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The prevalence of pathological conditions in a modern skeletal collection – implications for forensic anthropology

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The prevalence of pathological conditions in a modern skeletal collection – implications for forensic anthropology

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Abstract

This study examines skeletal health in a modern American population and its implication to forensic identification. Sometimes pathological conditions (e.g. healed fractures, surgical devices and other conditions) are used for personal identification even when there are no radiographs. The post-mortem remains are compared to ante-mortem written records or family reports, and a possible match is suggested. However, there is a debate whether these conditions are sufficiently individualizing for this purpose. This dissertation examines the frequencies of these conditions and their combinations and also compares the observed information on the reported medical histories.

The sample used in the study is from the W. M. Bass Donated Skeletal Collection housed at the Department of Anthropology at UTK. The sample consists of 180 individuals including both males and females, and self-donations and family donations. Skeletons were studied macroscopically for healed fractures, surgical devices, pathological lesions, osteoarthritis and skeletal anomalies. The results show that osteoarthritis and healed fractures are very common in this sample of elderly people. Osteoarthritis is limited to joint surfaces and thus combinations of affected areas are few, but healed fractures can be seen in various combinations in multiple elements. In addition, the more detailed the information is (e.g. specific location), the more combinations there will be. Factors such as sex, age, and BMI were found to affect presence of certain conditions.

The reported medical histories seem to have accurate reports on major surgical interventions such as open heart surgeries, prosthetics and amputations, but they are underreporting healed fractures, especially in ribs, and osteoarthritis. Differences in agreement of reported and observed conditions were seen between self- and family donations but no clear trends were seen between sexes.

Table of Contents

Chapter 1. Introduction 1
DNA 3
Dental identification 4
Radiography 5
Uniqueness required? 6
Justification in the court room 7
Focus of the current research 8
Chapter 2. Pathological conditions seen in the skeleton 12
Fractures 12
Surgical devices/implants 13
Bone formation and bone loss 13
Useful descriptions of pathological symptoms in living people 15
Ante-mortem fractures 15
Bone healing 16
Epidemiology of fractures 17
Cranium 19
Sternum 20
Clavicle 21
Scapula 21
Spine 21
Ribs 22
Upper limb bones 23
Hands 24
Pelvis 25
Lower limb bones 25
Feet 27
Bone lesions 27
Osteoarthritis 32
Surgical devices 33
Fracture fixation 34
Pins, screws, staples 34
Wire 35
Plates 35
Intramedullary nails and rods 36
Sutures 36
Joint replacements 37
Hip replacement 37
Knee replacement 37
Shoulder replacement 38
Other common surgical procedures 38
Other conditions 41
Sacroiliac fusion 41
Other pathological fusions 41
Schmorl's depressions 43
TMJ problems 44
Congenital fusions 45
Cleft neural arch in vertebrae 45
Spina bifida occulta 46

Spondylolysis 47
Bifurcated ribs 49
Cervical rib 49
Os acromiale 51
Button osteoma 52
Palatine torus and mandibular torus 53
Enlarged nasal turbinate 54
Words of caution 54
Chapter 3. Materials 57
The W. M. Bass Donated Skeletal Collection 57
Other characteristics of the study sample 63
Chapter 4. Methods 69
Skeletal analysis 69
Inventory 70
Fractures 70
Bone lesions 71
Osteoarthritis 71
Surgical devices 72
Other conditions 72
Differential diagnosis 73
Statistical methods 74
Matching the reported and observed conditions 75
Combinations of observed conditions 76
Chapter 5. Results 77
Antemortem data 77
Details of reported fractures 79
General medical history 79
Diseases and conditions affecting skeleton 83
Observed conditions 85
Observed healed fractures 86
Observed surgical devices and procedures 90
Observed lesions 92
Observed osteoarthritis 96
Other observed conditions 97
Matching the reported and observed conditions 101
Observed combinations of pathological conditions and applications for personal identification as likelihood ratios 112
Examples of likelihood ratios 121
Chapter 6. Discussion 123
Discussion on reported pathological conditions 123
Discussion on observed pathological conditions 125
Fractures 125
Surgical devices 126
Lesions 126
Osteoarthritis 127
Discussion on matching the reported and observed conditions 128
Discussion on combinations 130
Limitations and future directions 132
Practical implications of this study for data collection and identification 134

Conclusions 135
List of References 137
Appendices 164
VITA 197

List of Tables

Table 1. Basic demographics of the sample including minimum, maximum, mean, and median age. 59

Table 2. Skeletal elements present in this study. Vertebrae, ribs, metacarpals, carpals, metatarsals and tarsals are summed together. 62

Table 3. Reported causes of death by sex and donation type. 64

Table 4. Distribution of the occupational categories. 64

Table 5. Stature, weight and BMI information by sex. 68

Table 6. Agreement of reported and observed data. 76

Table 7. Frequencies of reported check boxes by sex and donation type.. 78

Table 8. Frequencies of reported fractures by sex and donation type. 80

Table 9. Frequencies of reported medical conditions by sex and donation type. 82

Table 10. Reported conditions affecting musculoskeletal system. 84

Table 11. The total fracture counts in males and females. 87

Table 12. Fractures by body segments. 87

Table 13. All the elements that have ten or more individuals with a fracture. 89

Table 14. Frequencies of surgical devices by type and sex. 91

Table 15. Frequencies of surgical devices by body segment. 91

Table 16. All the surgical procedure observed in the sample. 92

Table 17. Frequencies of individuals exhibiting skeletal lesions, both bone loss and bone formation by body segments, and maximum count of observed lesions in the specific segment. 94

Table 18. A number of individuals with healed periosteal reaction in lower limbs. 94

Table 19. Eburnation by body segments. 96

Table 20. Frequencies of individuals with joints showing eburnation. 98

Table 21. Frequencies of the skeletal anomalies and pathological degenerative changes. 100

Table 22. Details of the anomaly locations and severity. 102

Table 23. Agreement (percentages) between reported and observed data. 104

Table 24. Agreement (percentages) between reported and observed fractures by body segment 106

Table 25. Sensitivity and specificity percentages for major pathological conditions/surgical procedures. 108

Table 26. Sensitivity and specificity percentages for fractures by body segment. 110

Table 27. Reported pathological conditions and surgical procedures affecting the musculoskeletal system and the matching observations. 111

Table 28. Number of individuals showing different combinations of any pathological conditions.. 113

Table 29. Surgical devices by body segments. 115

Table 30. Osteoarthritis by body segments...115

Table 31. Lytic lesions by body segment. 115

Table 32. Bone formation lesions by body segment..116

Table 33. Number of individuals showing one or more healed fractures in specific body segments. 118

Table 34. Observed healed fractures by long bones. 118

Table 35. Observed rib fractures by their location. 120

Table 36. The most commonly observed conditions and combinations in the long bones. 121

Table A- 1. Reported fractures by location. 175

Table A- 2. Reported fractures without detailed location...176

Table A- 3. Observed fractures in cranium. 177

Table A- 4. Observed fractures in trunk and pelvis. 177

Table A- 5. Observed fractures in long bones. 178

Table A- 6. Observed fractures in metacarpals and metatarsals. 178

Table A- 7. Observed fractures in the vertebrae...179

Table A- 8. Observed fractures in the ribs...179

Table A- 9. Observed surgical devices in the cranium 180

Table A- 10. Surgical devices in long bones. 180

Table A- 11. Surgical devices in trunk, pelvis, spine, patella, metacarpals and metatarsals. 181

Table A- 12. Observed lesions in the cranium. 182

Table A- 13. Observed lesions in the trunk and pelvis. 182

Table A- 14. Observed lesions in the long bones. 183

Table A- 15. Observed lesions in the ribs...184

Table A- 16. Observed eburnation in the cranium and vertebrae. 185

Table A- 17. Observed eburnation in the trunk, pelvis and long bones. 185

Table A- 18. Observed eburnation in the metacarpals, metatarsals and greater multangulars. 186

Table A- 19. Matched reported and observed main conditions. 186

Table A- 20. Matched reported and observed fractures. 187

Table A- 21. Surgical devices by body segments. 187

Table A- 22. Osteoarthritis by body segments. 188

Table A- 23. Lytic lesions by body segments. 188

Table A- 24. Bone formation lesions by body segments. 189

Table A- 25. Healed fractures by body segments. 190

Table A- 26. Healed fractures by long bones.. 191

Table A- 27. Healed fracture counts in the left ribs. 192

Table A- 28. Healed fracture counts in the right ribs. 193

Table A- 29. All observed conditions and combinations in the long bones. 195

List of Figures

Figure 1. Nasal fractures....20

Figure 2. An example of vertebral body fracture....23

Figure 3. A healing fracture in the proximal shaft of a fifth metacarpal. 24

Figure 4. Malaligned healed fractures in the distal tibia and fibula....26

Figure 5. A healing periosteal reaction on the distal tibia. 29

Figure 6. A lytic lesion on the occipital....30

Figure 7. A craniotomy on the right parietal and temporal....32

Figure 8. Eburnation on the articular facets of L5. 33

Figure 9. An example of a sternum with wire fixation after open heart surgery. 35

Figure 10. An example of a surgical plate on cervical vertebrae....36

Figure 11. A hip replacemnt in the right acetabulum. 38

Figure 12. An example of vertobroplasty. 39

Figure 13. An example of laminectomy in lumbars 2-4. 40

Figure 14. An example of DISH....44

Figure 15. An example of a cleft atlas. 46

Figure 16. Spondylolysis in the fifth lumbar. 48

Figure 17. An example with sternal and xiphoid apertures. 50

Figure 18. A bifurcated fourth rib. 50

Figure 19. The seventh cervical vertebrae with a cervical rib on the right. 51

Figure 20. A right parietal showing two button osteomas. 53

Figure 21. A large palatine torus. 55

Figure 22. An example of an enlarged nasal turbinate. 55

Figure 23. A box-plot presenting the average age by sex and donation type. 59

Figure 24. Age distribution of the study sample divided into age groups (N=180). Age groups: 2= 30-39, 3= 40-49, 4= 50-59, 5= 60-69, 6= 70-79, 7= 80-89, 8= 90-99. 60

Figure 25. A summary of the content of the body donation questionnaire. 67

Figure 26. A summary of the check boxes included in the questionnaire. 67

Figure 27. An example of a seventh cervical with a bony extension of the left transverse process. 73

List of Attachments

File 1. Observed fractures ……………………………………………………………Observed fractures.pdf

File 2. Observed bone loss and formation……………………........... Observed bone loss and formation.pdf

File 3. Observed eburnation…………………………………………………...Observed eburnation.pdf

File 4. Observed surgical devices………………………………..………Observed surgical devices.pdf

File 5. Observed anomalies and degenerative changes…........... Anomalies and degenerative changes.pdf

Chapter 1.
Introduction

"A personal identification results from the comparison of antemortem and postmortem information. Forensic anthropologists should evaluate and compare antemortem and postmortem skeletal information in a systematic manner for the purpose of facilitating a scientifically reliable identification using appropriate techniques." (SWGANTH 2010)

As stated in the *Scientific Working Group for Forensic Anthropology* best practices guidelines: personal identification is one of the central tenets of forensic anthropology. The process of identifying skeletal remains begins with assessing the biological profile: sex, age, ancestry, and stature. If there are missing people that match these demographics or the assumed identity based on other factors, the actual identification process can start. There are several identification methods used in forensic work. The most common methods are dental identification, fingerprints and DNA. However, there are situations when the remains (e.g. burned, skeletonized, fragmentary, mutilated or decomposed) cannot be identified solely by these methods (Hines et al. 2007). All types of identification are based on patterns that are observed in both postmortem remains and antemortem data (Komar & Buikstra 2008). These methods can provide investigators with a positive identification. SWGANTH (2010) guidelines list radiography and surgical implants as the positive identification methods that anthropologists can contribute to. Nevertheless, there are other methods that are used in situations where the above methods cannot be applied, and these include biological profile, written medical records, skeletal anomalies, pathological conditions, and photo superimposition. These methods are not sufficient for a positive identification but they can indicate if postmortem findings are consistent or inconsistent with antemortem data (SWGANTH 2010). This dissertation concentrates on one of these methods; pathological conditions that can be found in the medical records or family reports but not necessarily in directly comparable x-rays. The goal of the study is to gain information on the frequencies of pathological conditions and their combinations in a modern skeletal sample, and this information can serve as a reference data to evaluate

how common the observed pathological conditions can be and if they have potential in personal identification. This study also evaluates the accuracy of the self- or family reported medical histories in order to improve the body donation and/or missing person forms, and thus, the validity of the reported data.

