showed a positive correlation and linear relationship between 2D cervical and RV measurements, showing that both measurements yield the same biological information. The stepwise discriminant function analysis based on the functions combining 2D cervical and RV variables also showed that in all functions RV measurements made the most significant contribution to discrimination.

Posterior probability results for RV measurements were that 75.75% of the data provided over 95% probability of correct classification, while 82.79% of the data provided between 80 to 100% probability of correct classification.

Precision testing demonstrated low intra-observer error, with R values > 0.99, rTEM < 2.06%, and TEM < 4.65. These results are slightly higher than 2D and 3D cervical measurements. However, the TEM values were significantly higher (< 4.65) compared with the cervical measurements (< 0.05). This difference is due to the positive association between the size of the TEM and the size of the measurements. For example, a large mean value will have a large TEM, and thus the comparison of measurements of different size cannot be assessed (Ulijaszek and Kerr, 1999). To overcome this problem, the TEM was transferred to relative TEM (rTEM%). The rTEM value for tooth root volume measurements (< 2.06) was slightly higher than that for cervical measurements (< 0.78). The results of inter-observer error analysis also showed R values of < 0.98 and rTEM of < 2.27%.

The sex estimation technique proposed here represents a novel technique based on tooth root volume measurements taken from CT images of permanent teeth. Flow charts outlining the overall analysis process applied in this research and also the suggested tooth measurements for sex estimation are presented in Appendix D. Based on the set of data used here, the estimation of sex using RV measurements is significantly effective. Inter- and intra-observer error was low for all variables. Therefore it appears that the technique proposed here is a valid alternative for sex estimation, with the added value that no manual handling of the teeth is necessary. In addition to all the advantages that 3D image analysis system methods present compared to 2D manual measuring methods, RV measurements are not influenced by severe dental wear or by pathological conditions such as enamel hypoplasia along the CEJ, which could impose limitations on 3D cervical measurements. Therefore, RV measurements are particularly useful for sex estimation in poorly preserved archaeological samples, such as the Hasanlu and Dinkha Tepe collections.

8.7. Conclusion

As previously discussed, the main objective of this study was to introduce dental metric standards for sex estimation in Iranian archaeological populations. Overall the results of the study showed that in all sets of measurements, Hasanlu and Dinkha Tepe males exhibited larger teeth than their female counterparts. Incisors and canines in all measurements presented the highest level of sexual dimorphism, which supports previous studies on crown and cervical measurements in different modern or archaeological populations, including Spanish, Italians, Japanese, Greek, and Turkish. The sex classification rates for all measurements ranged between 65.5 to 100%, depending on the measurement used. The classification rate was higher for males in most of the functions, indicating that females have a greater variation in tooth size and can more often be misclassified as males; or it could simply be because of the smaller sample size in respect of females. In general, as the results show, the highest classification rates using single measurements or a combination of different measurements were achieved by, first, RV measurements, second, 3D cervical measurements, and third, 2D cervical measurements. In addition, posterior probability

results also showed that 82.79% of the measurements used in all functions provided posterior probabilities between 80-100%, which is significantly higher than 2D cervical and 3D cervical measurements, with 51% and 70.31% posterior probability respectively.

It is necessary to define the data measurement points clearly so that scientific consistency and accuracy is ensured. This will eventually enable the researcher to understand the definition and to reproduce the measurements. The author herself and the second observer found the identification process of cervical landmarks on 3D images, as well as setting the appropriate threshold levels to segment the tooth and the root, easier, more accurate, and more repeatable compared to 2D cervical measurements. The reason for this is that a large number of in situ teeth in the collections made the landmark identification process using callipers, particularly on MD measurements, more difficult. In the case of root volume in particular, the whole process was easier to follow, due to no landmarks being involved. The results obtained from both the intra- and inter-observer error analyses conducted of all three sets of data revealed no differences between and within the observers, as none of the comparisons yielded statistical significance. Coefficients of reproducibility with statistical acceptance were also achieved. In countries such as Canada and the United States, scientific methodologies that are utilized by expert witnesses must fulfil the Mohan (1994) and Daubert (1993) admissibility criteria (Rogers and Allard, 2004; Christensen, 2004). In order for a methodology to fulfil their criteria, the minimum standard is an accuracy rate of equal to or greater than 80%, and an intra-observer error rate of less than or equal to 5% (Rogers and Allard, 2004; Christensen, 2004). 115 out of 146 functions analysed displayed overall accuracy rates of 80% or higher. Inter- and intra-observer error values for all the measurements were less than 10%. Due to the low error rates cited in this research, sex estimation from 2D and 3D measurements in the Hasanlu and Dinkha Tepe populations adheres to the Mohan and Daubert criteria. However, it should be noted that although these criteria are related to forensic cases, the high accuracy rate and the low intra- and inter-observer error values show the validity and accuracy of the methods introduced in this study.

One of the main objectives of this study was to introduce a new method that would be the most appropriate for sex estimation of archaeological samples using odontometric data. Among all the methods proposed in this study, root volume was found to be the most appropriate method for sexing archaeological samples in the case of the Hasanlu and Dinkha Tepe collections. Root volume provided the highest accuracy rates, excellent reliability, and presented fewer limitations, particularly compared to 2D cervical measurements. This method is also less likely to be affected by certain dental pathologies, which gives it an advantage over 3D cervical methods and allows the inclusion of more data in the analysis.

It must be stressed, however, that this study used an osteologically estimated sex sample to test the method. Despite the high level of accuracy of morphological techniques of sex assessment, the true sex of each of these individuals is unknown. It is therefore likely that the percentage of correct classifications of known sex may be a small degree higher or lower than in the presented data (Tuttösí and Cardoso, 2015). The other major limitation of this study was its small sample size. The study must be expanded, therefore, with a larger data sample in order to refine the proposed new method. However, the importance of this study lies in the fact that it can be applied to unknown skeletal remains belonging to the same period (the Iron Age) in Iran. This becomes even more important considering that teeth have a better chance of survival in severe taphonomic conditions compared with other skeletal elements. It is highly recommended that the reliable estimates be considered, with over 95% probability of correct classification. However, with regard to estimates with 80-95% probability, the predictions should be treated with caution, and when the probability rate of the estimate is lower than 80%, the method should be considered unreliable and other methods should be used instead.

CHAPTER 9 CONCLUSION

Odontometric standards for sex estimation are population specific in both time and space, and standards from one population may not work on another population. In addition, advances in technologies such as CT scanning have allowed for further examination of dental sexual dimorphism in modern and archaeological populations. CT scanning and 3D image analysis methods can be used for measuring and analysing both the internal and external structure of the tooth. Currently there is no odontometric reference data from Iranian populations; the present study contributes to the development of standards for sex estimation using two important Near Eastern archaeological sites in north-western Iran, Hasanlu and Dinkha Tepe. The present study aimed to examine the level of sexual dimorphism in the permanent teeth of Iranian archaeological populations using cervical and RV measurements, and to assess the applicability of these measurements in sex estimation based on discriminant function analysis. It also aimed to contribute to the growing knowledge of 3D imaging techniques in sex estimation and to help overcome methodological issues with traditional 2D odontometric methods. The tooth root volume was also introduced as a new parameter for sex estimation, which could be very helpful, particularly in archaeological and fragile samples. However, it would surely be worthwhile to examine the level of sexual dimorphism, particularly regarding the size differences between different skeletal elements, to have a better understanding of the level of sexual dimorphism in the Hasanlu and Dinkhah Tepe samples.

The main conclusions of the present study using Hasanlu and Dinkha Tepe collections are summarised as follows:

- Males had significantly larger teeth than females in all teeth and all measurements.
- In general, maxillary teeth were more sexually dimorphic than mandibular teeth.
- Incisors and canines in both jaws were the most sexually dimorphic teeth for all dimensions. This could be due to the significance of the canine in human evolution (see chapter three).

- In general, MD measurements were more sexually dimorphic than BL measurements in both 2D and 3D cervical measurements.
- Classification accuracy was higher when both MD and BL variables were used together.
- Discriminant function analysis showed the high sex classification accuracy rates of 2D and 3D cervical, and RV measurements in the Hasanlu and Dinkha Tepe collections.
- The total classification accuracy rates ranged from 65.5% to 100% for 2D cervical measurements, 77.4% to 100% for 3D cervical measurements, and 89.3% to 100% for RV measurements.
- In general, classification accuracy was higher for males compared to females in all measurements. This may suggest that females have greater variation in tooth size, or it could simply be attributed to the smaller sample size of the females in some of the functions.
- 3D cervical measurements resolved the limitations of 2D cervical measurements and provided better sex classification results.
- The volume of the tooth root demonstrated significant sexual dimorphism, and provided best sex classification percentages among all three sets of measurements.
- Student t-tests showed no statistically significant differences between 2D and 3D cervical measurements, and Pearson correlation also confirmed a very high positive correlation between these measurements.
- Pearson correlation analysis also showed a positive correlation between 2D cervical and RV measurements, showing that both measurements yield the same biological information.
- All three methods presented in this study showed excellent intra- and inter-observer error results.
- The cross-validation and bootstrap samples provided results similar or very close to the original results.
- 82.8% of the RV measurements, 51% of the 2D cervical measurements, and 70.3% of the 3D cervical measurements provided posterior probabilities between 80% and 100%.

- 3D methods are non-invasive and reduce the chances of damaging fragile and delicate archaeological samples. 3D technology also enables the user to obtain a variety of dental linear and volumetric measurements.
- A high classification accuracy rate, excellent inter- and intra-observer error results, as well as 3D cervical method's ability to overcome the limitations presented by Hillson et al. (2005), make it a reliable and effective technique for sex estimation in the Hasanlu and Dinkha Tepe collections.
- RV measurement was found to be the most appropriate method for sexing the Hasanlu and Dinkha Tepe samples, as it provided the highest accuracy rates, excellent reliability, and presented fewer limitations, particularly compared to 2D cervical measurements.
- All the measurements used in the present study are considered very effective in sex estimation with regards to the Hasanlu and Dinkha Tepe collections, as they are not prone to pathological conditions such as dental wear, which is very common in archaeological samples.

The findings of this study have allowed for a discussion of dental sexual dimorphism patterns in a rarely studied population, and introduced a novel sex estimation technique using CT images of permanent teeth. However, as with any study of these types of data, there are some limitations. One major issue is that of sampling. Within Hasanlu, not all the skeletons from the site were analysed in the study, and the skeletons which were included are not representative of the entire Hasanlu population. The sample size from Dinkha Tepe was also small and may not be representative of the larger population. Further excavation in the area and the inclusion of additional skeletons from Hasanlu and Dinkha Tepe would help greatly in supporting the conclusions drawn in this study. In addition, the sample sizes used in this study, particularly the 3D analysis sample size, were small, therefore further studies using large, contemporary populations of known sex should be undertaken in order to test the methods and to assess their usefulness as a new methodology for sex estimation of skeletal remains.

The dental metric data provided by the present study could also be used to examine the biological relationships between and within the Hasanlu and Dinkha Tepe collections, or might even be helpful for identification of invaders and locals in the site. The detailed analysis of the patterns of dental wear could also be used to study the health, diet or habitual activities of the Hasanlu and Dinkha Tepe individuals. The data presented in this study is a good start for conducting more sex estimation studies in either modern or archaeological Iranian populations, and also offers an effective comparative basis for other Near Eastern Iron Age period samples. The hope is that this work will be a valuable contribution to the validation of the available technologies in odontometric sex assessment, and also that it will introduce new methodologies regarding the quantification of 3D volumetric data, as well as anatomically precise 3D dental models. In addition, one of the more modern applications of the sex estimation techniques provided in this study could be the identification of unidentified human remains from the eight-year war between Iran and Iraq in the 1980s that resulted in the loss of a hundred thousand lives. This becomes even more significant when considering the fact that teeth are the most durable substance in the human body. Furthermore, as this study has shown, the sex of individuals can be estimated even using the volume of the tooth root, which can be very useful in the case of bodies that are beyond recognition due to decomposition, severe burning, mechanical trauma, etc. In such cases the odontometric methods proposed in this study could be a very useful and reliable complement to other sex identification methods, such as DNA analysis.