Before presenting the research questions and justifications for this particular study, a short introduction to forensic identification is necessary. Personal identification is required in forensic cases and disaster and other mass fatality contexts. Disaster Victim Identification (DVI) includes multiple victims who can be commingled, fragmentary and show different stages of preservation (Blau & Briggs 2011). The identification methods chosen depend upon the type of the fatality, number of victims, condition of the remains, and access to antemortem records (Sledzik & Kauffman 2008). For example, extensive fragmentation, calcined remains and large number of victims posed many challenges for the DVI process of the victims of the World Trade Center attacks (MacKinnon & Mundorff 2007). Identification of victims of homicides, accidents and mass disasters is essential for the family members both emotionally and legally (Ranson 2008). The legal aspects that are dependent on personal identification include among other things inheritance of the property, monetary benefits (insurance, pension), and remarriage (Christensen & Anderson 2013). Thus, it is important that the positive identifications are rendered.

There are three major categories of identification based on their level of certainty, even though there are some discrepancies in the use of these terms (Anderson 2007; Christensen & Anderson 2013). These categories are tentative, circumstantial and positive. A tentative identification is the least certain category. It is based on associated identification papers or other belongings that give a reason to assume we know who the individual is. A circumstantial (presumptive) identification is carries a higher level of certainty than tentative identification, and it is based on consistent circumstances and other evidence but there are no biologically based antemortem materials to verify the identification. A positive (personal) identification is based on a successful comparison of antemortem (AM) and postmortem (PM) features (Komar & Buikstra 2008; Christensen & Anderson 2013). A positive identification is the ideal type of identification but it is not always possible due to the lack of antemortem data or many other factors. It is also important to evaluate the quality of the AM and PM data and the

temporal period between the AM records and disappearance (e.g. Hill et al. 2011; Sweet 2010; Kvaal 2006).

DNA

A positive identification can be made using various methods. These methods include comparative DNA, dental and other medical x-rays, fingerprints and visual recognition. The last two methods require soft tissue to be present, thus they will not be discussed in this context. DNA is the most recent addition to the forensic identification set. There are two types of DNA that can be used: Mitochondrial (mtDNA) and nuclear DNA. There are several differences between these types of DNA that affect their use in forensic contexts. Mitochondrial DNA has more than 1000 copies per cell whereas nuclear DNA has only two (Butler 2005). Thus, mtDNA is easier to recover and extract from the sample, and it is used when the examined specimens are older and possibly degraded (Weedn & Jones 2012; Speller et al. 2012). Nevertheless, mtDNA is not unique like nuclear DNA since it is inherited only from mother to offspring, whereas nuclear DNA is a combination of maternal and paternal DNA. For mtDNA this means that any relative's mtDNA from the matrilineal line can be used for comparison, and the results are not unique to an individual. The most common nuclear DNA analysis applied in forensic identification is using short tandem repeat (STRs) loci which are also used in the National DNA Index System (Weedn & Jones 2012; Hammond et al. 1994). DNA results can be quantified by calculating the probability of two people sharing the same sequence (Cattaneo et al. 2006).

Nevertheless, DNA might not always be the best option in forensic identification. DNA analysis is still quite expensive and time-consuming. It requires a sample of antemortem DNA of the individual or a sample from relatives. Sometimes the preservation of the postmortem remains does not permit DNA recovery (Cattaneo et al. 2006). Selection of appropriate bone for DNA testing might improve the quantity and quality of the extracted samples. It has usually been suggested to use lower limb bones for sampling due to the best preservation of DNA (Mundorff et al. 2009). However, a new study suggests that smaller cancellous bones of the hand and foot might yield better DNA and continue doing so even with increasing postmortem interval (Mundorff & Davoren 2014).

Dental identification

Dental identification is based on a comparison of antemortem and postmortem dental x-rays. This is one of the most common methods of identification. Teeth preserve well and it is quite common to have dental x-rays taken at some point of time. Whether an individual has antemortem dental x-rays or not depends on several factors, for example, healthcare system, culture and wealth. If antemortem dental x-rays are located they will be compared to the postmortem x-rays. Forensic odontologists seek similarities and differences in the location and shapes of fillings, shape of the teeth and roots and the trabeculae of bone. They also look at the pattern of antemortem tooth loss. There can be differences between the ante- and postmortem records but the odontologist has to be able to explain why these exist (time between AM and PM x-rays or new treatment) if this is the same person (Pretty & Sweet 2001; Sweet 2010). Sometimes even the pattern of trabecular bone in the mandible can be used for inclusion or exclusion. There is no minimum number of features that should be matching between the AM and PM records in odontology but they should be unique and no unexplainable discrepancies should be present (Pretty & Sweet 2001; Hinchliffe 2011).

Hand-written dental charts or dental formulas are not considered reliable since people can make mistakes while recording the information. An example of false exclusion based on dental charts was published by Lorkiewicz-Muszynska et al. (2013). In their case results of written dental records excluded the individual while facial superimposition matched the individual so more antemortem records were requested. The identification was confirmed by anthropological examination through x-rays of a mandible and a fractured proximal humerus. The dental charts had several fillings marked in the wrong tooth. However, if this human error is assumed to be non-existent then dental patterns (restoration, unrestored, antemortem loss coded by tooth and tooth surface) are considered to be diverse enough for identification purposes. OdontoSearch is a computer program that includes over 40,000 dental patterns, and it can be used to calculate the uniqueness of the matched dental pattern and thus give quantifiable support for the identification (Adams 2003a; 2003b).

Radiography

Other radiological identification methods include comparison of orthopedic implants, pattern of trabecular bone and specific features in bone morphology. There are several publications documenting the use of x-rays for identification but most of them are case studies (for example Angyal & Derczy 1998; Adams & Maves 2002; Hogge et al. 1995; Hulewicz & Wilcher 2003; Mundorff et al. 2006; Murphy & Gantner 1982; Owsley & Mann 1992; Rhine & Sperry 1991; Riddick et al. 1983; Rouge et al. 1993; Simpson et al. 2007; Scott et al. 2010; Campobasso et al. 2007) whereas larger systematic methodological studies are more rare (Dean et al. 2005; Hogge et al. 1994; Koot et al. 2005; Kuehn et al. 2002; Watamaniuk & Rogers 2010; Stephan et al. 2011).

The possibility of using frontal sinuses in personal identification was recognized in the 1920s (Krogman & Iscan 1986). The first decade of the 21st century produced several studies on the reliability and accuracy of the method (e.g. Kirk et al. 2002; Christensen 2005; Cameriere et al. 2005; Cameriere et al. 2008). There are multiple ways frontal sinuses can be compared: metric, morphological and superimposition (Besana & Rogers 2010). Besana & Rogers (2010) suggested that the metric approach is not useful since too many measurements are dependent on each other and morphological traits are not sufficiently discriminative. Thus, superimposition would be the best method. Nevertheless, others have noted that there are problems with superimposition as well due to the orientation and angle of the x-rays (Cameriere et al. 2005). Christensen (2005) used sinus outlines and elliptic Fourier analysis to assess the likelihood ratios of the correct match. She concluded that, although time-consuming, this method is reliable and the results can be quantified for court purposes.

Trabecular bone patterns have been used for identification in situations when other means of identification are not available or the available x-rays do not show any peculiarities for morphological matching (e.g. Kahana & Hiss 1994; Brogdon et al. 2010). For example, Kahana & Hiss (1994) used trabecular bone pattern of the first metacarpal and proximal phalanx to identify a burned body that was later confirmed by fingerprints and DNA. In 1998, Kahana et al. reported their results on the uniqueness of the trabecular bone pattern based on a sample of 103 postmenopausal females with multiple antemortem radiographs. They found that the pattern of trabecular bone in the left wrist was quite unique and, even though age-related changes could be seen, the

distinct features could still be recognized. Mann (1998) came to the same conclusion by testing the uniqueness in the trabecular patterns of femora and tibiae. He found that there were no identical patterns when looking at the internal bone structure, especially radiodensities. Based on his sample at least four similarities were found between the x-rays, and thus, he suggested this number of matching features needed to be found before a positive identification can be made. However, this number may not be sufficient for other cases.

Specific features in bone morphology are commonly used in radiographic identification. There are multiple case reports that introduce a wide variety of features used in antemortem/postmortem x-ray comparison, e.g. osteoarthritic changes (Hulewicz & Wilcher 2003), surgical defects/devices (Hogge et al. 1995; Scott et al. 2010), general shape (Mundorff et al. 2006; Watamaniuk & Rogers 2010), and deformities and anomalies (Riddick et al. 1983; Rouge et al. 1993; Nozawa et al. 2002; Sudimack et al. 2002; Kuharic et al. 2011). Naturally, the more features that are compared (shape, degenerative changes, trauma, trabecular bone, irregularities) the more unique the feature combination should be (Owsley & Mann 1992). SWGANTH guidelines (2010) state that there is no minimum number of similarities that are needed for establishing a match. Nevertheless, *"The antemortem and postmortem radiographs should match in sufficient detail to conclude that they are from the same individual with no unexplainable differences."* The guidelines also suggest that frequencies of special skeletal features in a larger population, if they are available, should be used to calculate probabilities for the correct match.

Uniqueness required?

All the identification methods involving ante- and postmortem matches tend to rely on the assumption of uniqueness of the matched traits. In 1958 Sassouni wrote: "*In other words, the greater the number of characteristics, the fewer the number of persons possessing them in common. Ultimately, only one individual can be found to answer the entire set of variables; it is, in this sense, that he can be termed "unique"*." (Sassouni 1958:341).

This same applies to skeletal characteristics: the more characteristics are looked at the fewer individuals are likely to share the same combinations. For example, far more

people have a fractured left femur, than a fractured left femur, and 1st right rib in addition to craniotomy. However, this does not require uniqueness. The uniqueness in forensic identification is discussed in several publications (eg. Saks 2010; Page et al. 2011; Jayaprakash 2013). No trait can be proven to be unique in the entire world without examining all the traits in individuals that exist or ever existed, but they can be found to be more or less common in certain populations. Instead of claiming something to be unique, reference data on the specific population should be collected to show the variability and frequencies of those traits examined (Saks 2010; Steadman et al. 2006). The population data enables calculations of the probability of a match, as is done with DNA frequencies. In addition, instead of using single traits, combinations of traits for this statistical modeling should be utilized (Page et al. 2011; Saks 2010). Jayaprakash (2013) noted that quantifying qualitative traits can be difficult, since physical matching includes using general morphology and pattern in addition to several points of similarity. This is reflected also in studies showing smaller error rates when using superimposition rather than quantified features in matching (Besana & Rogers 2010; Rogers & Allard 2004).