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APPENDIX A

STATISTICAL ANALYSIS

Table 1. TEM and rTEM results evaluating intra-observer error in 2D cervical measurements

Measurements	N	Measurement 1		Measurement 2		Diff	TEM	rTEM	R
		Mean	SD	Mean	SD				
Mesiodistal									
UI1	36	6.18	0.59	6.19	0.59	-0.01	0.03	0.45	1
LI1	25	3.51	0.18	3.51	0.18	0	0.02	0.58	0.99
UI2	36	4.77	0.44	4.77	0.44	0	0.03	0.61	1
LI2	39	3.86	0.36	3.87	0.36	-0.01	0.04	0.78	0.99
UC	37	5.48	0.57	5.48	0.57	0	0.03	0.53	1
LC	48	5.3	0.6	5.31	0.6	-0.01	0.03	0.49	1
UP3	38	4.59	0.38	4.6	0.4	-0.01	0.04	0.72	0.99
LP3	50	4.82	0.33	4.83	0.33	-0.01	0.03	0.55	0.99
UP4	42	4.84	0.82	4.85	0.82	-0.01	0.03	0.65	1
LP4	38	5.08	0.87	5.08	0.86	0	0.04	0.47	1
UM1	48	7.66	0.56	7.66	0.55	0	0.04	0.39	1
LM1	31	8.85	0.52	8.86	0.53	-0.01	0.03	0.26	1
UM2	42	7.55	0.7	7.56	0.71	-0.01	0.04	0.45	1
LM2	22	9.01	0.65	9.02	0.64	-0.02	0.03	0.36	1
UM3	18	6.88	1	6.88	1.02	0	0.04	0.54	1
LM3	31	8.8	0.85	8.81	0.86	0	0.03	0.36	1
Buccolingual									
UI1	36	6.32	0.62	6.33	0.62	-0.01	0.03	0.48	1
LI1	22	5.64	0.37	5.64	0.37	0	0.03	0.49	0.99
UI2	36	5.64	0.43	5.64	0.43	0	0.02	0.44	1
LI2	39	6.04	0.34	6.05	0.35	-0.01	0.03	0.47	0.99
UC	37	7.81	0.8	7.81	0.8	0	0.03	0.33	1
LC	48	7.41	0.56	7.41	0.56	0	0.02	0.31	1
UP3	38	8.07	0.61	8.08	0.61	-0.01	0.03	0.38	1
LP3	50	6.72	0.41	6.72	0.42	0	0.03	0.45	0.99
UP4	42	8.29	0.83	8.28	0.82	0.01	0.03	0.39	1
LP4	38	7.14	0.57	7.14	0.58	0	0.03	0.35	1
UM1	41	9.93	0.56	9.93	0.56	-0.01	0.03	0.29	1
LM1	40	8.71	0.63	8.71	0.61	0	0.03	0.33	1
UM2	39	9.8	1.03	9.81	1.03	-0.01	0.03	0.32	1
LM2	37	8.18	0.77	8.17	0.76	0.01	0.03	0.38	1
UM3	25	9.6	0.82	9.59	0.81	0.01	0.03	0.36	1
LM3	31	8.1	0.7	8.11	0.7	-0.01	0.03	0.39	1

Table 2. TEM and rTEM results evaluating intra-observer error in 3D cervical measurements

Measurements	N	Measurement 1		Measurement 2		Diff	TEM	rTEM	R
		Mean	SD	Mean	SD				
Mesiodistal									
UI1	22	6.28	0.62	6.27	0.63	0	0.03	0.46	1
LI1	26	3.5	0.24	3.52	0.24	-0.01	0.02	0.7	0.99
UI2	21	4.64	0.57	4.65	0.58	-0.01	0.03	0.56	1
LI2	26	3.81	0.4	3.82	0.4	0	0.03	0.76	0.99
UC	34	5.45	0.55	5.45	0.56	0	0.03	0.6	1
LC	29	5.28	0.67	5.28	0.68	0	0.02	0.44	1
UP3	34	4.55	0.48	4.56	0.48	-0.01	0.03	0.6	1
LP3	32	4.71	0.44	4.7	0.46	0.01	0.03	0.62	1
UP4	31	4.52	0.41	4.51	0.43	0.01	0.03	0.57	1
LP4	30	4.93	0.51	4.92	0.51	0.01	0.02	0.5	1
UM1	29	7.79	0.42	7.79	0.43	0	0.03	0.38	1
LM1	29	8.81	0.55	8.82	0.55	-0.01	0.03	0.32	1
UM2	29	7.66	0.69	7.65	0.68	0	0.03	0.38	1
LM2	34	8.83	0.69	8.84	0.7	-0.01	0.03	0.37	1
UM3	14	6.85	0.83	6.85	0.85	0	0.03	0.39	1
LM3	21	8.98	0.75	8.97	0.75	0	0.03	0.29	1
Buccolingual									
UI1	22	6.18	0.57	6.17	0.56	0	0.03	0.46	1
LI1	26	5.32	0.38	5.3	0.37	0.01	0.03	0.58	0.99
UI2	21	5.53	0.41	5.52	0.42	0.01	0.03	0.6	0.99
LI2	26	5.67	0.4	5.66	0.41	0.01	0.02	0.43	1
UC	34	7.51	0.7	7.51	0.69	0	0.03	0.35	1
LC	29	7.07	0.93	7.07	0.92	0	0.03	0.45	1
UP3	34	7.81	0.71	7.82	0.71	-0.01	0.03	0.41	1
LP3	32	6.54	0.48	6.54	0.49	0	0.03	0.42	1
UP4	31	7.82	0.76	7.82	0.77	0	0.03	0.37	1
LP4	30	6.99	0.68	6.99	0.66	0	0.04	0.56	1
UM1	29	9.8	0.69	9.79	0.69	0	0.03	0.28	1
LM1	29	8.62	0.59	8.62	0.58	0	0.03	0.3	1
UM2	29	9.95	0.83	9.94	0.82	0.01	0.03	0.29	1
LM2	34	8.22	0.58	8.21	0.6	0	0.04	0.51	0.99
UM3	14	9.1	0.86	9.1	0.87	0	0.03	0.32	1
LM3	21	7.9	0.5	7.92	0.5	-0.01	0.03	0.33	1

Table 3. TEM and rTEM results evaluating intra-observer error in RV measurements

Measurements	N	Measurement 1		Measurement 2		Diff	TEM	rTEM	R
		Mean	SD	Mean	SD				
Root volume									
UI1	22	218.3	59.07	216.8	58.82	1.5	3.61	1.66	1
LI1	26	99.13	19.37	98.4	19.09	0.73	1.94	1.97	0.99
UI2	26	135.55	44.99	134.75	44.17	0.8	2.6	1.93	1
LI2	24	128.36	28.58	128.98	28.48	-0.62	2.4	1.87	0.99
UC	34	248.2	87.39	248.18	86.97	0.03	3.89	1.57	1
LC	26	235.31	64.15	233.43	63.62	1.89	2.96	1.26	1
UP3	34	164.73	50.75	163.52	50.14	0.95	3.09	1.88	1
LP3	31	153.35	36.06	153.61	35.77	-0.26	2.81	1.83	0.99
UP4	32	170.9	51.95	170.17	51.35	0.73	3.32	1.94	1
LP4	30	184.49	48.88	184.79	48.62	-0.3	3.8	2.06	0.99
UM1	28	429.91	99.69	428.99	98.6	0.92	4.16	0.97	1
LM1	29	411.4	80.98	415.07	79.65	0.73	3.77	0.91	1
UM2	31	399.02	108.83	399.65	108.15	-0.63	4.59	1.15	1
LM2	32	368.17	80.77	368.08	82.95	0.09	3.76	1.02	1
UM3	10	310.27	104.71	312.3	108.99	-2.02	4.65	1.49	1
LM3	20	330	85.43	329.29	86.15	0.71	3.66	1.11	1

Table 4. TEM and rTEM results evaluating inter-observer error in 2D cervical measurements

Measurements	N	Measurement 1		Measurement 2		Diff	TEM	rTEM	R
		Mean	SD	Mean	SD				
Mesiodistal									
UI1	26	6.21	0.52	6.22	0.52	-0.01	0.04	0.57	1
LI1	21	3.44	0.18	3.43	0.19	0.01	0.03	0.75	0.98
UI2	28	4.65	0.55	5.64	0.57	0.01	0.05	0.75	1
LI2	27	3.89	0.44	3.9	0.44	-0.01	0.03	0.87	0.99
UC	30	5.39	0.59	5.38	0.59	0.01	0.04	0.68	1
LC	31	5.22	0.53	5.22	0.53	0.01	0.04	0.69	1
UP3	29	4.6	0.51	4.62	0.51	-0.01	0.04	0.76	1
LP3	28	4.58	0.45	4.56	0.45	0.01	0.03	0.76	0.99
UP4	30	4.81	0.46	4.81	0.44	0	0.04	0.75	0.99
LP4	27	4.76	0.44	4.75	0.44	0.01	0.04	0.83	0.99
UM1	27	7.69	0.58	7.69	0.56	0	0.05	0.56	0.99
LM1	29	8.53	0.68	8.53	0.65	0	0.04	0.52	1
UM2	28	7.13	0.6	7.15	0.6	-0.02	0.05	0.62	0.99
LM2	25	8.48	0.63	8.46	0.65	0.02	0.05	0.57	0.99
UM3[a]	14	6.61	1.3	6.64	1.31	-0.02	0.04	0.61	1
LM3	20	8.27	0.82	8.25	0.81	0.02	0.05	0.54	1
Buccolingual									
UI1	26	6.17	0.8	6.17	0.8	0.01	0.04	0.58	1
LI1	21	5.43	0.51	5.44	0.5	-0.01	0.04	0.68	0.99
UI2	28	5.61	0.51	5.61	0.5	0	0.03	0.61	1
LI2	27	5.9	0.38	5.9	0.36	0	0.04	0.65	0.99
UC	30	7.32	0.73	7.32	0.75	0	0.04	0.49	1
LC	31	7.24	0.63	7.24	0.62	-0.01	0.03	0.44	1
UP3	29	7.61	0.54	7.6	0.54	0	0.04	0.56	0.99
LP3	28	6.25	0.54	6.23	0.54	0.02	0.04	0.69	0.99
UP4	30	7.83	0.97	7.84	0.96	-0.01	0.04	0.55	1
LP4	27	7.01	0.76	7.01	0.75	0	0.05	0.71	1
UM1	27	9.83	0.54	9.85	0.52	-0.02	0.04	0.46	0.99
LM1	29	8.83	0.69	8.82	0.68	0.01	0.04	0.53	1
UM2	28	9.58	0.82	9.58	0.82	0	0.04	0.52	1
LM2	25	8.75	0.8	8.74	0.82	0.01	0.04	0.49	1
UM3[a]	14	8.92	0.77	8.86	0.81	0.06	0.04	0.62	1
LM3	20	8.78	0.96	8.8	0.94	-0.02	0.04	0.48	1

Table 5. TEM and rTEM results evaluating inter-observer error in 3D cervical measurements