Justification in the court room

The idea of using frequency data on pathological conditions or skeletal features to calculate probabilities was emphasized in an article by Steadman et al. (2006). This article used biological profile components, dentition and osteological pathology for identification. They computed likelihood ratios for the identification based on known population frequency data. These likelihood ratios can then be used to evaluate the certainty of the identification and bring scientific justification into the court room.

It is preferable, and probably in the future required, that the validity of the results based on forensic anthropology methods can be presented in a numerical fashion. Since 1993, the admissibility of evidence and expert testimony have been recommended to follow the Daubert guidelines. They originated from the case of *Daubert v. Merrell-Dow Pharmaceuticals, Inc*. (1993) and they followed the general acceptance test (the Frye rule) in which the only standard was that the evidence and testimony must be based on generally accepted methods in the particular field. According to Daubert guidelines, the testimony/conclusions have to be based on scientific methods

- which have and can be tested,
- which are peer reviewed and published,

- which have been applied consistently and reliably,
- which have known or potential error rates.

These guidelines have forced anthropologists to test methods and their error rates and create methods for which the error rates can be calculated (Christensen 2005). This means that the methods should concentrate on features that can be quantified. However, there are some aspects in forensic anthropology that are difficult to test empirically or quantify, for example pathology and trauma analysis. Grivas and Komar (2008) discuss the Kumho decision (1999) versus Daubert in their publication. The Kumho decision includes three main points: Theories can be based on witnesses' own observations and experience, all expert witness testimony is evaluated with the same level of rigor, and Daubert standards are flexible guidelines that may not always be applicable in expert witness testimony.

The requirement of Daubert standards has been guiding the research in forensic anthropology in the past decade. Steadman et al. (2006) used healed fractures as their skeletal pathology sample. They were not able to locate fracture data for modern Americans other than soldiers listed missing in Korean War. They agree this is not necessarily an ideal reference sample for forensic cases, since it is all younger males who might have acquired injuries during their training. Steadman et al. (2006) suggest that a suitable reference data for skeletal pathology should be created.

Focus of the current research

Inspired by Steadman et al.'s (2006) article, this research compiles skeletal pathology data from a modern skeletal collection. These data can eventually be used as a reference sample that can provide frequency data for computing probabilities. This study could be a beginning for a similar computer program as OdontoSearch but using fractures and pathological conditions. The data could also be collected from hospitals of living people and their x-rays or CT-scans (for example Verna et al. 2013), but a different type of material was chosen for the research, a modern skeletal collection. A skeletal collection was chosen because it would allow studying healed fractures that can be observed on bone, and thus would be similar to the forensic case material. Hospital records consist mainly of x-rays from the ER and thus they would represent injuries without signs of healing. This would give the frequency of all the fractures that happened and were treated whereas the skeletal collection gives us the frequency of

fractures that can be observed on the bone after several years of healing, and also those fractures that were not treated at a hospital.

This study uses the W. M. Bass Donated Skeletal Collection housed at the University of Tennessee. More details of the collection are presented in Chapter 3. Most of the individuals are older European-Americans who have donated themselves or were donated by their families to this collection. Thus, the demographics of the W. M. Bass Donated collection does not necessarily reflect the usual demographics of forensic cases. However, this donated collection was preferred over any forensic collection since skeletons in forensic collections might have been returned to their families after examination or identification. In the Donated collection the known skeletons are physically present, and include reported medical histories in many cases, and this material can be used to study the second aspect of the research, which is to evaluate the reported medical data.

Even when there are no antemortem x-rays, the written medical records can indicate that the individual had a hip replacement surgery ten years ago, or a family member reports the individual had four left ribs fractured five years ago and the right arm fractured as a teenager. This information can be compared to the skeletal remains to see if they are consistent or inconsistent (Djuric 2004). Especially in situations of war victims, family reported medical histories can be used as the basis of personal identification. Nevertheless, the usefulness of this type of reported data may vary (Komar 2003a). In forensic, disaster or human rights cases the access to antemortem records can be influenced by various factors including socioeconomic status, culture, religion, and access to health care systems (Sledzik & Kauffman 2008), but also loss of records due to war (Brkic et al. 2000) or natural disasters (Petju et al. 2007).

The reported data might have some problems. Perhaps the broken ribs were actually on the right side, or maybe the fractured arm is so well-healed that it cannot be detected in the skeleton. The Bass Donated Collection is a known collection that has varying amounts of information on the donated individuals. The accuracy of self- or family-reported information in clinical settings has been studied previously. In those studies the accuracy has been found to vary depending on several factors, for example, the disease or conditions reported, the type of a question in the questionnaire, time of the diagnosis, and relationship to the family member (e.g. Chen et al. 2004; Chang et al. 2006; Molenaar et al. 2006; Honkanen et al. 1999; Kehoe et al. 1994)

The pathological conditions included in this study are healed fractures, surgical devices, pathological lesions, osteoarthritis and some skeletal anomalies and degenerative changes. Multiple types of conditions are included in order to gain holistic information on skeletal health rather than focusing on a certain part of the skeleton or certain types of conditions. Many of the conditions might be associated to each other and thus a holistic approach is required.

This current research contributes to forensic identification by providing frequency data of skeletal pathological conditions and their combinations. Komar & Lathrop (2006) did a similar study on two forensic collections and found that certain skeletal pathological conditions, (e.g. healed fractures), are common, and thus may not be useful in identification. In this current study, more emphasis is placed on the observed combinations of skeletal pathological conditions in addition to single conditions. Instead of reporting rib fractures collectively, the frequency of fractures in single ribs is also reported to allow more detailed combinations. It is understood that medical records might not always report individual rib numbers, but in case they do these details might be useful. In addition this current study matches the reported medical conditions with the observed morphology.

The main questions this dissertation addresses are divided into two sub-topics; firstly, reported medical histories and the reliability of these data; secondly, frequency data of the pathological conditions. More specific research questions are the following:

1) How the reported medical history data corresponds to the observed pathological conditions?

What kind of conditions are usually reported?
Which conditions are usually not reported but observed?
Which conditions are usually reported but not observed?
Are there differences between self and family-reported data?
How can the questionnaires for the donation program be improved?

These questions can be formulated into some hypotheses by using assumptions based on previous research. Many studies suggest that females give more accurate reports on health than males (Navarro et al. 2006; Okura et al. 2004). Some studies have reported that individuals over 6o years of age and females tend to give more accurate information on their family medical history. This is explained by older individuals being more interested in the family issues and females having tighter family ties (Aitken et al.

1995; Huerta et al. 2009; Chang 2006; Molenaar et al. 2006). Usually family reports are less accurate than self-reported data (Chen et al. 2004). Other variables that have been found to affect the reported data on health are education level (Navarro et al. 2006) and how recently the reporter has used medical care services (Molenaar et al. 2006). Based on this background it is expected in this study that self-reports will be more accurate than family-reports and that females give more reliable reports than males. Also major medical conditions are expected to be reported more accurately than minor health issues (Okura et al. 2004). Correspondence of the reported and observed data is evaluated by studying the agreement between these data groups. There can be several factors that affect the agreement and disagreement and those will be discussed in the chapter 6.

2) What are the frequencies of the observed healed fractures, surgical interventions and other pathological conditions, such as lytic and periosteal lesions and osteoarthritis?

Are there differences between sexes and age groups?
Are certain conditions and combinations of conditions more common than others?
Can these be used for personal identification?

Based on previous research it is known that fractures and other pathological conditions and their frequencies depend on several factors, for example sex, age, and fracture site (Court-Brown & Caesar 2006a), and thus it is expected to see some differences in this sample as well.

Chapter 2.
Pathological conditions seen in the skeleton

This chapter will introduce general information about pathological conditions that can be observed in skeletons. Before getting into details of those conditions, the reader is equipped with examples of how these conditions can be used in forensic identification, if they are documented in the antemortem data (Beggan et al. 2014). There are several reports on forensic identification based on skeletal features in the literature. This background chapter will summarize those situations, and then introduce the major conditions used in this research: ante-mortem fractures, pathological lesions, osteoarthritis, surgical devices and other skeletal anomalies.

Fractures

One of the most common pathological conditions observed in a skeleton are healed fractures. For example, fractures were used in identification of war victims in the former Yugoslavia (Komar 2003a; Slaus et al. 2007). Haglund et al. (1987) confirmed an identity of a serial killer victim by using a well-healed fracture in an os coxa. Since there was no tentative identity for the victim, the information was published in a newspaper a year and a half following the recovery of the remains. A relative of the victim saw the article and reported this possible match to the police the next day. Medical records verified the identity.

In addition to fractures, muscle-related injuries can be detected as ossified tissue. These exostoses, such as myositis ossificans, can associate the victim with activities, like sports, where injuries are common. A person suffering from this kind of injury is likely to seek medical care and it could be mentioned in the medical records (DiMaio & Francis 2001). Also fracture fixation can provide a means of identification. A surgical plate or rod indicates that there should be medical records of the procedure. Simpson et al. (2007) report several separate cases in which identifications were made using fractures, orthopedic implants and irregularities in bones. Five cases out of eight involved an orthopedic implant. Hip replacement, spinal rods and a plate in a fractured ulna provided identification after comparison of appropriate x-rays. Two cases consisted

of only a fragment of a long bone with a surgical plate. These cases could not be identified, since there was no indication to whom this fragment belonged. The plates in these two unidentified fragments had a manufacturer name and some numbers but no information that could identify the individual or the hospital where the surgery was done. Their study demonstrates that there are two possible ways in which surgical implants can help to identify individuals: 1) when a tentative identification is known, AM and PM records can be compared (e.g. Bennett & Benedix 1999), and 2) when there is no tentative identification a tracking system of the device can be used (e.g. Sathyavagiswaran et al. 1992).

Surgical devices/implants

Since 1993 the U.S. Food and Drug Administration (FDA) has required the manufactures of surgical implants to have a tracking system in which an individual serial number can trace the implant to the hospital where it was implanted, to the doctor who did the surgery and maybe even to the person receiving it (Ubelaker & Jacobs 1995). These regulations were mainly concerned about medical devices that were life-supporting, e.g. pacemakers instead of fixation devices (Simpson et al. 2007). In the early 1990s Sathyavagiswaran et al. (1992) reported successful identification using model and serial numbers of a pacemaker. These regulations were modified in 1997 and all devices that are permanently implanted are now supposed to be under the tracking system (Wilson et al. 2011).

In addition to permanent metal devices, surgeries can leave other marks in the skeleton. For example, a treatment for intracranial hematoma includes placement of a drainage shunt through a burr hole in the cranium. Scott et al. (2010) reported a case in which the postmortem remains show a healed trephination on the left parietal after this kind of surgery. Also surgical sutures in bone indicate procedures that would be noted in the medical records (Shepherd et al. 2010).