Measurements	N	Measurement 1		Measurement 2		Diff	TEM	rTEM	R
		Mean	SD	Mean	SD				
Mesiodistal									
UI1	19	6.27	0.63	6.25	0.63	0.01	0.04	0.61	1
LI1	21	3.5	0.23	3.51	0.24	-0.01	0.03	0.9	0.98
UI2	20	4.63	0.59	4.64	0.6	-0.01	0.04	0.78	1
LI2	20	3.78	0.37	3.78	0.37	0	0.03	0.88	0.99
UC	24	5.48	0.56	5.48	0.59	0	0.04	0.77	1
LC	23	5.15	0.57	5.14	0.58	0.02	0.03	0.59	1
UP3	24	4.56	0.43	4.56	0.42	-0.01	0.04	0.8	0.99
LP3	22	4.61	0.42	4.59	0.44	0.02	0.04	0.79	0.99
UP4	22	4.45	0.39	4.42	0.4	0.03	0.04	0.81	0.99
LP4	23	4.83	0.46	4.81	0.46	0.02	0.04	0.77	0.99
UM1	24	7.77	0.45	7.76	0.45	0.01	0.04	0.5	0.99
LM1	23	8.75	0.57	8.75	0.57	0	0.04	0.44	1
UM2	24	7.63	0.73	7.61	0.72	0.02	0.03	0.46	1
LM2	24	8.74	0.75	8.73	0.75	0.01	0.04	0.43	1
UM3	8	6.36	0.64	6.35	0.69	0.01	0.04	0.7	1
LM3	13	8.96	0.84	8.95	0.84	0.02	0.05	0.51	1
Buccolingual									
UI1	19	6.12	0.52	6.12	0.5	0	0.04	0.61	0.99
LI1	21	5.3	0.36	5.28	0.34	0.02	0.04	0.66	0.99
UI2	20	5.5	0.4	5.48	0.4	0.02	0.04	0.75	0.99
LI2	20	5.6	0.39	5.58	0.39	0.02	0.03	0.6	0.99
UC	24	7.65	0.69	7.65	0.67	0	0.03	0.45	0.99
LC	23	7.09	0.76	7.08	0.75	0.01	0.04	0.62	1
UP3	24	7.94	0.72	7.94	0.73	0	0.04	0.49	1
LP3	22	6.46	0.51	6.46	0.52	0	0.04	0.54	1
UP4	22	7.87	0.83	7.85	0.83	0.02	0.04	0.5	1
LP4	23	6.93	0.72	6.92	0.73	0.01	0.03	0.5	1
UM1	24	9.74	0.74	9.73	0.75	0.01	0.03	0.34	1
LM1	23	8.56	0.56	8.55	0.55	0.01	0.03	0.4	1
UM2	24	9.89	0.89	9.88	0.88	0.01	0.04	0.36	1
LM2	24	8.16	0.59	8.16	0.61	0	0.05	0.62	0.99
UM3	8	9.13	1	9.1	1	0.03	0.04	0.44	1
LM3	13	7.88	0.4	7.91	0.43	-0.03	0.04	0.57	0.99

Table 6. TEM and rTEM results evaluating inter-observer error in RV measurements

Measurements	N	Measurement 1		Measurement 2		Diff	TEM	rTEM	R
		Mean	SD	Mean	SD				
Volume									
UI1	20	227.31	53.34	225.49	52.02	1.82	4.8	2.12	0.99
LI1	21	100.14	17.7	100.29	18.46	-0.16	2.21	2.2	0.98
UI2	23	147.33	37.12	145.92	35.93	1.41	3.33	2.27	0.99
LI2	20	127.78	24.89	126.48	23.42	1.3	2.77	2.18	0.99
UC	25	249.5	86.28	249.14	84.89	0.36	4.63	1.86	1
LC	22	247.09	69.42	246.18	69.6	0.91	3.69	1.5	1
UP3	22	152.41	34.9	152.09	34.68	0.32	3.05	2.01	0.99
LP3	24	161.08	38.31	162.22	37.26	-1.14	3.2	1.98	0.99
UP4	24	174.6	51.38	173.48	49.79	1.12	3.9	2.24	0.99
LP4	23	186.36	52.64	185.93	52.79	0.43	4.13	2.22	0.99
UM1	25	432.25	73.76	432.17	73.57	0.07	4.56	1.06	1
LM1	23	429.04	87.83	429.32	88.96	-0.27	4.24	0.99	1
UM2	24	410.3	112.62	409.84	111.6	0.46	4.98	1.21	1
LM2	22	384.16	90.85	384.99	92.22	-0.83	4.23	1.1	1
UM3	6	277.94	85.49	278.91	87.43	-0.97	4.71	1.69	1
LM3	12	322.62	67.65	320.64	69.76	1.97	4.46	1.39	1

Table 7. Independent student t-test comparing the means between Hasanlu and Dinkha Tepe collections including original and bootstrap samples– 2D cervical measurements.

Measurements	Hasanlu			Dinkha Tepe			*t*-value	*p*-value	Bootstrap *p*-value
	N	Mean	SD	N	Mean	SD			
Mesiodistal									
UI1	44	6.30	0.55	8	6.05	0.42	1.21	0.23	0.13
LI1	55	3.52	0.25	20	3.49	0.21	0.32	0.75	0.72
UI2	43	4.85	0.44	12	4.62	0.47	1.64	0.10	0.14
LI2	68	3.85	0.32	23	3.97	0.33	-1.48	0.14	0.17
UC	64	5.60	0.50	20	5.53	0.54	0.55	0.58	0.59
LC	75	5.31	0.50	27	5.43	0.60	-0.99	0.32	0.34
UP3	71	4.56	0.39	16	4.58	0.50	-0.20	0.84	0.86
LP3	84	4.73	0.37	27	4.84	0.37	-1.41	0.16	0.16
UP4	64	4.69	0.39	19	4.76	0.44	-0.71	0.48	0.48
LP4	80	4.97	0.41	24	5.13	0.38	-1.69	0.09	0.08
UM1	67	7.72	0.45	17	7.73	0.36	-0.14	0.88	0.87
LM1	73	8.89	0.56	22	9.00	0.53	-0.75	0.46	0.43
UM2	62	7.47	0.71	20	7.71	0.66	-1.30	0.20	0.18
LM2	79	8.88	0.73	28	8.95	0.62	-0.45	0.65	0.62
UM3	33	6.78	0.59	13	7.37	0.57	-2.99	0.00	0.00
LM3	47	8.57	0.91	21	8.96	0.90	-1.63	0.11	0.10
Buccolingual									
UI1	44	6.29	0.40	8	6.07	0.56	1.32	0.19	0.28
LI1	55	5.54	0.38	20	5.45	0.34	0.90	0.37	0.36
UI2	43	5.73	0.45	12	5.52	0.46	1.41	0.16	0.16
LI2	68	6.00	0.35	23	5.97	0.39	0.30	0.77	0.80
UC	63	7.87	0.62	20	7.57	0.65	1.33	0.19	0.12
LC	74	7.45	0.59	27	7.45	0.70	0.00	1.00	1.00
UP3	71	7.98	0.58	16	7.75	0.56	1.47	0.15	0.15
LP3	84	6.65	0.52	26	6.75	0.60	-0.87	0.39	0.41
UP4	64	8.19	0.72	19	7.99	0.51	1.14	0.26	0.16
LP4	80	7.08	0.65	23	7.32	0.57	-1.61	0.11	0.08
UM1	66	9.96	0.61	17	9.87	0.47	0.54	0.59	0.53
LM1	74	8.71	0.62	22	8.78	0.65	-0.45	0.65	0.66
UM2	62	9.82	0.82	20	10.05	0.70	-1.11	0.27	0.22
LM2	79	8.30	0.71	27	8.33	0.65	-0.24	0.81	0.80
UM3	32	9.44	0.92	13	9.22	0.95	0.71	0.48	0.49
LM3	47	7.95	0.55	21	8.03	0.59	-0.55	0.59	0.59

Table 8. Independent student t-test comparing the means between Hasanlu and Dinkha Tepe collections including original and bootstrap samples– 3D cervical measurements.

Measurements	Hasanlu			Dinkha Tepe			*t*-value	*p*-value	Bootstrap *p*-value
	N	Mean	SD	N	Mean	SD			
Mesiodistal									
UI1	15	6.34	0.59	7	6.17	0.53	0.65	0.53	0.49
LI1	12	3.54	0.24	15	3.5	0.24	0.46	0.65	0.66
UI2	13	4.81	0.48	9	4.4	0.56	1.84	0.08	0.09
LI2	12	3.83	0.37	14	3.81	0.39	-0.05	0.96	0.96
UC	21	5.51	0.52	14	5.34	0.58	0.95	0.35	0.35
LC	14	5.16	0.56	16	5.21	0.58	-0.25	0.81	0.8
UP3	23	4.58	0.41	12	4.57	0.54	0.03	0.98	0.98
LP3	17	4.64	0.44	17	4.83	0.39	-1.33	0.19	0.19
UP4	19	4.54	0.32	12	4.59	0.44	-0.33	0.75	0.75
LP4	17	4.85	0.52	15	5.03	0.42	-1.12	0.27	0.28
UM1	20	7.76	0.45	10	7.8	0.44	-0.23	0.82	0.8
LM1	16	8.66	0.57	14	8.52	0.45	0.74	0.47	0.45
UM2	20	7.63	7.42	10	7.78	0.54	-0.57	0.57	0.52
LM2	18	8.15	0.59	18	8.31	0.58	-0.81	0.42	0.42
UM3	7	6.4	0.68	7	7.29	0.76	-2.33	0.04	0.05
LM3	6	7.9	0.44	16	7.93	0.48	-0.13	0.9	0.91
Buccolingual									
UI1	15	6.27	0.41	7	6.32	0.7	-0.23	0.82	0.86
LI1	12	5.44	0.38	15	5.29	0.33	1.14	0.26	0.28
UI2	13	5.65	0.4	9	5.39	0.4	1.49	0.15	0.17
LI2	12	5.75	0.4	14	5.76	0.31	0.16	0.88	0.87
UC	21	7.66	0.7	14	7.36	0.57	1.3	0.2	0.16
LC	14	7.17	0.78	16	7.18	0.77	-0.03	0.97	0.97
UP3	23	8.01	0.65	12	7.59	0.48	1.97	0.07	0.06
LP3	17	6.5	0.5	17	6.64	0.42	-0.86	0.4	0.42
UP4	19	8.02	0.85	12	7.74	0.48	1.05	0.3	0.24
LP4	16	7.12	0.64	15	7.08	0.46	0.19	0.84	0.84
UM1	20	9.87	0.64	10	9.65	0.51	0.95	0.35	0.29
LM1	16	8.81	0.64	14	8.85	0.38	-0.19	0.85	0.84
UM2	20	9.99	0.79	10	10.02	0.74	-0.1	0.92	0.92
LM2	18	8.74	0.78	18	8.99	0.49	-1.13	0.27	0.29
UM3	7	9.26	0.99	7	8.98	0.69	0.6	0.56	0.54
LM3	6	8.67	0.78	16	9.07	0.69	-1.16	0.26	0.28

Table 9. Independent student t-test comparing the means between Hasanlu and Dinkha Tepe collections including original and bootstrap samples– root volume measurements.

Measurements	Hasanlu			Dinkha Tepe			*t*-value	*p*-value	Bootstrap *p*-value
	N	Mean	SD	N	Mean	SD			
UI1	14	219.13	53.35	7	192.24	64.35	1.02	0.32	0.35
LI1	14	102.66	20.14	15	100.58	16.68	0.30	0.76	0.79
UI2	14	153.85	41.71	11	127.77	47.88	0.32	0.16	0.16
LI2	15	129.44	29.93	14	128.88	31.45	0.05	0.96	0.97
UC	20	258.92	88.19	15	228.77	83.15	1.03	0.31	0.32
LC	16	224.36	63.24	16	243.45	61.58	-0.87	0.39	0.42
UP3	23	161.73	39.37	18	145.60	41.99	1.26	0.21	0.22
LP3	19	153.39	32.59	18	161.63	34.51	-0.75	0.46	0.47
UP4	19	166.85	35.77	14	169.08	44.73	-0.16	0.88	0.88
LP4	17	181.60	52.83	15	191.61	33.11	-0.63	0.53	0.53
UM1	19	444.34	79.79	11	420.62	84.92	0.77	0.45	0.44
LM1	15	415.37	85.59	15	440.87	60.95	-0.94	0.36	0.36
UM2	21	406.79	106.81	10	406.06	79.19	0.02	0.99	0.98
LM2	18	366.23	91.69	18	397.43	68.00	-1.16	0.25	0.25
UM3	7	260.90	49.86	7	277.73	40.93	-0.69	0.50	0.53
LM3	9	323.73	78.21	15	317.01	68.04	0.22	0.83	0.83

Table 10: Paired student t-test comparing the means between right and left side teeth-Females, 2D cervical measurements.

Measurements	N	Average	SD	t- value	*p* value
Mesiodistal					
URI1	12	6.38	0.35	-0.65	0.53
ULI1	12	6.41	0.41		
URI2	11	4.58	0.44	1.71	0.12
ULI2	11	4.51	0.44		
URC	15	5.30	0.44	-1.21	0.25
ULC	15	5.33	0.45		
URP3	17	4.26	0.38	-1.31	0.21
ULP3	17	4.34	0.48		
URP4	14	4.70	0.84	1.17	0.26
ULP4	14	4.47	0.29		
URM1	16	7.53	0.30	1.18	0.26
ULM1	16	7.50	0.33		
URM2	13	7.25	0.57	1.09	0.30
ULM2	13	7.18	0.56		
URM3	5	6.96	0.85	0.46	0.67
ULM3	5	6.94	0.77		
LRI1	14	3.40	0.23	0.27	0.79
LLI1	14	3.40	0.22		
LRI2	20	3.79	0.32	0.1	0.92
LLI2	20	3.78	0.29		
LRC	22	4.98	0.39	0.67	0.51
LLC	22	4.97	0.41		
LRP3	24	4.61	0.33	1.2	0.24
LLP3	24	4.54	0.39		
LRP4	19	4.84	0.38	0.11	0.91
LLP4	19	4.84	0.42		
LRM1	18	8.69	0.64	0.81	0.43
LLM1	18	8.57	0.67		
LRM2	16	8.39	0.55	0.99	0.34
LLM2	16	7.88	2.17		
LRM3	6	8.45	1.33	-0.24	0.82
LLM3	6	8.48	1.29		
Buccolingual					
URI1	12	6.25	0.37	-0.71	0.49
ULI1	12	6.29	0.32		

Continued

Table 10 continued

Measurements	N	Average	SD	t- value	*p* value
URI2	11	5.61	0.43	-1.14	0.28
ULI2	11	5.63	0.43		
URC	15	7.38	0.83	-0.90	0.38
ULC	15	7.50	0.62		
URP3	17	7.65	0.66	0.61	0.55
ULP3	17	7.63	0.67		
URP4	14	7.95	0.65	1.32	0.21
ULP4	14	7.89	0.63		
URM1	16	9.56	0.31	0.71	0.49
ULM1	16	9.42	0.81		
URM2	13	9.27	0.60	1.06	0.31
ULM2	13	9.17	0.84		
URM3	5	9.28	0.48	1.18	0.30
ULM3	5	9.05	0.29		
LRI1	14	5.38	0.34	-1.00	0.34
LLI1	14	5.41	0.30		
LRI2	20	5.87	0.38	1.21	0.24
LLI2	20	5.85	0.37		
LRC	22	7.18	0.58	0.50	0.62
LLC	22	7.16	0.49		
LRP3	24	6.45	0.40	1.33	0.20
LLP3	24	6.42	0.44		
LRP4	19	7.07	0.54	-0.11	0.91
LLP4	19	7.07	0.55		
LRM1	18	8.40	0.52	0.86	0.40
LLM1	18	7.99	2.06		
LRM2	16	7.82	0.51	-1.89	0.08
LLM2	16	7.89	0.49		
LRM3	6	7.52	0.54	-1.55	0.18
LLM3	6	7.70	0.69		

Table 11: Paired student t-test comparing the means between right and left side teeth- Males, 2D cervical measurements.

Measurements	N	Average	SD	t- value	*p* value
Mesiodistal					
URI1	17	6.26	0.40	-0.35	0.73
ULI1	17	6.27	0.41		
URI2	15	4.73	0.29	-0.77	0.45
ULI2	15	4.76	0.29		
URC	34	5.84	0.38	-0.15	0.89
ULC	34	5.85	0.41		
URP3	32	4.68	0.34	-0.63	0.53
ULP3	32	4.71	0.43		
URP4	25	4.75	0.35	-1.2	0.24
ULP4	25	4.77	0.36		
URM1	28	7.82	0.41	0.76	0.46
ULM1	28	7.78	0.46		
URM2	26	7.78	0.61	1.89	0.07
ULM2	26	7.72	0.54		
URM3	13	7.02	0.82	-1.62	0.13
ULM3	13	7.18	0.79		
LRI1	27	3.60	0.17	-0.19	0.85
LLI1	27	3.60	0.15		
LRI2	35	4.06	0.32	-0.93	0.36
LLI2	35	4.08	0.33		
LRC	42	5.54	0.44	-1.57	0.12
LLC	42	5.60	0.44		
LRP3	48	4.92	0.31	-0.93	0.36
LLP3	48	4.95	0.37		
LRP4	50	5.11	0.38	0.83	0.41
LLP4	50	5.01	0.82		
LRM1	49	8.94	0.69	-0.7	0.49
LLM1	49	9.00	0.51		
LRM2	49	9.09	0.60	-0.63	0.53
LLM2	49	9.11	0.63		
LRM3	19	8.89	0.89	1.55	0.14
LLM3	19	8.77	0.82		
Buccolingual					
URI1	17	0.83	0.83	-0.91	0.38
ULI1	17	0.41	0.41		

Continued

Table 11 continued

Measurements	N	Average	SD	t- value	*p* value
URI2	15	5.71	0.40	0.50	0.62
ULI2	15	5.67	0.39		
UC	34	8.05	0.55	-0.03	0.98
LC	34	8.05	0.49		
URP3	32	8.09	0.61	-0.34	0.73
ULP3	32	8.10	0.63		
URP4	25	8.38	0.68	0.09	0.93
ULP4	25	8.38	0.66		
URM1	28	10.00	0.84	-0.30	0.76
ULM1	28	10.05	0.78		
URM2	26	10.14	0.76	0.95	0.35
ULM2	26	10.02	1.09		
URM3	13	9.84	0.94	0.16	0.88
ULM3	13	9.81	1.03		
LRI1	27	5.66	0.33	1.00	0.33
LLI1	27	5.64	0.34		
LRI2	35	6.11	0.28	1.44	0.16
LLI2	35	6.08	0.31		
LRC	42	7.67	0.51	1.23	0.23
LLC	42	7.59	0.62		
LRP3	48	6.90	0.48	1.48	0.15
LLP3	48	6.84	0.60		
LRP4	50	7.29	0.61	1.66	0.10
LLP4	50	7.27	0.61		
LRM1	49	8.88	0.55	-1.00	0.32
LLM1	49	27.84	132.44		
LRM2	49	8.54	0.55	-1.75	0.09
LLM2	49	8.59	0.52		
LRM3	19	8.33	0.65	-1.60	0.13
LLM3	19	8.42	0.71		

Table 12. Paired student t-test comparing the means between 2D and 3D cervical measurements including original and bootstrap samples.

Measurements	2D cervical			3D cervical			t-value	p-value	Bootstrap p-value
Mesiodistal	N	Mean	SD	N	Mean	SD			
UI1	21	6.28	0.51	21	6.28	0.58	0.03	0.98	0.98
LI1	23	3.49	0.23	23	3.49	0.23	-0.19	0.84	0.84
UI2	20	4.68	0.50	20	4.59	0.55	1.97	0.06	0.06
LI2	24	3.85	0.35	24	3.83	0.38	1.03	0.31	0.31
UC	33	5.45	0.51	33	5.43	0.51	1.02	0.32	0.32
LC	30	5.20	0.56	30	5.19	0.56	0.81	0.43	0.43
UP3	30	4.58	0.43	30	4.59	0.43	-0.39	0.70	0.71
LP3	34	4.73	0.37	34	4.73	0.42	-0.22	0.83	0.82
UP4	29	4.61	0.36	29	4.57	0.36	2.00	0.06	0.06
LP4	32	4.95	0.44	32	4.93	0.47	0.94	0.36	0.33
UM1	25	7.76	0.42	25	7.77	0.41	-0.32	0.75	0.75
LM1	28	8.89	0.51	28	8.87	0.52	0.71	0.48	0.46
UM2	28	7.63	0.61	28	7.63	0.66	0.19	0.85	0.84
LM2	35	8.88	0.62	35	8.83	0.62	2.24	0.03	0.03
UM3	14	6.88	0.85	14	6.85	0.83	1.51	0.16	0.16
LM3	21	9.00	0.77	21	8.97	0.74	1.53	0.14	0.12
Buccolingual									
UI1	21	6.27	0.40	21	6.25	0.48	1.10	0.23	0.28
LI1	23	5.38	0.33	23	5.36	0.36	0.79	0.44	0.43
UI2	20	5.58	0.47	20	5.54	0.43	1.45	0.16	0.16
LI2	24	5.83	0.36	24	5.78	0.34	1.99	0.06	0.07
UC	33	7.58	0.63	33	7.54	0.66	1.68	0.10	0.10
LC	29	7.28	0.74	29	7.22	0.72	2.42	0.20	0.03
UP3	30	7.91	0.68	30	7.91	0.64	-0.11	0.91	0.91
LP3	34	6.58	0.48	34	6.57	0.46	0.13	0.90	0.90
UP4	29	7.95	0.75	29	7.92	0.74	1.25	0.22	0.22
LP4	31	7.15	0.55	31	7.1	0.55	1.81	0.08	0.08
UM1	25	9.75	0.63	25	9.79	0.58	-1.38	0.18	0.17
LM1	28	8.62	0.52	28	8.63	0.51	-0.80	0.44	0.44
UM2	28	9.90	0.76	28	9.97	0.77	-3.07	0.00	0.02
LM2	35	8.19	0.60	35	8.22	0.59	-1.40	0.17	0.17
UM3	14	9.16	0.86	14	9.12	0.83	1.11	0.23	0.31
LM3	21	7.96	0.51	21	7.95	0.45	0.24	0.81	0.82

Table 13. Classification accuracy of original and bootstrapped samples- 3D cervical measurements- direct discriminant analysis

Functions	Predicted Group Membership					
	Original 3D cervical measurements					
	Original %			Cross-validated %		
	Male	Female	Total	Male	Female	Total
F16:UI1	100	71.4	90.9	93.3	71.4	86.4
F17:LI1	86.7	100	92.6	86.7	100	92.6
F18:UI2	100	100	100	100	100	100
F19:LI2	86.7	100	92.3	86.7	100	92.3
F20:UC	95	100	97.1	95	100	97.1
F21:LC	94.7	100	96.7	94.7	100	96.7
F22:UP3	85.7	92.9	88.6	85.7	92.9	88.6
F23:LP3	85	78.6	82.4	85	78.6	82.4
F24:UP4	81.3	86.7	83.9	81.3	86.7	83.9
F25:LP4	90	72.7	83.9	85	72.7	80.6
F26:UM1	88.2	100	93.3	88.2	100	93.3
F27:LM1	82.4	84.6	83.3	82.4	76.9	80
F28:UM2	90.5	88.9	90	90.5	88.9	90
F29:LM2	85.7	86.7	86.1	85.7	80	83.3
	Bootstrap 3D cervical measurements*					
F16:UI1	100	71.4	90.9	93.3	71.4	86.4
F17:LI1	85.7	100	92.3	85.7	100	92.3
F18:UI2	100	100	100	100	100	100
F19:LI2	86.7	100	92.3	86.7	100	92.3
F20:UC	94.7	100	97.1	94.7	93.3	94.1
F21:LC	88.2	100	92.9	88.2	100	92.9
F22:UP3	85	92.9	88.2	85	92.9	88.2
F23:LP3	83.3	85.7	84.4	83.3	78.6	81.3
F24:UP4	80	86.7	83.3	80	86.7	83.3
F25:LP4	90	72.7	83.9	85	72.7	80.6
F26:UM1	87.5	100	93.1	67.5	100	93.1
F27:LM1	80	84.6	82.1	80	76.9	78.6
F28:UM2	90.5	88.9	90	90.5	88.9	90
F29:LM2	84.2	86.7	85.3	78.9	80	79.4

*Based on 1000 bootstrapped samples.