Bone formation and bone loss

It is important to remember that not all diseases are detectable in the skeleton and that absence of skeletal manifestations does not necessarily mean that the individual did not suffer from the reported disease (Cunha 2006). It is clear that some pathological

conditions are more useful in identification than others. For example, degenerative changes in bone caused by osteoarthritis (OA) are very common and thus signs of OA in general are not sufficient for identification. However, if recent x-rays exist individual osteophytes might prove to be useful (Kahana et al. 2002; Valenzuela 1997).

Another skeletal change that might not be very useful in identification due to its high frequency is periosteal lesions. A periosteal reaction can be caused by several factors (mainly infection, neoplasms, and trauma) so it is considered non-specific. Sometimes extensive periosteal reaction can aid with the identification. For example, a case in Portugal showed extensive periosteal reaction in lower limb bones indicating a probable vascular pathology, which was later confirmed by a family report and the actual medical history (Pinheiro et al. 2004).

Neoplasms are more rare than periosteal reactions or OA and thus could be more useful for identification. Both benign and malignant tumors may provide important information. For instance a benign button osteoma might be visible on a skull, and in the case of malignant tumors the person has likely seen a doctor (Gruspier 1999). The cancer-related lesions seen on a skeleton are lytic, proliferative or a mixture of these two. The actual tumor site might not be evident when there are multiple metastatic lesions. In order to get a good understanding of the lesion distribution the remains showing lytic lesions should be x-rayed. Differential diagnosis (discussed more in Chapter 4) should be used to diagnose the possible cancer type (Marks & Hamilton 2007).

Sometimes physical activity can be detected in the skeleton through enthesopathies. Enthesopathy refers to skeletal changes in insertion site of a tendon or a ligament. These changes usually involve extra bone growth but also porous lesions can be seen. Enthesopathies can indicate repetitive occupational stress on muscles, certain rheumatic diseases or trauma (Jurmain 1999; Mariotti et al. 2004). Using these markers requires recognition of a general pattern of stress that might be associated with certain activities (Wilczak & Kennedy 1998; Saul & Saul 1999). Thus, enthesopathies can be useful if an individual's activity type and level is known (Cunha 2006; Klepinger 1999; Kennedy 1983). In this study enthesopathies are not examined unless they are related to diffuse idiopathic skeletal hyperostosis.

Useful descriptions of pathological symptoms in living people

Maples (1984) encouraged forensic anthropologists to describe in their reports the symptoms that could be seen in a living person associated with the conditions seen in the skeleton. In one of his cases a cholesteatoma was observed in a male skull on the right temporal. This would have caused “loss of hearing and a foul-smelling drainage” in a living person. The medical records of a missing person indicated he had complained about bad hearing in the right ear and he was reported to have drainage from the ear. The same emphasis on description was pointed out by Cunha (2006) in cases like ankylosing spondylitis (AS) in which the fusion of spine will lead to limited movement.

Ante-mortem fractures

The most common pathological findings in skeletons are healed fractures. There are several different types of fractures and they will be summarized here, even though it may not always be possible to determine the fracture type from healed fractures.

There are three types of classification systems in clinical trauma studies: 1) fracture-specific classification, 2) generic or universal classification, and 3) soft tissue injury classification (Dirschl & Cannada 2006). The fracture-specific system will classify fracture types into a single location; for example, femoral neck fractures or proximal tibia fractures. The generic system can classify all fractures in a similar manner regardless of the location. This OA/OTA (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association) system was created to standardize research and make communication easier. It consists of five points that all the classifications must include: bone injured, location in the bone, fracture type (simple fracture, some comminution, highly comminuted), group of the fracture (e.g. spiral, oblique, transverse) and subgroup of the fracture (group divided into even more specific groups) (Dirschl & Cannada 2006). The soft tissue injury system classifies different types of open and closed fractures. Open fractures have break the skin surface which allows bacteria from the outside to enter the wound, whereas closed fractures do not break the skin (Roberts & Manchester 2005).

There are two main injury mechanisms: direct trauma and indirect trauma. Direct trauma usually results generally in transverse, penetrating, comminuted or crush

fractures. Indirect trauma can be seen as spiral, oblique, greenstick, burst or avulsion fractures. Some of the fracture types are difficult to differentiate with considerable healing, for example oblique from spiral. In trauma analysis identification of the fractured bone and specific location within the bone is essential. The appearance of the injury should be described including type of the fracture and observations on the healing or complications like angulation, shortening, rotation (Lovell 1997).

Bone healing

Since the current study focuses on healed fractures, some basics of the healing process are presented. A skeletal injury proceeds through three different stages: inflammation, repair and remodeling. These can also be called cellular, metabolic and mechanical stages (e.g. Sheikh 2000a; Roberts & Manchester 2005). When a bone is fractured the fracture ends will bleed and form a hematoma right after the injury. Bone next to the fracture will die due to disruption in the blood supply and connective tissue will form. This phase lasts about 1-2 weeks. In the metabolic phase the soft callus will be formed and turned into hard callus, woven bone. This phase can last from weeks to months. Presence of the hard callus starts the mechanical phase. In this phase callus is remodeled into lamellar bone, and this can continue for several years but eventually can restore the original architecture of the bone (McGuigan 2010; Hosalkar et al. 2009; Roberts & Manchester 2005; Sheikh 2000a).

A fracture is considered healed when there is callus formation, and the fracture line is blurred (Sheikh 2000b). There are several factors that influence fracture healing. The main components are infection, poor vascular supply, age, treatment, hormones, bone type, nutrition, and various bone diseases (Buckwalter et al. 2006). Different types of bone will heal differently. Cancellous bone tends to heal faster than cortical bone (Lovell 1997). It is said that a long bone fracture in a healthy adult takes about six weeks to three months to heal depending on the bone type (Burke 2011), but the healing process is much faster in children than in adults (Ortner 2003). Also the type of fracture and method of fixation will affect the healing results (Sheikh 2000a). It has been suggested that fixation methods (cast, rod, pin, screw, external fixation) that allow some motion at the fracture site heal faster due to the increased callus formation (secondary

bone healing). Compression plates do not allow motion and thus the fracture healing is slower and occurs without callus (Hoppenfeld 2000).

Complications of healed fractures in bone include infection, shortening of the bone, malalignment and traum atic osteoarthritis. The fracture can be well realigned and in that case it would be hard to tell that a fracture ever existed. Sometimes, especially without treatment, a fracture can leave bone ends malaligned and the entire bone can be angulated. In addition to malalignment, another feature that will make a healed fracture obvious is non-union of the fractured ends of the bone. Non-union could indicate that the fracture site never fused or the fusion is delayed and would eventually have been united if more time was passed (Moholkar & Ziran 2006). Roberts and Manchester (2005) state the most likely reasons for non-union of fractures include insufficient stabilization, infection, poor blood supply, or poor nutrition.

Epidemiology of fractures

When fractures and their distributions are studied, it is important to note that there are several factors that can affect these distribution (Court-Brown & Ceasar 2006b). Therefore a short introduction to fracture epidemiology is needed. The epidemiology of fractures involves reporting fracture frequency in living people documented and treated in hospitals and trauma centers. There are several factors that can influence these epidemiological surveys and thus the results can vary according to geographical area or temporal era and socioeconomic status. This means that not all the surveys can be directly compared but it is assumed that the general trends should be similar in different populations (Court-Brown & Ceasar 2006a). For example, Bacon and Hadden (2000) found differences in hip fracture rates according to income class. Jonsson et al. (1993) reported lower fracture rates for a rural community rather than for an urban community in which people could be more prone to osteoporotic fractures due to lower level of physical activity.

Epidemiology studies also the influence of various factors on fracture incidence, such as sex and age. In many cases, the cause of the fracture is recorded and thus certain types of fractures can be associated to certain activities, for example nasal fractures associated with violence (Fornazieri et al 2008). Fracture epidemiology is by no means

static; changes can be seen in the patterns and distributions due to changes in societies and medicine that enable longer and more active lives. Some decades ago sport-related fractures affecting young individuals were the center of the attention in medicine, whereas recently the incidence of aging-related fractures due to osteoporosis has increased and the range of affected elements has become larger (Court-Brown & Caesar 2006a). In their review of epidemiology of fracture, Court-Brown and Caesar (2006a) report the worldwide incidence of fractures to be 9.0-22.8/1000/year based on the literature. They assume that there will be regional and population-based differences in the incidence counts. They studied radiographs of patients treated at an orthopedic trauma unit in Edinburgh in Scotland. The unit treated over 530,000 patients in 2000, and 5,953 fractures were recorded. They reported the average age to be 49.1 years and sex ratio was 50:50.

Fracture data from the trauma unit at the Royal Infirmary in Scotland have been used for numerous studies. A study on general fracture epidemiology was based on over 15 000 patients with over 16 000 fractures. Most of the fractures were isolated, and only 3.5% of patients had multiple fractures. Males under 50 years of age had higher incidence of fractures than females, but females over 60 years were more likely to have fractures than males. The age and sex distributions vary depending on the fractured element (Singer et al. 1998; Court-Brown & Caesar 2006ab).

Fracture epidemiology is also influenced by pathological fractures. These include osteoporotic fractures that are more common in older females due to the lower bone mineral density. Areas most affected are the distal radius, vertebrae, proximal humerus, femoral neck and pelvis (Karlsson et al. 2006). There are also other areas that are prone to osteoporotic fractures, including elbow, knee, pelvis, ankle and femoral diaphysis (Court-Brown & Caesar 2006b). Fractures in the wrist, spine and hip have high morbidity and mortality rates and thus their prevention and treatment are major concerns in modern societies (Guggenbuhl et al. 2005).

Other conditions that make bone weak and thus prone to fractures are metastatic bone diseases. Cancerous lytic lesions are commonly seen in vertebrae, pelvis, ribs, cranium and proximal ends of long bones (Weber 2006). In addition to traumatic and pathological fractures stress fractures can be encountered. Stress fractures are caused by

overwhelming stress to a normal, healthy bone. This can be seen mostly in athletes and military staff (Teague 2006).

The next paragraphs will concentrate on describing fractures in certain skeletal elements, their frequencies in living people (using mainly Court-Brown & Caesar study from 2006ab), their causes and also treatment possibilities. The most common causes of fractures in modern societies are assaults, motor vehicle accidents, and falls from heights or from standing height (Galloway 1999).

Cranium

Studies on cranial and facial fractures (Figure 1) show that the main causes behind these injuries are accidents and violence (e.g. Haug et al. 1994; Brasileiro & Passeri 2006; Fornazieri et al. 2008; Trinidade et al. 2013). Haug et al. (1994) studied patients from a trauma center in Ohio with cranial and facial fractures between 1984 and 1992. Out of over 800 patients, 39 individuals presented with both cranial and facial fractures. There fractures were most common in young individuals 16-30 years of age and males. The frontal was the most commonly fractures bone, followed by the sphenoid, temporal, mandible and zygomatic bones.

Some studies have concentrated on nasal fractures because the nose is a prominent feature and unprotected (Fornazieri et al. 2006; Trinidade et al. 2013). However, when maxillofacial fractures were studied in Brazil, it was noted that the most commonly fractured bone was the mandible (44%) followed by zygomatics (32%) and then nasals (16%) (Brasileiro & Passeri 2006).

Figure 1. Nasal fractures. Photo permission: FAC.