Table 14. Classification accuracy of original and bootstrapped samples- univariate discriminant analysis of 3D cervical MD measurements.

Functions	Predicted Group Membership					
	Original 3D cervical measurements					
	Original %			Cross-validated %		
MD	Male	Female	Total	Male	Female	Total
F103: UI1	86.7	71.4	81.8	86.7	71.4	81.8
F104: LI1	86.7	100	92.6	86.7	100	92.6
F105: UI2	100	87.5	95.5	100	87.5	95.5
F106: LI2	86.7	100	92.3	86.7	100	92.3
F107: UC	95	93.3	94.3	95	93.3	94.3
F108: LC	94.7	90	93.3	89.5	90.9	90
F109: UP3	85.7	92.9	88.6	85.7	92.9	88.6
F110: LP3	85	92.9	88.2	85	85.7	85.3
F111: UP4	81.3	80	80.6	81.3	80	80.6
F112: LP4	90	75	84.4	90	75	84.4
F113: UM1	94.1	100	96.7	94.1	100	96.7
F114: LM1	82.4	69.2	76.7	82.4	69.2	76.7
F115: UM2	85.7	66.7	80	81	66.7	76.7
F116: LM2	85.7	66.7	77.8	85.7	66.7	77.8
	Bootstrap* 3D cervical measurements					
F103: UI1	86.7	71.4	81.8	86.7	71.4	81.8
F104: LI1	85.7	100	92.3	85.7	100	92.3
F105: UI2	100	87.5	95.5	100	87.5	95.5
F106: LI2	86.7	100	92.3	86.7	100	92.3
F107: UC	95	93.3	94.3	95	93.3	94.3
F108: LC	94.7	90	93.3	89.5	90.9	90
F109: UP3	85	92.9	88.2	85	92.9	88.2
F110: LP3	83.3	92.9	87.5	83.3	92.9	87.5
F111: UP4	80	86.7	83.3	80	80	80
F112: LP4	88.9	75	83.3	88.9	75	83.3
F113: UM1	93.8	100	96.6	93.8	92.3	93.1
F114: LM1	80	69.2	75	80	69.2	75
F115: UM2	85	66.7	79.3	80	66.7	79.3
F116: LM2	84.2	66.7	76.5	84.2	66.7	76.5

*Based on 1000 bootstrapped samples.

Table 15. Classification accuracy of original and bootstrapped samples- univariate discriminant analysis of 3D cervical BL measurements.

Functions	Predicted Group Membership					
	Original 3D cervical measurements					
	Original %			Cross-validated %		
BL	Male	Female	Total	Male	Female	Total
F117: UI1	93.3	85.7	90.9	93.3	85.7	90.9
F118: LI1	86.7	91.7	88.9	86.7	91.7	88.9
F119: UI2	85.7	75	81.8	85.7	75	81.8
F120: LI2	80	100	88.5	80	100	88.5
F121: UC	85	73.3	80	85	73.3	80
F122: LC	89.5	90.9	90	89.5	90.9	90
F123: UP3	90.5	78.6	85.7	90.5	78.6	85.7
F124: LP3	85	71.4	79.4	85	71.4	79.4
F125: UP4	75	80	77.4	75	80	77.4
F126: LP4	90	54.5	77.4	90	54.5	77.4
F127: UM1	76.5	84.6	80	76.5	84.6	80
F128: LM1	88.2	76.9	83.3	88.2	76.9	83.3
F129: UM2	90.5	88.9	90	90.5	88.9	90
F130: LM2	81	80	80.6	81	80	80.6
F131: LM3	85.7	75	81.8	78.6	75	77.3
	Bootstrap* 3D cervical measurements					
F117: UI1	93.3	85.7	90.9	93.3	85.7	90.9
F118: LI1	85.7	91.7	88.5	85.7	91.7	88.5
F119: UI2	84.6	75	81	84.6	75	81
F120: LI2	80	100	88.5	80	100	88.5
F121: UC	85	73.3	80	85	73.3	80
F122: LC	88.2	90.9	89.3	88.2	90.9	89.3
F123: UP3	90.5	78.6	85.7	90.5	78.6	85.7
F124: LP3	83.3	71.4	78.1	83.3	71.4	78.1
F125: UP4	73.3	86.7	83.3	73.3	80	76.7
F126: LP4	90	54.5	77.4	90	54.5	77.4
F127: UM1	75	84.6	79.3	75	84.6	79.3
F128: LM1	86.7	76.9	82.1	86.7	76.9	82.1
F129: UM2	90	88.9	89.7	90	88.9	89.7
F130: LM2	78.9	80	79.4	78.9	80	79.4
F131: LM3	84.6	75	81	76.9	75	76.2

*Based on 1000 bootstrapped samples.

APPENDIX B

IMAGES

Fig 1. Maxillary and mandibular teeth, Skeleton (60-20-224), Low Mound (IV), Female, Middle Adult.

Fig 2: Mandibular teeth, skeleton (60-20-222), Low Mound (IV), female, middle adult.

Fig 3: Maxillary and mandibular teeth, skeleton (58-4-103), Low Mound (IV), female, young adult.

Fig 4: Mandibular teeth, skeleton (58-4-107), Low Mound (IV), male, old adult.

Fig 5: Mandibular teeth, skeleton (60-20-225), Low Mound (IV), female, young adult.

Fig 6: Maxillary teeth, skeleton (59-4-105), High Mound (IVB), male, young adult.

Fig 7: Maxillary teeth, skeleton (59-4-109), Low Mound (V), male, old adult.

Fig 8: Mandibular teeth, skeleton (60-20-229), Low Mound (IV), male, young adult

APPENDIX C- A

LIST OF HASANLU AND DINKHA TEPE SKELETONS

Museum number	Period	Location	Age	Sex*
58-4-95	III/IV	Low Mound	MA	F
58-4-96	IV	Low Mound	MA	I
58-4-97	IV	Low Mound	AD	I
58-4-98	IV	Low Mound	CH	I
58-4-99	IV	Low Mound	YA	M
58-4-100	IV	Low Mound	SA	I
58-4-101	IV	Low Mound	OA	I
58-4-102	IV	Low Mound	MA	F
58-4-103	IV	Low Mound	YA	F
58-4-104	IV	Low Mound	OA	I
58-4-105	V?	Low Mound	MA	F
58-4-106	V	Low Mound	YA	F
58-4-107	IV	Low Mound	OA	M
58-4-108	IV	Low Mound	YA	M
58-4-109	V	Low Mound	OA	M
58-4-110	IV	Low Mound	SA	I
58-4-112	IV	Low Mound	OA	M
59-4-102	V	Low Mound	MA	F
59-4-103	V	Low Mound	MA	F
59-4-104	V	Low Mound	MA	F
59-4-105	IVB	High Mound	YA	M
59-4-106	IVB	High Mound	YA	M
59-4-107	IVB	High Mound	MA	F
59-4-110	IV	High Mound	MA	M
60-20-220	V	Low Mound	MA	F
60-20-221	IV	Low Mound	MA	F
60-20-222	IV	Low Mound	MA	F
60-20-223	V	Low Mound	MA	M
60-20-224	IV	Low Mound	MA	F
60-20-225	IV	Low Mound	YA	F
60-20-226	V	Low Mound	CH	I
60-20-227	V	Low Mound	OA	F
60-20-228	V	Low Mound	OA	F
60-20-229	IV	Low Mound	YA	I
60-20-231	IVB	High Mound	MA	F
60-20-232	IVB	High Mound	OA	M
60-20-233	IV	Low Mound	MA	M
60-20-235	IV	Low Mound	SA	I
60-20-236	V	Low Mound	OA	M

*Sex of the skeletons are based on conventional morphological analysis.

Museum number	Period	Location	Age	Sex
61-5-340	IVB	High Mound	YA	M
61-5-341	IVB	High Mound	YA	M
61-5-343	IVB	High Mound	CH	I
61-5-345	IVB	High Mound	MA	F
61-5-346	IVB	High Mound	YA	M
61-5-347	IVB	High Mound	MA	F
61-5-348	IVB	High Mound	YA	I
63-5-301	IVB	High Mound	OA	M
63-5-302	IVB	High Mound	YA	F
63-5-303	IVB	High Mound	YA	M
63-5-305	IVB	High Mound	YA	F
63-5-307	IVB	High Mound	MA	M
63-5-308	IVB	High Mound	MA	M
63-5-309	IVB	High Mound	OA	M
63-5-310	IVB	High Mound	MA	F
63-5-311	IVB	High Mound	YA	M
63-5-312	IVB	High Mound	SA	I
63-5-313	IVB	High Mound	YA	M
63-5-314	IVB	High Mound	MA	M
63-5-318	IVB	High Mound	SA	I
63-5-319	IVB	High Mound	MA	M
63-5-320	IVB	High Mound	SA	I
63-5-321	IVB	High Mound	YA	I
63-5-323	IVB	High Mound	MA	M
65-31-727	IV	Low Mound	IN	I
65-31-728	IV	Low Mound	CH	I
65-31-729	IV	Low Mound	IN	I
65-31-730	IV	Low Mound	IN	I
65-31-732	IV	Low Mound	MA	F
65-31-733	IV	Low Mound	MA	F
65-31-734	IV	Low Mound	MA	M
65-31-735	IV	Low Mound	IN	I
65-31-736	IV	Low Mound	IN	I
65-31-737	V	Low Mound	MA	M
65-31-738	IVB	High Mound	IN	I
65-31-739	IV	Low Mound	CH	I
65-31-740	IV	Low Mound	YA	M
65-31-742	IV	Low Mound	YA	F
65-31-743	IV	Low Mound	OA	F
65-31-744	IV	Low Mound	MA	M
65-31-745	IV	Low Mound	YA	M
65-31-747	IV	Low Mound	YA	M
65-31-749	IV	Low Mound	MA	M

Museum number	Period	Location	Age	Sex
65-31-750	IV	Low Mound	CH	I
65-31-751	IV	Low Mound	OA	M
65-31-752	IV	Low Mound	YA	M
65-31-753	IV	Low Mound	OA	M
65-31-754	IV	Low Mound	OA	M
65-31-756	IV	Low Mound	MA	M
65-31-757	IVB	High Mound	SA	M
65-31-760	IV	Low Mound	CH	I
65-31-761	IV	Low Mound	CH	I
65-31-762	IV	Low Mound	SA	I
65-31-763	IVB	High Mound	YA	M
65-31-764	IV	Low Mound	YA	M
65-31-765	IV	Low Mound	IN	I
65-31-766	V	Low Mound	IN	I
65-31-767	IV	Low Mound	IN	I
65-31-768	IV	Low Mound	YA	F
65-31-771	IV	Low Mound	YA	F
65-31-769	IVB	High Mound	MA	M
65-31-770	IV	Low Mound	CH	I
65-31-772	IVB	High Mound	MA	M
65-31-773	IV	Low Mound	OA	M
65-31-774	IV	Low Mound	MA	F
65-31-775	V	Low Mound	YA	F
65-31-776	IV	Low Mound	OA	M
65-31-777	IVB	High Mound	MA	M
65-31-778	IV	Low Mound	CH	I
65-31-780	IV	Low Mound	IN	I
65-31-782	IV	Low Mound	IN	I
65-31-783	IV	Low Mound	CH	I
65-31-784	IV	Low Mound	IN	I
65-31-786	IV	Low Mound	CH	I
65-31-788	V	Low Mound	MA	M
65-31-789	V	Low Mound	MA	M
65-31-790	IV	Low Mound	MA	F
65-31-791	IV	Low Mound	OA	F
65-31-792	IV	Low Mound	YA	M
65-31-793	IVB	High Mound	OA	M
65-31-794	IV	Low Mound	SA	I
65-31-795	IV	Low Mound	MA	F
65-31-796	IV	Low Mound	MA	F
65-31-797	IVB	High Mound	OA	I
65-31-798	IVB	High Mound	MA	I
65-31-805	IV	Low Mound	OA	M