Nasal fractures have been found to be more common in males than in females and usually affect younger individuals (Fornazieri et al. 2006), but a study in the United Kingdom showed that the incidences of nasal fractures in females have increased tremendously in the past 20 years, especially in the younger age groups (Trinidade et al. 2013). There are multiple possible explanations but one of the suggested reason was the rise of a male-like drinking habits of females (Trinidade et al. 2013). Mandibular fractures are common even though the bone is more robust than other facial bones. Ogundare et al. (2003) reported that almost 80% of mandibular fractures in an urban trauma center in DC were caused by violence, and usually affected young males, which are the most common group involved with violence or accidents.

Sternum

A study by Recinos et al. (2009) on sternal fractures found that sternal fractures are not that common, since only 0.33% of patients admitted to ER in California over a 10-year period had a sternal fracture. Most of the patients were males who were involved with a motor vehicle accident. Almost half of the patients with sternal fractures also had rib fractures (Recinos et al. 2009). Similar trends were seen in Greece, where most of the patients with sternal fractures were middle-aged men and the cause of the fracture was motor vehicle accident (MVA). Most of the associated fractures in this study as well were observed in the ribs (Athanassiadi et al. 2002).

Sternal fractures do not necessarily need operative fixation but if fixation is applied usually plates and wires are used (Harston & Roberts 2011).

Clavicle

The Edinburgh data were used to study the epidemiology of clavicular fractures. Court-Brown and Caesar (2006b) reported an incidence of 3.3%. This injury was more common in males with a peak under 20 years of age. The incidence was lower in females but peaked in the 80s. The main causes of clavicle injuries were sports in young males, and falls in older males and females (Robinson 1998). The usual treatment for clavicular fractures is a non-operative sling, but also plates, screws and pins are used for fixation. Non-union in clavicle fractures is not uncommon, but in many cases it stays asymptomatic and does not require special treatment (Lazarus & Seon 2006). Clavicle fractures take approximately 6-12 weeks to heal (Gaudinez & Hoppenfeld 2000).

Scapula

Scapula fractures are not very common. Court-Brown and Caesar (2006b) observed an incidence of 0.3%. The fractures are generally seen in the body or the neck of the scapula. Usually fractures are related to blunt force trauma caused by motor vehicle accident or falls from height (Burke 2011), and thus they are generally associated with fractures in other areas. Scapula fractures can be treated non-surgically or surgically. Surgical treatment includes use of screws, staples, sutures or plates (Butters 2006).

Spine

Fractures in the cervical vertebrae are usually caused by falls or motor vehicle accidents, whereas thoraco-lumbar vertebrae (Figure 2) can also be fractured due to minor factors when osteoporosis has made the bone weak (Court-Brown & Caesar 2006a). In addition to osteoporosis, vertebral compression fractures can be triggered by bone metastasis (Jung et al. 2003). The vertebral fracture frequencies are not often reported and if they are, frequencies are commonly low, for example 0.7% (Court-Brown & Caesar 2006a). The low frequencies are often explained by asymptomatic fractures and under-diagnosis of vertebral fractures. A study on a Norwegian population

reported low rates as well; 3% for females and 7.5% for males under 60 years of age. In individuals over 75 years the incidence reached 20% (Waterloo et al. 2012). Treatment of spinal fractures depends on the location and type of a fracture. Usually plates, rods or wire are used for internal fixation (Mirza et al. 2006; Lonner et al. 2000; Patel et al. 2000). Sometimes cement can be injected to the vertebral body to treat osteoporotic fractures (Eastlack & Bono 2006). Vertebral fractures are reported to heal somewhere between six and 16 weeks (Lonner et al. 2000; Patel et al. 2000). Spondylolysis, even though considered a fracture, is included in this study in the skeletal anomalies, because it probably occurs in individuals with a congenital weakness in the lamina (Wiltse et al. 1975).

Ribs

Rib fractures are very frequent and important since they are related to high morbidity and mortality (Wuermser et al. 2011; Bulger et al. 2000). A study of older males found that rib fractures were the most common non-spinal fracture among these men. Twenty-four percent of all the non-spinal fractures were rib fractures (Barrett-Connor et al. 2010). Another study reported that during a 2-year period, 39% of all the thoracic trauma cases in a Turkish clinic had rib fractures. Approximately 60% of these cases with rib fractures were males. Most of the rib fractures are due to falls (standing height or higher), or motor vehicle accidents (Sirmali et al. 2003), but they can also be a consequence of severe coughing. Rib fracture frequency is positively correlated with age. Several risk factors have been found for rib fractures in elderly people. Age is the most important factor, but also low bone mineral density and previous fractures impact the risk (Barrett-Connor et al. 2010). It has been suggested that rib fractures in elderly individuals should be evaluated as osteoporotic fractures (Wuermser et al. 2011; Barrett-Connor et al. 2010).

Figure 2. An example of vertebral body fracture. Photo permission: FAC.

Upper limb bones

Humeral fractures are most common in the proximal end (5.7% according to Court-Brown & Caesar 2006b), i.e. head and neck, and the least common in the distal end (0.5% according to Court-Brown & Caesar 2006b). Humeral fractures are usually caused by a fall, a direct blow or a motor vehicle accident. The usual methods of treatment for humeral fractures are plates, screws, intramedullary nails and head replacements. The healing process takes from 6 to 12 weeks depending on the fracture site (Gaudinez et al. 2000a; Hoisington & Thomas 2000; Lewin & Vasantha 2000). It is reported that in 2008, 370,000 emergency department visits were done in the US due to humeral fractures. Almost half of these visits were due to a fracture in the proximal humerus, and about 60% of patients were females (Kim et al. 2012).

The most common type of fracture of the forearm occurs in the distal radius and is called a Colles' fracture. This fracture occurs usually 3-4 cm proximal of the distal articular surface and it is usually caused by a fall. It is especially common in elderly females and is one of the major osteoporotic fractures (Sheikh & Vasantha 2000). Actually, fractures of distal radius were the most common fractures (17.5% of all fractures) observed at an orthopedic trauma unit in Edinburgh in Scotland (Court-Brown & Caesar 2006b). Treatment options for Colles' fracture are usually external fixators (pins screwed into the bone but the main device stays outside of the arm), pins and plates. Fractures in the proximal radius and ulna are usually treated with wire and

screws, but also excision of the fragments is possible. Forearm fractures are expected to heal in 6-12 weeks. Fractures in forearm bones can lead to synostosis, fusion of the radius and ulna (Gaudinez et al. 2000b; Spero & Vasantha 2000; Hoisington & Vasantha 2000a; Sheikh & Vasantha 2000).

Hands

Hand fractures are very frequent, especially in metacarpals and fingers (Figure 3). Court-Brown and Caesar (2006b) found metacarpal fractures to be the most common fracture right after the distal radius. Metacarpals accounted for 11.7% of all the fractures coming to the trauma unit. Fingers are commonly injured (9.6%) whereas carpals are less frequently affected (2.7%). It has been reported that women have more carpal fractures, whereas men show more metacarpal and phalangeal fractures (Chung & Spilson 2001). The most typical fractured carpal is scaphoid which articulates with distal radius. Fractures in the hands are fixed surgically using pins, screws and plates. Depending on the fracture site bone healing can take from three to 20 weeks (Hoisington & Vasantha 2000b; Kram & Vasantha 2000c; Kram & Vasantha 2000d). Hand bones are typically injured as a result of falls and blows from a person or an object (Chung & Spilson 2001).

Figure 3. A healing fracture in the proximal shaft of a fifth metacarpal. Photo permission: FAC.

Pelvis

Pelvic fractures are uncommon. Court-Brown & Ceasar (2006a) studied the fracture cases from the Edinburgh trauma unit during the year of 2000, and pelvic fractures made up only 1.5 % of all the fractures. They were more common in females. Regardless of their rarity, pelvic fractures can be fatal or at least cause severe complications to the patients. In addition to the bone (sacrum, os coxae) injury, pelvic ring fractures can cause injuries to gastrointestinal, genitourinary and vascular systems (McCormack et al. 2010; Demetriades et al. 2002). Pelvic fractures, especially in the iliac wing and sacrum, tend to heal quickly since they are surrounded by blood vessels and muscle. If surgical fixation is needed, screws and plates are usually used (Starr & Malekzadeh 2006). The most common type of pelvic fracture is pubic ramus fracture. These fractures are usually accompanied by a fracture in the posterior ring. These also are more common in females and are usually caused by a fall from standing height or a motor vehicle accident. Pubic ramus fractures heal well without surgical treatment but the recovery takes longer than expected, and elderly patients might lose their independence due to the event (Studer et al. 2013). Frailty, low bone mass, and frequent falls increase the risk of pelvic fractures, as well as fractures in the proximal humerus and hip (Kelsey et al. 2005).

Lower limb bones

Femoral fractures can be divided into several groups: neck, intertrochanteric, subtrochanteric, shaft and subcondylar fractures. Most of these fractures are typically caused by a fall or a motor vehicle accident. Neck and intertrochanteric fractures are especially common in elderly people, and more so in females with osteoporosis. These fractures are commonly reported as hip fractures (Cumming et al. 1997). Incidence of proximal femur fractures has been reported to be 11.6% in a Scottish sample, whereas shaft and distal femur were both under 1% (Court-Brown & Caesar 2006b). The Edinburgh trauma data showed no difference between sexes until 60 years of age in incidences of hip fractures. After 60 years of age the incidence increased in both sexes but females were more likely sustain a hip fracture (Singer et al. 1998).

Neck and intertrochanteric fractures are fixed using screws and plates or a combination of the two. Also femoral head replacements can be used for fixation. Shaft

fractures are usually fixed with an intramedullary nail or a plate. The healing process of femoral fractures generally takes from 12 to 16 weeks (Taylor & Vasantha 2000a; Taylor & Hoppenfeld 2000; Taylor & Vasantha 2000b; Kram & Vasantha 2000a; Leighton 2006; Koval & Cantu 2006; Nork 2006).

Tibial fractures (Figure 4) are one of the most common types of long bone fractures that are surgically fixed. This is because the anterior surface of the bone is so close to the skin that the fractures tend to be open more often than in other areas (Marsh & Saltzman 2006). Diaphyseal fractures are the most common type of tibial fractures (1.9%) followed by proximal tibia (1.2%) and distal tibia (0.7%) (Court-Brown & Caesar 2006b). Tibial fractures are usually caused by motor vehicle accidents, assaults, sports and falls (Court-Brown & McBirnie 1995). They usually involve young males or elderly females. Depression fractures in tibial condyles are usually associated with older patients. The main methods of fixation are screws, plates and intramedullary nails. Tibial fractures are expected to heal somewhere between six and 12 weeks. (Kram & Vasantha 2000b; Taylor & Vasantha 2000c; McCormack & Hoppenfeld 2000; Court-Brown 2006). Lower limb fractures may impact both the tibia and fibula or they can be isolated. Ankle fractures can involve either the fibula or tibia or both, and the talus can also be affected. A fractured ankle commonly follows twisting the joint or hyperflexion/extension (McCormack & Hoppenfeld 2000; Marsh & Saltzman 2006; Court-Brown 2006).

Figure 4. Malaligned healed fractures in the distal tibia and fibula. Photo permission FAC.

Fractures of the patella are mainly due to a direct blow, such as a motor vehicle accident or a fall. The frequency of patellar fractures was reported to be 1.0% by Court-Brown and Caesar (2006b). Common treatment methods used to fix patella includes wires, screws, and sometimes a partial or total removal of the patella (Harris 2006).

Feet

A foot consists of 26 bones. Metatarsals are the most commonly fractured foot bones according to Court-Brown & Caesar (2006b). In their study metatarsals accounted for 6.8% of all the fractures in the sample. Toe phalanges followed with 3.6%, calcaneus 1.2%, midfoot and talus together accounted for 0.7%. Foot fractures are usually results of a direct blow or twisting occurring in a motor vehicle accident, or a fall. Also hitting a foot on furniture or dropping objects on a foot can cause fractures. Common fixation methods are pins, screws and plates. Bone healing is expected to complete in 4-12 weeks depending on which bone is injured (McCormack 2000a; McCormack 2000b; McCormack 2000c; McCormack & Hoppenfeld 2000b).

Bone lesions

Description and interpretation of pathological bone lesions requires understanding of the bone remodeling mechanism. Remodeling of bo ne is a continuous process that will occur throughout life. Remodeling has two main events: resorption and formation of bone. The cycle of remodeling has been presented in five cycles. (This brief summary presented here is based on Ortner 2003). 1) Activation - after some damage or hormonal signals the bone lining cells withdraw and expose the bone layer underneath. Bone lining cells send signals to preosteoclasts and osteoclast precursor cells appear on the site and differentiate into osteoclasts. 2) Resorption - osteoclasts are bone destroying cells that use enzymes to remove and break down the organic matrix. After finishing resorption osteoclasts die. 3) Reversal - starts the repair process with macrophage-like cells that clean the margins of resorption pit and lay down a layer of cement that will bind the new bone to the old surface. 4) Formation - osteoblast are bone forming cells that arrive to the resorption area and deposit layers of osteoid. This will be followed by osteoid mineralization. 5) Quiescence - after mineralization, osteoblasts transform into

bone lining cells on the new surface. Some of these osteoblasts become osteocytes which is the major bone cell type present in mature bone. As long as resorption and formation stay in balance, bone properties will remain relatively stable. An example of disturbed balance is increased endosteal removal due to natural aging which tends to exceed bone formation. This disturbance is even more pronounced when the changes are due to osteoporosis.

Diseases affecting the skeleton can be seen as five forms of abnormality. These abnormal features include bone formation, bone destruction, bone density, bone size and bone shape. Bone can respond to disease stimuli by new bone formation, bone destruction or a mixture of these two (Ortner 2003).

Abnormal bone formation under the periosteum, on the outer surface of bone, is usually called periostitis or periostosis in the paleopathological literature. Periostitis refers to bone formation that is related to inflammation, whereas periostosis refers to bone formation regardless of its origins (Ortner 2003). In newer clinical literature the term periosteal reaction is used, and this term will be used in this study as well regardless of the origin of the bone formation. Periosteal reactions can be divided into two forms: aggressive and nonaggressive. The nonaggressive form can deposit layers that are thin, solid, thick or irregular. The aggressive form is generally seen as laminated, spiculated, sunburst, or disorganized bone (Rana et al. 2009).

Periosteal lesions can be caused by several factors (Figure 5), including a fracture, infection, tumor or arthritis. Sometimes the type of the periosteal reaction may be attributable to a specific condition but many times there is some overlap. However, it is suggested that if periosteal reaction is affecting skeletal elements bilaterally, there might be a systemic disease behind the lesions. The unilateral expression is usually caused by trauma, infection or a tumor (Rana et al. 2009). This non-specific infection is a common finding, especially in the lower limbs, in both archaeological and modern skeletons (Waldron 2009).

Osteomyelitis is an infection which starts in the bone marrow and involves mostly the internal structures of bone, but can also eventually affect the outer surfaces. Osteomyelitis is usually associated with trauma or surgery. The process of osteomyelitis starts usually in the metaphysis as a lytic lesion. This spreads and causes problems with the blood supply to the cortex that will eventually die (sequestrum). Nevertheless the

periosteum will continue to form new bone which forms around the sequestrum like an envelope (involucrum). The involucrum will have small openings (cloacae) for pus to drain out of the bone. These three features (sequestrum, involucrum and cloaca) are typical for pyogenic osteomyelitis, and without them the correct diagnosis is difficult (Ortner 2003).

In addition, neoplasms can be counted into the bone formation category. They are usually caused by proliferated growth of bone or other tissue. Neoplasms can be either benign or malignant. Benign tumors are localized tumors with mature bone, and they include examples like osteomas, cysts and exostoses. Malignant tumors consist of immature bone. They grow uncontrolled, and thus can also spread around the skeleton. Some lytic and periosteal lesions are results of malignant tumors that have spread (metastasized) from the primary tumor to different parts of the body. Typical examples of malignant neoplasms are sarcomas and carcinomas (Ortner 2003; Aufderheide & Rodriguez-Martin 1998).

Figure 5. A healing periosteal reaction on the distal tibia. Photo permission: FAC.

Abnormal bone loss can be observed as lytic lesions or osteoporosis (Figure 6). Lytic lesions can be observed in cancers and also infections like tuberculosis or brucellosis and fungal diseases like blastomycosis (Hershkovitz et al. 1998). It has been reported in clinical literature that 80% of all metastatic bone disease cases are caused by breast and prostate cancers (Coleman 2001). Cancer can metastasize to the bone and cause both osteolytic and osteoblastic lesions. However, lytic lesions are more common, especially in lung, breast, thyroid, and kidney cancers. Prostate cancer causes more new bone formation. Both lytic and new bone lesions can be seen in any type of cancer but these mixed lesions are commonly seen in breast cancer. Metastases are generally seen in cancellous bone (vertebrae, proximal metaphyses of femur and humerus, cranium, ribs and pelvis) due to their high marrow content. Metastases can cause severe pain, nerve compression, impaired movement and pathological fractures (Ortner 2003; Roodman 2004; Coleman 2001). Pathological fractures due to metastatic destruction are most common in vertebral bodies and ribs. Treatment options for metastases include radiotherapy and radiopharmaceuticals (Coleman 2001; Mundy 2002).

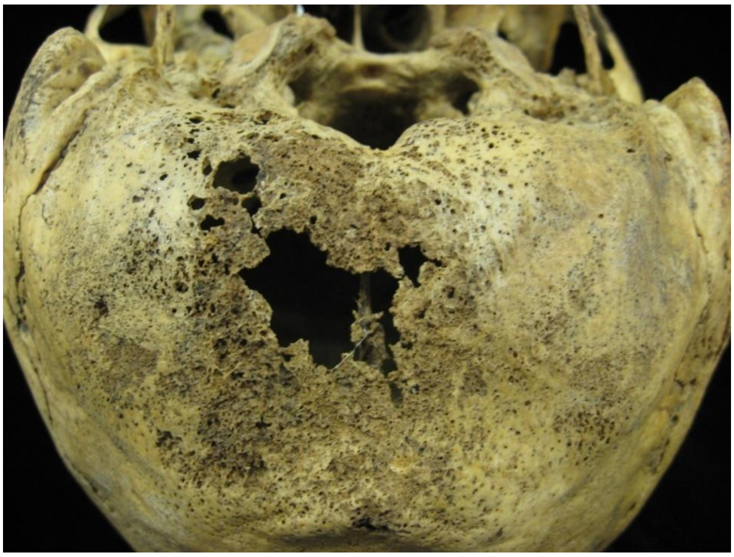

Figure 6. A lytic lesion on the occipital. Photo permission: FAC.

Differentiating antemortem and postmortem bone destruction can be difficult. Ortner (2003) states that in most cases antemortem destruction shows some kind of healing. The margins of the lesion are rounded or new bone might be present. In general, antemortem lesions are smoother and rounder than postmortem destruction. The type of the lesion margins will also indicate whether the disease process has been slow or fast. A slow disease process will have reactive bone in the margins, whereas more aggressive disease will show clear margins without reactive bone and possibly a gradual change showing partially lytic bone between healthy bone and lytic lesion. Use of microscopic methods makes the differentiation of these lesions easier (Ortner 2003).

Osteoporosis can be detected from the bones by the light weight, but that is not a reliable method to diagnose the disease. The bone density and the internal structure of should be examined by radiographs or DEXA. In this current study osteoporosis is not reported due to the use of macroscopic analysis only.

In this current study, surgical bone removal is included in abnormal bone loss whereas it usually is included in trauma (e.g. Lovell 1997). Surgical bone removal refers in this study to craniotomy (Figure 7), amputations or harvesting area of a bone graft, but also removal of extra bone growth (rotator cuff surgery). Amputation might be required when there is an overwhelming infection or destruction of vascular system that has affected a limb beyond repair. Injuries that might require amputation are common in war wounds but also in civilian contexts e.g. motor vehicle accidents. Tibial and femoral amputations are the most common types of amputation (Dougherty 2006). In addition, diabetes can be a factor contributing to amputations (Adler et al. 1999).

Figure 7. A craniotomy on the right parietal and temporal. Photo permission: FAC.

Osteoarthritis

Osteoarthritis (OA) is one of the most common rheumatic diseases. Rheumatic diseases are a group of over 100 different diseases which generally affect joints and bones but also soft tissues and organs. Osteoarthritis is a disease in which the hyaline cartilage on the joints is damaged and worn out resulting in bone-on-bone-contact. Thus, it is quite easy to observe on the skeleton. There are two types of osteoarthritis: primary and secondary osteoarthritis. Primary OA is defined as the original conditions affecting the joint, whereas secondary OA is caused by some other condition such as trauma, malformations or inflammations. Primary OA will affect one or usually multiple joints and is caused by the common wear and tear. It is very common in older individuals whereas secondary OA is seen also in younger individuals, and it usually affects just one joint which has been injured or otherwise compromised (Ortner 2003; Waldron 2009).

The bony changes that occur in OA include eburnation, porosity, osteophytic formation on the margins, new bone formation on the surface and changes in the contour of the joint. The diagnosis of OA from skeletal remains can be made in several different ways (Waldron 2009; Weiss & Jurmain 2007; Bridges 1993). If the individual exhibits eburnation (Figure 8) that can be diagnosed as OA, but if other changes are used at least two of them should be present for a correct diagnosis (Waldron 2009).

Figure 8. Eburnation on the articular facets of L5. Photo permission: FAC.

OA has been most often reported to affect hands, proximal and distal femur, acetabulum, proximal tibia and spine. For example, in the US 350,000 joint replacements (knee and hip) are implanted every year (Arden & Nevitt 2006). Wrist, elbow, shoulder and ankle are less frequently affected. OA tends to be more common in females. Especially the number of affected joints is greater in females than in males (Langley 2003). Prevalence increases with age, especially in the knee, hip and hands (Arden & Nevitt 2006). OA in the hip joint has been found to be less frequent than OA in the knees and hands but it is usually more severe (Mannoni et al. 2003).

OA causes tenderness, swelling, stiffness and pain in the joints which then result in joint instability and limited movement. Diagnosis can be made based on these symptoms or x-rays of joints. Treatment is usually based on medication and different types of physical therapy and aims to reduce pain. When joint destruction is too severe joint replacement is an option to reduce pain and restore mobility (American College of Rheumatology Subcommittee on Osteoarthritis Guidelines 2000).

Surgical devices

There are several types of surgical devices that can be seen in modern skeletal collections. Most of them are for fracture fixation, for example pins, screws, wires,

plates and rods. In addition to these, there are several types of replacements and anchors that are used to fix other medical problems. Only devices that are physically fixed into the skeletal remains are taken into account in this study. Thus, heart valves, stents, pace makers and catheters are excluded.