Museum number	Period	Location	Age	Sex
65-31-806	IV	Low Mound	YA	F
65-32-737	V	Low Mound	SA	I
65-32-740	IV	Low Mound	MA	M
65-32-765	IV	Low Mound	CH	I
65-32-792	IV	Low Mound	OA	I
65-32-805	IV	Low Mound	YA	M
71-23-500	IVB	High Mound	YA	F
71-23-503	IVB	High Mound	CH	I
71-23-504	IVB	High Mound	YA	M
71-23-505	IVB	High Mound	OA	M
71-23-509	IVB	High Mound	AD	I
71-23-510	IVB	High Mound	YA	F
71-23-511	IVB	High Mound	YA	M
71-23-513	IVB	High Mound	MA	M
71-23-514	IVB	High Mound	AD	I
71-23-515	IVB	High Mound	MA	M
71-23-516	IVB	High Mound	MA	F
71-23-517	IVB	High Mound	IN	I
71-23-518	IVB	High Mound	MA	F
71-23-520	IVB	High Mound	SA	I
71-23-521	IVB	High Mound	SA	I
71-23-522	IVB	High Mound	YA	F
71-23-523	IVB	High Mound	CH	I
71-23-524	IVB	High Mound	MA	M
71-23-525	IVB	High Mound	YA	M
71-23-526	IVB	High Mound	MA	F
71-23-528	IVB	High Mound	CH	I
71-23-529	IVB	High Mound	MA	F
71-23-531	IVB	High Mound	OA	I
71-23-532	IVB	High Mound	CH	I
71-23-533	IVB	High Mound	AD	I
71-23-534	IVB	High Mound	SA	I
71-23-535	IVB	High Mound	YA	M
71-23-537	IVB	High Mound	AD	M
71-23-539	IVB	High Mound	MA	I
71-23-540	IVB	High Mound	MA	I
71-23-544	IVB	High Mound	CH	I
71-23-545	IVB	High Mound	YA	M
73-5-503	IVB	High Mound	MA	M
73-5-508	IVB	High Mound	CH	I
73-5-509	IVB	High Mound	IN	I
75-29-500	IVB	High Mound	YA	F
75-29-550	IVB	High Mound	SA	I

Museum number	Period	Location	Age	Sex
75-29-501	IVB	High Mound	YA	M
75-29-502	IVB	High Mound	CH	I
75-29-503	IVB	High Mound	YA	I
75-29-504	IVB	High Mound	OA	M
75-29-507	IVB	High Mound	AD	M
75-29-508	IVB	High Mound	YA	M
75-29-509	IVB	High Mound	YA	M
75-29-510	IVB	High Mound	YA	M
75-29-512	IVB	High Mound	SA	I
75-29-513	IVB	High Mound	CH	I
75-29-514	IVB	High Mound	SA	F
75-29-516	IVB	High Mound	SA	F
75-29-521	IVB	High Mound	MA	M
75-29-523	IVB	High Mound	CH	I
75-29-524	IVB	High Mound	IN	I
75-29-525	IVB	High Mound	AD	I
75-29-526	IVB	High Mound	MA	M
75-29-527	IVB	High Mound	MA	F
75-29-529	IVB	High Mound	SA	M
75-29-530	IVB	High Mound	AD	I
75-29-531	IVB	High Mound	MA	I
75-29-532	IVB	High Mound	CH	I
75-29-533	IVB	High Mound	SA	I
75-29-534	IVB	High Mound	OA	M
75-29-535	IVB	High Mound	AD	I
75-29-536	IVB	High Mound	YA	M
75-29-537	IVB	High Mound	AD	I
75-29-538	IVB	High Mound	AD	I
75-29-539	IVB	High Mound	AD	I
75-29-540	IVB	High Mound	SA	M
75-29-541	IVB	High Mound	AD	I
75-29-542	IVB	High Mound	MA	M
75-29-543	IVB	High Mound	MA	M
75-29-544	IVB	High Mound	YA	I
75-29-545	IVB	High Mound	SA	I
75-29-546	IVB	High Mound	SA	I
75-29-548	IVB	High Mound	IN	I
75-29-549	IVB	High Mound	AD	I
75-29-550	IVB	High Mound	SA	I
75-29-551	IVB	High Mound	YA	I
75-29-552	IVB	High Mound	OA	I
75-29-553	IVB	High Mound	MA	M
75-29-554	IVB	High Mound	MA	M

Museum number	Period	Location	Age	Sex
NMN-4	IVB	High Mound	FE	I
NMN-9	IVB	High Mound	AD	I
66-23-370	-	Dinkha Tepe	MA	F
66-23-371	-	Dinkha Tepe	OA	F
66-23-372	-	Dinkha Tepe	MA	M
66-23-373	-	Dinkha Tepe	MA	I
66-23-374	-	Dinkha Tepe	MA	M
66-23-375	-	Dinkha Tepe	MA	F
66-23-376	-	Dinkha Tepe	MA	M
66-23-377	-	Dinkha Tepe	YA	F
66-23-378	-	Dinkha Tepe	MA	I
66-23-379	-	Dinkha Tepe	CH	I
66-23-380	-	Dinkha Tepe	YA	F
66-23-381	-	Dinkha Tepe	YA	F
66-23-382	-	Dinkha Tepe	OA	I
66-23-383	-	Dinkha Tepe	MA	F
66-23-384	-	Dinkha Tepe	YA	F
66-23-385	-	Dinkha Tepe	YA	M
66-23-386	-	Dinkha Tepe	YA	F
66-23-387	-	Dinkha Tepe	MA	F
66-23-388	-	Dinkha Tepe	MA	M
66-23-389	-	Dinkha Tepe	MA	M
66-23-390	-	Dinkha Tepe	MA	M
66-23-391	-	Dinkha Tepe	SA	I
66-23-392	-	Dinkha Tepe	MA	M
66-23-393	-	Dinkha Tepe	MA	M
66-23-394	-	Dinkha Tepe	OA	F
66-23-395	-	Dinkha Tepe	MA	M
66-23-396	-	Dinkha Tepe	YA	F
66-23-397	-	Dinkha Tepe	OA	F
66-23-398	-	Dinkha Tepe	MA	M
66-23-399	-	Dinkha Tepe	OA	M
66-23-400	-	Dinkha Tepe	MA	F
66-23-401	-	Dinkha Tepe	MA	M
66-23-402	-	Dinkha Tepe	YA	M
66-23-403	-	Dinkha Tepe	OA	F
66-23-404	-	Dinkha Tepe	YA	M
66-23-405	-	Dinkha Tepe	MA	M
66-23-406	-	Dinkha Tepe	OA	M
66-23-407	-	Dinkha Tepe	OA	F
66-23-408	-	Dinkha Tepe	YA	M
66-23-409	-	Dinkha Tepe	MA	M
66-24-381	-	Dinkha Tepe	MA	M

Museum number	Period	Location	Age	Sex
66-24-382	-	Dinkha Tepe	OA	I
66-24-383	-	Dinkha Tepe	MA	F
69-33-2	-	Dinkha Tepe	OA	F
69-33-3	-	Dinkha Tepe	YA	M
69-33-4	-	Dinkha Tepe	MA	F
69-33-5	-	Dinkha Tepe	IN	I
69-33-6	-	Dinkha Tepe	CH	I
69-33-7	-	Dinkha Tepe	MA	M
69-33-8	-	Dinkha Tepe	OA	M
69-33-9	-	Dinkha Tepe	OA	M

APPENDIX C-B

THE COMPARISON BETWEEN MORPHOLOGICAL SEX ESTIMATION ANALYSIS AND RV MEASUREMENTS ANALYSIS

Comparison between morphological sex estimation results and RV measurement sex estimation results – upper jaw.

Museum Number	Sex	RV UI1	RV UI2	RV UC	RV UP3	RV UP4	RV UM1	RV UM2
58-4-95	**M***	-	-	F	F	F	F	F
	T	-	-	F	M	F	F	F
58-4-96	**M**	-	-	M	M	-	M	M
	T	-	-	M	**M**	-	M	M
58-4-100	**M**	F	F	F	**F**	F	F	F
	T	F	F	F	**M**	F	F	F
58-4-106	**M**	**F**	-	F	**F**	F	F	F
	T	**M**	-	F	F	F	F	F
58-4-107	**M**	-	**M**	-	**M**	**M**	-	**M**
	T	-	**F**	-	**F**	**F**	-	**F**
59-4-102	**M**	-	-	F	F	F	F	F
	T	-	-	F	F	F	F	F
59-4-107	**M**	-	-	F	F	F	F	F
	T	-	-	F	F	F	F	F
60-20-221	**M**	-	-	-	-	**F**	-	F
	T	-	-	-	-	**M**	-	F
60-20-222	**M**	F	F	-	F	F	F	-
	T	F	F	-	F	F	F	-
60-20-227	**M**	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-
60-20-233	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M
60-20-235	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M
63-5-308	**M**	M	M	M	-	-	M	M
	T	M	M	M	-	-	M	M
63-5-311	**M**	-	-	-	M	-	M	M
	T	-	-	-	M	-	M	M
65-31-389	**M**	-	-	-	M	-	-	-
	T	-	-	-	M	-	-	-
65-31-734	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M
65-31-745	**M**	M	M	M	M	M	-	M
	T	M	M	M	M	M	-	M
65-31-752	**M**	-	-	M	M	M	**M**	**M**
	T	-	-	M	M	M	**F**	**F**
65-31-753	**M**	M	M	M	M	-	M	-
	T	M	M	M	M	-	M	-
65-31-777	**M**	M	M	M	M	M	-	M
	T	M	M	M	M	M	-	M
65-31-789	**M**	-	-	-	**M**	-	-	-
	T	-	-	-	**F**	-	-	-
65-31-792	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M
65-31-805	**M**	-	-	-	M	M	M	-
	T	-	-	-	M	F	F	-

*Sex of the skeletons are based on conventional morphological analysis.
S: sex estimation based on **Skeletal** analysis, T: sex estimation using **Tooth** measurements, M: males, F: females.
Bold letters show the differences between the results of the two methods.

Comparison between morphological sex estimation results and RV measurement sex estimation results – upper jaw.

Museum Number	Sex	RV UI1	RV UI2	RV UC	RV UP3	RV UP4	RV UM1	RV UM2
66-23-370	**M**	-	F	F	F	F	F	F
	T	-	F	F	F	F	F	F
66-23-372	**M**	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-
66-23-374	**M**	-	-	F	F	-	-	-
	T	-	-	F	F	-	-	-
66-23-375	**M**	-	F	F	F	F	**F**	-
	T	-	F	F	F	F	**M**	-
66-23-377	**M**	F	F	-	F	F	F	-
	T	F	F	-	F	F	F	
66-23-380	**M**	-	-	F	F	F	F	F
	T	-	-	F	F	F	F	F
66-23-381	**T**	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-
66-23-387	**M**	F	F	F	F	F	-	-
	T	F	F	F	F	F	-	-
66-23-388	**M**	-	-	-	-	-	-	M
	T	-	-	-	-	-	-	M
66-23-390	**M**	-	-	-	M	-	-	-
	T	-	-	-	M	-	-	-
66-23-392	**M**	-	-	-	M	-	-	-
	T	-	-	-	M	-	-	-
66-23-393	**M**	M	M	M	M	M	M	-
	T	M	M	M	M	M	M	-
66-23-394	**M**	-	-	F	F	-	-	-
	T	-	-	F	F	-	-	-
66-23-395	**M**	M	M	M	M	M	-	M
	T	M	M	M	M	M	-	M
66-23-396	**M**	F	F	F	F	F	F	F
	T	F	F	F	F	F	F	F
66-23-400	**M**	-	-	F	F	F	-	-
	T	-	-	F	F	F	-	-
66-23-401	**M**	-	M	M	M	M	M	M
	T	-	M	M	M	M	M	M
66-23-402	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M
66-23-405	**M**	-	-	M	M	M	M	M
	T	-	-	M	M	M	M	M
66-23-406	**M**	-	M	M	M	M	M	M
	T	-	M	M	M	M	M	M
66-23-408	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M
66-23-409	**M**	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-
71-23-516	**M**	F	F	F	F	F	-	F
	T	F	F	F	F	F	-	F
75-29-500	**M**	-	-	F	F	F	**F**	F
	T	-	-	F	F	F	**M**	F
75-29-501	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M

Comparison between morphological sex estimation results and RV measurement sex estimation results – upper jaw.