Fracture fixation

Fracture treatment aims to stabilize the bone and thus to make the healing process faster and allow faster mobilization of the broken element. There are three main methods for fracture fixation: conservative method, external and internal fixation (Connolly 2006). The conservative method, also called the non-operative method, includes casts, splints and braces. The non-operative methods use immobilization and pain relief as treatment. Non-operative methods reduce infection risk, and risk of errors made in more complicated operative methods (Connolly 2006). External fixation includes pins that are placed into the bone through the skin and are connected to the fixation rods/clamps which are outside the soft tissue and stabilizing the pins (Watson 2006). Internal fixation is the best option for treatment in case of displaced intra-articular or comminuted fractures. Even though the risk of infection or human error is greater in this method of fixation, it can restore the skeletal anatomy more precisely than the other methods (Kretterk & Gösling 2006). Internal fixation includes, as mentioned above, pins, wires, intramedullary rods, screws, plates, staples, and clamps (Taljanovic et al. 2003a). Sometimes bone grafting is used to treat fractures with delayed unions and for reconstruction of vertebrae. The most typical internal fixation methods are described below.

Pins, screws, staples

Pins, screws and staples of stainless steel or titanium are used to fix fractures. Pins are often used for temporary fixation of a fracture. They are used as guides to accurately place the larger rods or screws. Screws are often used with plates, nails and rods to stabilize them. There are several types of screws that are suitable for different kind of bone: cortical or cancellous. Sometimes screws will have a metal ring (washer) around the head to make sure the head of the screw will stay outside the bone. Some screws

(cannulated) are hollow and they are placed over the guiding pins (Taljanovic et al. 2003a).

Wire

A metal wire is used to fix surgery or fractures by holding separate fragments together (Figure 9). Wire can be used alone or in addition to other fixation methods like pins and screws. Wire can stabilize bone externally when intramedullary pin is placed, or in case of periprosthetic fractures (Cofield et al. 2006). One of the most common situations of wire use is reattaching sternum fragments after open heart surgery (Taljanovic et al. 2003a).

Plates

Metal plates are used to fix and align a fractured bone (Figure 10). There are several types of plates and most of them are made of stainless steel or titanium. Plates are used in multiple occasions but they are a preferred method for fractures that affect articular surfaces. Plates are mostly used to fix fractures in long bones (Taljanovic et al. 2003a).

Figure 9. An example of a sternum with wire fixation after open heart surgery.

Figure 10. An example of a surgical plate on cervical vertebrae. Photo permission: FAC.

Intramedullary nails and rods

Metal rods are used to fix and align a bone fracture. Plates are inserted on the external surface of the bone, but rods are put inside the medullary cavity. These are mainly used for diaphyseal fractures in the femora and tibiae, but also for the spinal fractures. Intramedullary rods resist torsion and bending, and they make the weight-bearing long bones functional earlier than other methods. Rods and nails are stabilized with interlocking screws that are used in the proximal and distal ends of the rod. There are different types of rods and nails to fix different elements. There are also flexible intramedullary pins that are smaller in diameter and are used for children and adolescents (Taljanovic et al. 2003a) or upper extremities (clavicle and proximal humerus) in adults (Krettek & Gösling 2006).

Sutures

Sutures are usually used to close wounds and attach tissues to bone. There are several types of sutures that are chosen carefully depending on the tissues they attach and the surgical procedure conducted. Most of the sutures consist of synthetic polymer fibers. They can be bioabsorbable or non-bioabsorbable depending on how permanent the tie between tissues should be (Hunter 2001; Suzuki & Ikada 2012).

Joint replacements

Another group of surgical devices is joint replacement. These can sometimes serve as fracture fixation (fractured humeral or femoral head/neck), but also treat degenerative joint disease, necrosis or inflammatory arthropathy. Fixation of these implants to the bone can be done with or without cement (Taljanovic et al. 2003b). Hip, knee and shoulder replacements are most common. Elbow, wrist and ankle replacements less common.

Hip replacement

There are three types of hip replacements: unipolar, bipolar and total replacement. A unipolar replacement consists of a replaced femoral head. The metal head is the size of the acetabulum and is directly in contact with the cartilage. A bipolar replacement consists of small femoral head and a separate acetabular part that stays together with the head. The acetabular part is as big as the actual acetabulum and articulates with it. A total replacement includes two separate components: a femoral head and a fixed acetabular cup (Figure 11). The fixation can include cement or be cementless in which case the prosthesis surface is rough or porous allowing bone ingrowth. Severe OA requires a complete replacement but femoral neck fractures can be fixed with the femoralcomponent only (Taljanovic et al. 2003b).

Knee replacement

A total knee replacement involves the articular surfaces of distal femur, proximal tibia and patella. Also only one condyle surface can be replaced and usually that is the medial condyle. The femoral part is metal and the tibial plateau is made of polyethylene surface and metal. The patellar surface is made of polyethylene. Knee replacement is usually to treat severe OA (Taljanovic et al. 2003b).

Figure 11. A hip replacemnt in the right acetabulum.

Shoulder replacement

Shoulder replacement can be complete or partial. A complete replacement consists of a metal head inserted into the neck and a plastic/metal replacement for the glenoid cavity. This replacement is usually done due to severe OA. A partial replacement (humeral head) is used as an injury fixation to proximal humerus fractures or rotator cuff tears (Taljanovic et al. 2003b). There are also different types of replacements. Sometimes when extensive rotator cuff damage occurs the glenoid cavity can be replaced with a metal ball and the humeral head with a socket. This is called a reverse shoulder replacement (Roberts et al. 2007).

Other common surgical procedures

Bone grafts are used as a treatment for bone defects that are usually caused by injury or infection. The defect area can be filled with bone graft that is most commonly extracted from individual’s ilium (Taljanovic et al. 2003). Bone from the ilium can be used for both cortical and cancellous bone grafting. Other source for cancellous bone is the distal radius, and for cortical bone, ribs and fibula (Kakar et al. 2006).

Amputations are sometimes the only option to treat badly wounded extremities. This is required when there is a severe infection or the vascular system is totally destroyed. One major reasons for amputation in older individuals is dysvascular disease that is often accompanied by diabetes (Ziegler-Graham et al. 2008). Poor circulation might result in necrosis or infection unless treated. In this procedure the bone is cut in an appropriate place and skin flaps are used to close the incision. Tibial and fibular removals are the most common types of amputations (John Hopkins Medicine n.d.).

A vertebroplasty is a technique used in treating vertebral compression fractures. In this method polymethylmethacrylate bone cement is injected into the vertebral body to provide support and strength (Figure 12). It is supposed to relieve pain by immobilizing the fracture and stopping further compression (Hunter et al. 2004a; Karlsson et al. 2006).

A laminectomy removes a part of the vertebral lamina in order to treat compressed spinal cord or nerves (Figure 13). Compression may be due to trauma, tumor, narrowing of the spinal canal or herniated disks. Laminectomy is required if non-operative treatments do not ease the lower back pain. This procedure may be followed by a surgical fusion of two to three vertebrae to stabilize the vertebral bodies. Plates or rods are used for the stabilization (Johns Hopkins Medicine n.d.).

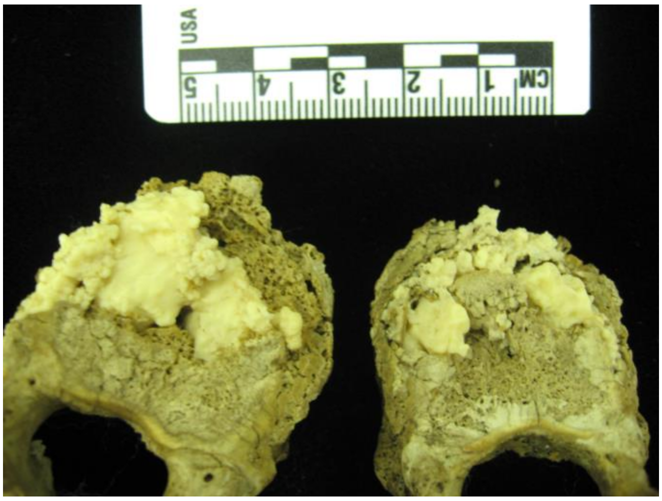

Figure 12. An example of vertobroplasty. Photo permission: FAC.

Figure 13. An example of laminectomy in lumbars 2-4. Photo permission: FAC.

Rotator cuff surgery is performed to fix the muscles and tendons holding the shoulder joint together. The surgery might be needed after an injury that tore muscles or tendons or as a consequence of degeneration in older individuals. Rotator cuff problems usually cause pain, muscle weakness, and can prevent normal arm movements. In the surgery the tendons/muscles are repaired but also bone spurs can be removed from the inferior surface of the acromion (Johns Hopkins Medicine n.d.).

A craniotomy is a surgery in which a part of a cranial bone is removed to gain access to the brain. Burr holes are drilled to the corners of the bone plate that is being removed. A craniotomy is performed for multiple reasons. The most common reasons are removal of a hematoma or a tumor, placement of drainage or other devices, fracture fixation or pressure control. The removed bone flap is placed over the incision again and plates and sutures are used for reattachment (Johns Hopkins Medicine n.d.).

An open-heart surgery impacts the skeleton since surgeon accesses to the heart by cutting the sternum into two vertical halves. An open-heart surgery is used for variety of purposes: to bypass blocked coronary arteries, replace a heart valve, and place a heart transplant or other devices. The sternum is closed by using sternal wires (Hunter et al. 2004b), which can be seen in addition to the healed scar on the bone.

Other conditions

This section consists mainly of skeletal anomalies which can be congenital or degenerative changes observed in the skeleton. This study does not include all the possible conditions but the list of chosen conditions was influenced by the author's prior experience on the examined skeletal material. Many of these may not be diagnosed because the individual may not have any symptoms (e.g. sternal aperture), but some of them might cause pain or discomfort (spondylolysis or long styloid process). The diagnosis of these conditions may occur by accident while examining x-rays for other reasons. It is important to know how common these anomalies and changes are if they are going to be used in identification.

Sacroiliac fusion

Sacroiliac fusion is considered as a separate in this study, even though it is commonly associated with other conditions such as ankylosing spondylitis (AS) and reactive spondyloarthropathy (Waldron 2009). This conditions is found more frequently in males than in females, and in older individuals (Dar & Hershkovitz 2006; Waldron & Rogers 1990). In a small CT-scan study the condition was seen in 34% of the males, and only in 5% of the females (Dar & Hershkovitz 2006). The fusion can be bilateral or unilateral, and in the case of AS the fusion is typically bilateral.

Other pathological fusions

Pathological fusions include mainly vertebral fusions but also other elements like sternum, phalanges and long bones can be found fused to other elements. Usually this is caused by osteoarthritis or trauma. The main interest in this research is in fusion of vertebrae and sacroiliac joints.