Museum Number	Sex	RV UI1	RV UI2	RV UC	RV UP3	RV UP4	RV UM1	RV UM2
75-29-542	**M**	M	M	M	M	-	**M**	**M**
	T	M	M	M	M	-	**F**	**F**
75-29-543	**M**	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M

Comparison between morphological sex estimation results and RV measurement sex estimation results – lower jaw.

Museum Number	Sex	RV LI1	RV LI2	RV LC	RV LP3	RV LP4	RV LM1	RV LM2	RV LM3
58-4-95	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
58-4-96	**M**	M	M	**M**	**M**	M	-	**M**	**M**
	T	M	M	**F**	**F**	M	-	**F**	**F**
58-4-100	**M**	F	F	F	F	-	F	F	-
	T	F	F	F	F	-	F	F	-
58-4-106	**M**	F	F	F	F	F	F	F	-
	T	F	F	F	F	F	F	F	-
58-4-107	**M**	M	M	M	M	**M**	M	**M**	-
	T	M	M	M	M	**F**	M	**F**	-
59-4-102	**M**	F	F	F	F	F	F	F	F
	T	F	F	F	F	F	F	F	F
59-4-107	**M**	F	F	F	F	F	F	F	F
	T	F	F	F	F	F	F	F	F
60-20-221	**M**	-	-	F	F	F	F	F	-
	T	-	-	F	F	F	F	F	-
60-20-222	**M**	-	F	-	F	F	F	F	-
	T	-	F	-	F	F	F	F	-
60-20-227	**M**	-	-	F	F	-	-	-	-
	T	-	-	F	F	-	-	-	
60-20-233	**M**	M	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M	M
60-20-235	**M**	M	M	M	M	**M**	M	**M**	-
	T	M	M	M	M	**F**	M	**F**	-
63-5-308	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
63-5-311	**M**	-	-	-	M	M	M	M	**M**
	T	-	-	-	M	M	M	M	**F**
65-31-389	**M**	-	-	-	M	-	-	-	-
	T	-	-	-	M	-	-	-	-
65-31-734	**M**	M	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M	M
65-31-745	**M**	M	M	**M**	M	M	M	M	M
	T	M	M	**F**	M	M	M	M	M
65-31-752	**M**	M	M	M	M	M	**M**	M	M
	T	M	M	M	M	M	**F**	M	M
65-31-753	**M**	M	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M	M
65-31-777	**M**	M	M	M	M	M	-	M	-
	T	M	M	M	M	M	-	M	-
65-31-789	**M**	-	-	-	-	-	-	M	-
	T	-	-	-	-	-	-	M	-
65-31-792	**M**	M	M	M	M	M	M	M	-
	T	M	M	M	M	M	M	M	-
65-31-805	**M**	-	-	-	-	M	-	-	-
	T	-	-	-	-	M	-	-	-

*Sex of the skeletons are based on conventional morphological analysis.
S: sex estimation based on **Skeletal** analysis, T: sex estimation using **Tooth** measurements, M: males, F: females.
Bold letters show the differences between the results of the two methods.

Comparison between morphological sex estimation results and RV measurement sex estimation results – lower jaw.

Museum Number	Sex	RV LI1	RV LI2	RV LC	RV LP3	RV LP4	RV LM1	RV LM2	RV LM3
66-23-370	**M**	**F**	-	F	F	F	F	F	F
	T	**M**	-	F	F	F	F	F	F
66-23-372	**M**	-	-	M	M	M	M	M	M
	T	-	-	M	M	M	M	M	M
66-23-374	**M**	F	F	F	F	-	-	F	F
	T	F	F	F	F	-	-	F	F
66-23-375	**M**	F	F	F	F	**F**	F	**F**	F
	T	F	F	F	F	**M**	F	**M**	F
66-23-377	**M**	**F**	**F**	F	**F**	F	-	**F**	-
	T	**M**	**M**	F	**M**	F	-	**M**	-
66-23-380	**M**	-	-	-	F	**F**	F	F	**F**
	T	-	-	-	F	**M**	F	F	**M**
66-23-381	**T**	-	-	M	M	M	M	M	**M**
	M	-	-	M	M	M	M	M	**F**
66-23-387	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
66-23-388	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
66-23-390	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
66-23-392	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
66-23-393	**M**	M	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M	M
66-23-394	**M**	F	F	F	F	F	-	-	F
	T	F	F	F	F	F	-	-	F
66-23-395	**M**	-	M	M	M	M	M	M	M
	T	-	M	M	M	M	M	M	M
66-23-396	**M**	F	F	-	F	-	F	F	-
	T	F	F	-	F	-	F	F	-
66-23-400	**M**	F	F	**F**	**F**	F	F	**F**	F
	T	F	F	**M**	**M**	F	F	**M**	F
66-23-401	**M**	M	M	**M**	**M**	-	M	M	M
	T	M	M	**F**	**F**	-	M	M	M
66-23-402	**M**	M	M	-	M	M	M	M	-
	T	M	M	-	M	M	M	M	-
66-23-405	**M**	M	M	M	M	M	M	M	M
	T	M	M	M	M	M	M	M	M
66-23-406	**M**	M	M	-	M	M	M	M	M
	T	M	M	-	M	M	M	M	M
66-23-408	**M**	M	M	M	M	M	M	M	-
	T	M	M	M	M	M	M	M	-
66-23-409	**M**	M	M	M	M	M	-	M	M
	T	M	M	M	M	M	-	M	M
71-23-516	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
75-29-500	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
75-29-501	**M**	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-

Comparison between morphological sex estimation results and RV measurement sex estimation results – lower jaw.

Museum Number	Sex	RV LI1	RV LI2	RV LC	RV LP3	RV LP4	RV LM1	RV LM2	RV LM3
75-29-542	M	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-
75-29-543	M	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-

APPENDIX D

DENTAL METRIC STANDARDS FOR SEX ESTIMATION

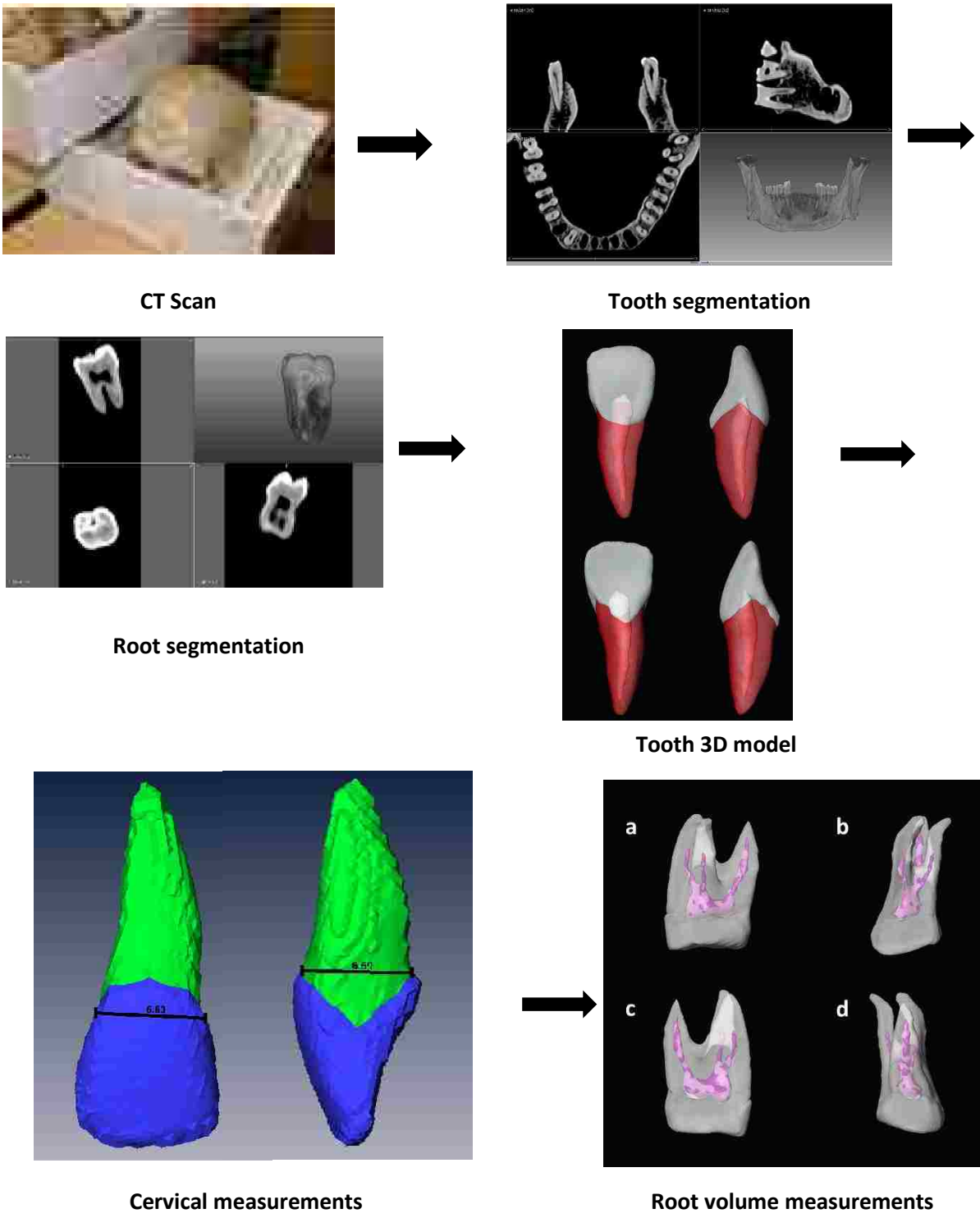

Fig 1. Flow chart outlining the overall analysis process in this project.

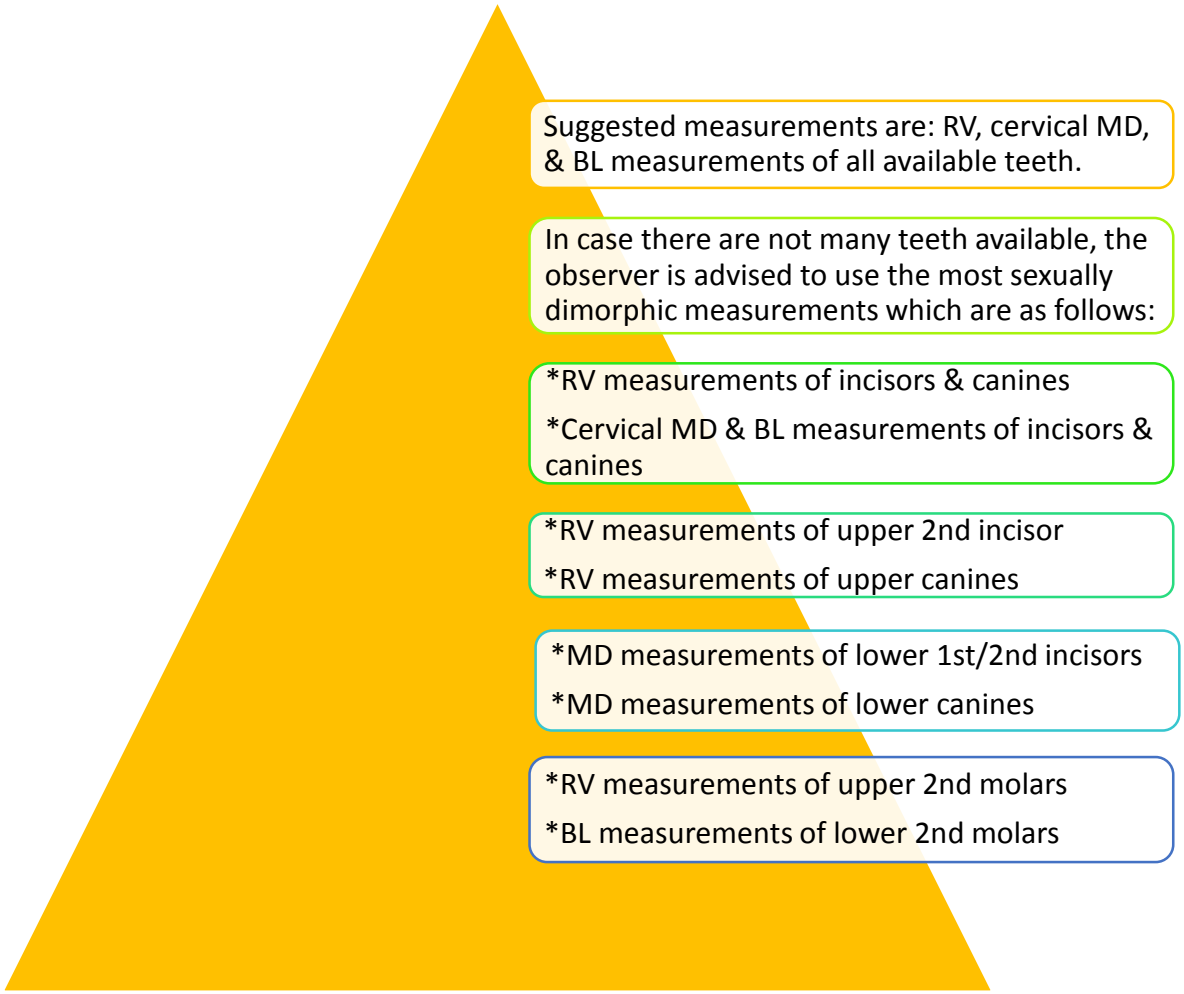

Fig 2. Flow chart outlining the most sexually dimorphic measurements for sex estimation.

Functions	
F 1	(UI1MD X 0.82) + (UI1BL X 2.33) + (-19.74)
F 2	(LI1MD X 4.2) + (LI1BL X 0.99) + (-20.21)
F 3	(UI2MD X 0.95) + (UI2BL X 1.99) + (-15.84)
F 4	(LI2MD X 2.91) + (LI2BL X 1.54) + (-20.51)
F 5	(UCMD X 1.88) + (UCBL X 0.95) + (-17.93)
F 6	(LCMD X 1.69) + (LCBL X 0.86) + (-15.42)
F 7	(UP3MD X 3.05) + (UP3BL X -0.04) + (-13.57)
F 8	(LP3MD X 2.89) + (LP3BL X 0.45) + (-16.74)
F 9	(UP4MD X 2.44) + (UP4BL X 0.46) + (-15.20)
F 10	(LP4MD X 2.37) + (LP4BL X 0.56) + (-15.86)
F 11	(UM1MD X 1.32) + (UM1BL X 1.32) + (-23.27)
F 12	(LM1MD X 0.96) + (LM1BL X 1.29) + (-19.79)
F 13	(UM2MD X 0.96) + (UM2BL X 1.05) + (-17.61)
F 14	(LM2MD X 0.99) + (LM2BL X 1.15) + (-18.33)
F 15	(LM3MD X 0.54) + (LM3BL X 1.69) + (-18.12)
F 16	(UI1MD X 0.85) + (UI1BL X 2.40) + (-20.45)
F17	(LI1MD X 7.71) + (LI1BL X -0.15) + (-26.30)
F 18	(UI2MD X 2.76) + (UI2BL X 1.33) + (-20.15)
F 19	(LI2MD X 1.68) + (LI2BL X 3.16) + (-24.62)
F 20	(UCMD X 2.97) + (UCBL X 0.63) + (-20.94)
F 21	(LCMD X 2.50) + (LCBL X 0.67) + (-17.80)
F 22	(UP3MD X 3.25) + (UP3BL X 0.40) + (-18.02)
F 23	(LP3MD X 2.51) + (LP3BL X 1.40) + (-21.06)
F 24	(UP4MD X 2.73) + (UP4BL X 0.75) + (-18.41)
F 25	(LP4MD X 2.72) + (LP4BL X 0.26) + (-15.30)
F 26	(UM1MD X 3.16) + (UM1BL X 0.53) + (-29.68)
F 27	(LM1MD X 1.14) + (LM1BL X 1.77) + (-25.21)
F 28	(UM2MD X 0.77) + (UM2BL X 1.26) + (-28.46)
F 29	(LM2MD X 1.33) + (LM2BL X 0.95) + (-29.57)
F 30	(LI2MD X 2.25) + (LI2BL X 2.97) + (UI1BL X 1.75) + (-49.04)
F 31	(UCMD X 1.90) + (UCBL X 0.85) + (-17.26)
F 32	(UP3MD X 3.13) + (-14.25)
F 33	(UM2MD X 1.69) + (-12.61)
F 34	(UM2MD X 1.20) + (UM1BL X 1.29) + (-22.00)
F 35	(LI2MD X 3.98) + (LCBL X 2.14) + (UI1BL X 2.05) + (-44.29)
F 36	(UCMD X 1.68) + (UP3MD X 1.81) + (-17.88)
F 37	(UCMD X 2.60) + (-14.90)
F 38	(UCMD X 2.82) + (-16.20)
F 39	(LI1MD X 5.29) + (LI2MD X 3.36) + (-31.43)
F 40	(LCMD X 2.50) + (UCMD X 1.80) + (-22.84)
F 41	(UP3MD X 4.70) + (-21.70)
F 42	(LP3MD X 3.37) + (-15.92)
F 43	(UM1MD X 4.17) + (-32.90)
F 44	(LM2MD X 2.10) + (-18.580
F 45	(UP3MD x 2.81) + (UCMD x 2.21) + (-25.14)

Functions	
F 46	(UCMD X 2.80) + (LP3MD X 1.62) + (-22.88)
F 47	(UCMD X 2.35) + (UM1MD X 2.14) + (-30.24)
F 48	(UCMD X 3.37) + (-18.23)
F 49	(LI2 X 0.07) + (-9.34)
F 50	(UC X 0.04) + (-8.50)
F 51	(UP3 X 0.03) + (UP4 X 0.03) + (-9.19)
F 52	(UP4 X 0.03) + (UP3 X 0.02) + (-8.15)
F 53	(LP3 X 0.06) + (-9.27)
F 54	(UM2 X 0.02) + (-7.41)
F 55	(LM1 X 0.02) + (-10.00)
F 56	(UC X 0.02) + (LI2 X 0.05) +(-11.53)
F 57	(UC X 0.03) + (-7.54)
F 58	(UC X 0.04) + (-9.82)
F 59	(UC X 0.03) + (-6.61)
F 60	(UC X 0.04) + (-9.04)
F 61	(LI1RV X 0.09) + (MD X 7.47) + (BL X -3.61) + (-15.70)
F 62	(LI2RV X 0.07) + (-9.09)
F 63	(UCRV X 0.03) + (-6.41)
F 64	(LCRV X 0.03) + (-6.25)
F 65	(UP3RV X 0.03) + (MD X 1.43) + (-11.36)
F 66	(LP3RV X 0.08) + (BL X -1.39) + (-2.78)
F 67	(UP4RV X 0.04) + (BL X 0.91) + (-13.49)
F 68	(LP4RV X 0.04) + (-6.86)
F 69	(UM1RV X 0.02) + (-7.66)
F 70	(LM1RV X 0.03) + (-10.79)
F 71	(UM2RV X 0.02) + (-6.40)
F 72	(LM2RV X 0.02) + (-7.30)
F 73	(UI1MD X 2.06) + (-12.88)
F 74	(LI1MD X 5.26) + (-18.45)
F 75	(UI2MD X 2.47) + (-11.88)
F 76	(LI2MD X 3.79) + (-14.71)
F 77	(UCMD X 2.75) + (-15.38)
F 78	(LCMD X -1.18) + (0.65)
F 79	(UP3MD X 3.01) + (-13.74)
F 80	(LP3MD X 3.42) + (-16.25)
F 81	(UP4MD X 3.03) + (-14.23)
F 82	(LP4MD X 2.93) + (-14.68)
F 83	(UM1MD X 2.77) + (-21.36)
F 84	(LM1MD X 2.07) + (-18.44)
F 85	(UM2MD X 1.83) + (-13.78)
F 86	(LM2MD X 1.76) + (-15.62)
F 87	(LM3MD X 1.16) + (-10.12)
F 88	(UI1BL X 2.86) + (-17.90)
F 89	(LI1BL X 3.13) + (-17.27)
F 90	(UI2BL X 2.62) + (-14.89)
F 91	(LI2BL X 3.15) + (-18.88)
F 92	(UCBL X 2.09) + (-16.36)

Functions	
F 93	(LCBL X 2.05) + (-15.28)
F 94	(UP3BL X 1.84) + (-14.59)
F 95	(LP3BL X 2.21) + (-14.74)
F 96	(UP4BL X 1.67) + (-13.62)
F 97	(LP4BL X 1.73) + (-12.36)
F 98	(UM1BL X 2.07) + (-20.59)
F 99	(LM1BL X 1.89) + (-16.49)
F 100	(UM2BL X 1.67) + (-16.48)
F 101	(LM2BL X 1.83) + (15.19)
F 102	(LM3BL X 2.06) + (-16.40)
F 103	(UI1MD3D X 2.18) + (-13.72)
F 104	(LI1MD3D X 7.53) + (-26.46)
F 105	(UI2MD3D X 3.35) + (-15.54)
F 106	(LI2MD3D X 4.02) + (-15.35)
F 107	(UCMD3D X 3.50) + (-19.04)
F 108	(LCMD3D X 3.22) + (-16.70)
F 109	(UP3MD3D X 3.58) + (-16.39)
F 110	(LP3MD3D X 3.53) + (-16.72)
F 111	(UP4MD3D X 3.83) + (-17.47)
F 112	(LP4MD3D X 2.91) + (-14.36)
F 113	(UM1MD3D X 3.67) + (-28.57)
F 114	(LM1MD3D X 2.29) + (-20.18)
F 115	(UM2MD3D X 1.87) + (-14.39)
F 116	(LM2MD3D X 2.00) + (-17.75)
F 117	(UI1BL3D X 2.96) + (-18.61)
F 118	(LI1BL3D X 3.80) + (-20.37)
F 119	(UI2BL3D X 3.41) + (-18.90)
F 120	(LI2BL3D X 4.60) + (-26.47)
F 121	(UCBL3D X 2.17) + (-16.34)
F 122	(LCBL3D X 2.05) + (-14.70)
F 123	(UP3BL3D X 1.90) + (-14.92)
F 124	(LP3BL3D X 2.95) + (-19.41)
F 125	(UP4BL3D X 1.78) + (-14.12)
F 126	(LP4BL3D X 1.10) + (-14.17)
F 127	(UM1BL3D X 2.05) + (-20.09)
F 128	(LM1BL3D X 2.50) + (-21.46)
F 129	(UM2BL3D X 1.77) + (-17.71)
F 130	(LM2BL3D X 2.17) + (-17.82)
F 131	(LM3BL3D X 2.49) + (-19.72)
F 132	(UI1RV X 0.04) + (-8.04)
F 133	(LI1RV X 0.09) + (-8.90)
F 134	(UI2RV X 0.05) + (-7.76)
F 135	(LI2RV X 0.07) + (-9.15)
F 136	(UCRV X 0.03) + (-6.91)
F 137	(LCRV X 0.03) + (-6.17)
F 138	(UP3RV X 0.04) + (-6.40)
F 139	(LP3RV X 0.06) + (-8.64)

Functions	
F 140	(UP4RV X 0.04) + (-7.30)
F 141	(LP4RV X 0.04) + (-6.85)
F 142	(UM1RV X 0.02) + (-7.78)
F 143	(LM1RV X 0.02) + (-10.00)
F 144	(UM2RV X 0.02) + (0.89)
F 145	(LM2RV X 0.02) + (-6.91)
F 146	(LM3RV X 0.02) + (-6.73)