Ankylosing spondylitis (AS) and Diffuse Idiopathic Skeletal Hyperostosis (DISH) can cause vertebral fusion. AS is one of the rheumatic diseases whereas DISH is not, but is often confused with rheumatic conditions due to similar skeletal manifestations. AS usually starts at the sacroiliac joints, which fuse bilaterally (sacroiliitis). The disease continues to the spine and starts fusion from lumbars towards cervicals. Fusion does not skip any vertebrae, and it is not restricted to one area of the vertebral body but goes

around it. It is known also as “bamboo spine” because the concave shape of the bodies will be squared off. The apophyseal joints (the articular facets) are also affected as well as costal joints (rib facets). Skeletal involvement external to spine is not typical (Ortner 2003; Waldron 2009). AS diagnoses are made for males more frequently than for females and the onset is in early adulthood. AS is usually diagnosed based on the sacroiliac fusion, back pain, and limited spinal mobility. Postural changes are usually indicative of AS, but patients with DISH can also express similar changes (Olivieri et al. 2007). Usual treatment options are physical therapy, medication, and in worst cases, surgery (Mansour et al. 2007).

DISH is characterized by ossification of the anterior longitudinal ligament but only on the right side (Figure 14). The left side of the vertebral body is spared due to the presence of descending aorta. The ossification of the ligament is thick and is commonly referred to as flowing candle-wax. DISH does not typically affect the apophyseal joints and also the normal disc space is retained. There are several methods to diagnose DISH based on the number of fused vertebrae and extraspinal involvement (Van der Merve et al. 2012; Rogers & Waldron 2001). The most common method (Resnick & Niwayama 1976) requires at least four consecutive vertebrae to be fused before the condition can be diagnosed as DISH. DISH usually involves thoracic and lumbar vertebrae. In addition to the spine DISH affects other ligament and muscle attachment sites by calcification. These enthesopathies can be seen most often in the ischial tuberosity, iliac crest, trochanters, patella, linea aspera and calcaneus. DISH usually does not affect the sacroiliac joints (Aufderheide & Rodriguez-Martin 1998; Rogers & Waldron 2001; Ortner 2003).

Most people with DISH will be asymptomatic and do not need treatment (Hannallah et al. 2007). Patients mostly complain about back pain, which can be accompanied by stiffness. This can also lead to decreasing range of motion (Resnick et al. 1975). Nevertheless, DISH-patients may not even experience back pain. For example, a study found that DISH-patients did not have any more back pain than control individuals (Schlapbach et al. 1989). Physical therapy and anti-inflammatory medications are usually enough to treat the pain. Surgery is rarely used as a treatment unless vertebral fractures are involved. Sometimes osteophytic formations in the cervical area can cause dysphagia and might need to be removed (Hannallah et al.

2007). DISH is more common in males than in females (Langley 2003; Weinfeld et al. 1997) and the prevalence increases with age (Holton et al. 2011).

AS and DISH can be differentiated by the skeletal manifestation but also by the demographics of the affected individual. Both conditions are more common in males than females, but DISH is seen in older individuals whereas AS can be seen in the younger years in early adulthood (Mansour et al. 2007). The major differences are seen in the sacroiliac fusion, apophysial and costal joints and extraspinal involvement in the form of enthesophytes. DISH tends to be more common than AS. These conditions are rarely reported to coexist (Jordana et al. 2009; Rillo et al. 1989).

Schmorl's depressions

Schmorl's depressions are small depressions on vertebral endplates. They are caused by Schmorl's nodes which are bulging intervertebral discs that herniate into the bone leaving an eroded lesion. They are thought to be a result of trauma or degenerative processes. Usually there can be some remodeling seen on the edges of the lesion. These depressions can vary in size and shape but they are most common in the lower part of the spine: thoracic and lumbar vertebrae (Waldron 2009; Pfirrmann & Resnick 2001). They are reported to be very common, especially in individuals over 45 years of age (Aufderheide & Rodriguez-Martin 1998) even though the results of prevalence studies in modern populations vary. This variation can be explained by different observation methods since it is easier to miss a node in a regular radiograph than using other methods such as cross-sectional imaging or observing the bone itself. In a study of 100 cadavers 58% of the individuals had one or more Schmorl's nodes. The average age of the sample was 68. Over 80% of the nodes were between T7 and L2 (Pfirrmann & Resnick 2001).

Figure 14. An example of DISH. Photo permission: FAC.

Schmorl's nodes can be asymptomatic and never be known to exist, but they can also be found in individuals with lower back pain. It is not clear whether the nodes cause the pain or if pain is related to other degenerative changes that accompany nodes (Williams et al. 2007; Pfirrmann & Resnick 2001). When back pain exists medication, massage, and physical therapy are recommended. Occasionally when the conservative treatment does not help surgical fusion treatment might be considered (Peng et al. 2009).

TMJ problems

Temporomandibular joint (TMJ) problems refer in this context to pathological changes in the mandibular condyle or the mandibular fossa in temporals. These changes include changes that are common in osteoarthritis: eburnation, osteophytes, porosity and change in joint contours.

Congenital fusions

Congenital fusions can be seen in the skeletal elements. Congenital fusions are most common in vertebrae and sternum. This phenomenon is not exactly a fusion but actually a failure of segmentation. The manubrio-mesosternal joint fusion occurs when the fibrous lamina between the manubrium and the first segment of the sternal body does not develop. Thus they start fusing which happens approximately between 12 and 16 years of age in males and females respectively. Fusions caused by developmental defect should be distinguishable from pathological fusions. Congenital fusion at the joint is smooth, whereas pathological fusion usually has a clear bone build-up (Barnes 1994).

Block vertebra refers to two or multiple vertebral segments that failed to separate during development. This can be seen as united bodies, united arches or both parts united. Multiple block vertebrae are not as common as single block vertebrae which can be commonly seen in C2-C3 or C3-C4 and sometimes in thoracics but rarely in lumbars (Barnes 2012).

Cleft neural arch in vertebrae

If the two sides of the neural arch in vertebrae fail to fuse during skeletal development, this will result in a cleft arch. The cleft can occur if the arches are underdeveloped or they do not develop at all, thus the expressions can vary from bifurcated laminae and spinous process to cleft arch without spinous process. These defects are considered non-pathological and are most commonly seen in atlas, C1 (Figure 15). A cleft thoracic is a quite rare phenomenon as well as involvement of several presacral vertebrae in the same spine (Barnes 2012). Guenkel et al. (2013) studied CT-scans of the cervical region in order to investigate the frequency of cleft arch in cervicals and determine the range of variation. Their sample of 1069 scans showed atlas arch defects in 3.8 % of the individuals. The most common type of the defect was a cleft in the posterior side (83% of all anomalies). Cleft neural archs are commonly incidental findings on x-rays or CT-scans and can sometimes be confused to an acute trauma (Chen et al. 2006).

Figure 15. An example of a cleft atlas. Photo permission: FAC.

Spina bifida occulta

Spina bifida occulta is the same defect as the cleft neural arch in presacral vertebrae, but seen in sacrum. Sacral cleft neural arches are the most common type of clefting of spine. Spina bifida occulta can be partial or complete and usually remain asymptomatic. The definition of spina bifida in the literature is sometimes confusing and thus can cause problems in research and comparison of different data (e.g. Kumar & Shane Tubbs 2011; Albrecht et al. 2007). For example, Barnes (2012) divides cleft sacrum into clefting of neural arch and spina bifida. Spina bifida in her definition is a neural tube defect that will cause neurological symptoms. Barnes says that these two sacral defects can be separated from each other by the alignment of the arches. In the cleft sacrum the arches retain their original alignment and a normal vertebral canal, whereas in spina bifida the vertebral canal is wider than normal with arches that are pushed outward (Barnes 2012).

Ortner (2003) and Aufderheide & Rodriguez-Martin (1998) divide spina bifida into two categories: occulta and cystica. Spina bifida occulta is equivalent to Barnes' cleft neural arches and spina bifida cystica corresponds to the neural tube effect. According to their literature review, these conditions can be best separated in a living individual in whom the spina bifida cystica involves protrusion of spinal cord and nerves. Spina bifida cystica causes neurological symptoms and is often fatal. In this study, the definition of Ortner (2003) and Aufderheide & Rodriguez-Martin (1998) is used to report the frequency of spina bifida occulta.

There are studies reporting frequencies of spina bifida on skeletal collecti ons and/or clinical populations (Fidas et al. 1987; Saluja 1988; Albrecth et al. 2007). For example, a clinical study on a normal population in the United Kingdom showed a frequency of 23% of partial or complete spina bifida occulta, and males had a higher frequency than females (Fidas et al. 1987).

Spondylolysis

Spondylolysis can be seen most commonly in the fifth lumbar where the dorsal part with laminae, spinous processes and inferior articular processes are separate from the body (Figure 16). This separation can be complete or partial. There are two main explanations for spondylolysis: it is a congenital defect due to ossification failure, or it

Figure 16. Spondylolysis in the fifth lumbar. Photo permission: FAC.

is caused by a stress fracture (Aufderheide & Rodriguez-Martin 1998). Spondylolysis, its etiology and epidemiology have been studied in several skeletal collections (e.g. Bridges 1989; Waldron 1992; Merbs 2002; Mays 2006; Ward et al. 2010), but also in clinical patients (Kobayashi et al. 2013; Kim & Green 2011).

Spondylolysis is more common in males, and as a stress fracture it is considered to be a sign of hard work or activity that puts stress on the lower spine (Merbs 1996). In clinical studies spondylolysis has been found to be associated with young athletes and their lower back pain (Drazin et al. 2011; Sys et al. 2001). Spondylolysis can be asymptomatic but it is documented to cause low back pain and it is mostly treated with bracing, restriction of activity and physical therapy (Standaert & Herring 2000).

Sternal aperture

This is a product of incomplete caudal cohesion in which sternal bands do not fuse completely (Figure 17). It can be a small or large, round or oval aperture between third and fourth sternebrae (Barnes 1994). Studies on thoracic CT-scans have found the sternal aperture in about 5% of the studied individuals (Verna et al. 2013; Yekeler et al. 2006).

Bifurcated ribs

In bifurcated ribs the development is disturbed and the sternal end of the rib separate forming two ends (Figure 18). This is reported to be mostly occurring through ribs 3-5 (Barnes 2012). In a French CT-scan sample bifurcated ribs were present in 11 individuals (2.2%) (Verna et al. 2013).

Cervical rib

A cervical rib is an expression of a cranial shift in the cervical-thoracic border (Figure 19). The shift usually affects the seventh cervical and especially the transverse processes. A cervical rib can be a complete separate rib with an articular facet, or a bony extension of transverse process without an articular facet (Barnes 2012). Guttentag and Salwen (1999) separate elongated transverse processes from actual cervical ribs.

Figure 17. An example with sternal and xiphoid apertures. Photo permission: FAC.

Figure 18. A bifurcated fourth rib. Photo permission: FAC.

Figure 19. The seventh cervical vertebrae with a cervical rib on the right. Photo permission: FAC.

Cervical ribs can cause problems to blood circulation and the neurogenic system (Thoracic outlet syndrome), but usually they remain asymptomatic and are found in association with other problems like after a neck injury. If the symptoms do not get better with physical therapy, surgical removal of the rib can be conducted. Cervical ribs (at least the symptomatic thus treated) seem to be more common in females (Sanders & Hammond 2002).

Os acromiale

An os acromiale is considered to be the most common form of developmental anomalies in the scapula. This is caused by secondary ossification that failed to unite tip of the acromion to its base (Barnes 2012). There is also another less popular explanation which considers this non-union to be related to mechanical stress, i.e. activity, during the development. Case et al. (2006) tried to find the most likely explanation by examining the frequencies of os acromiale in two distant (geographically, genetically and temporally) skeletal samples. The samples compared were a modern African collection and a medieval European collection. The frequency was much higher in the African sample, as has been shown by other studies as well (e.g. Sammarco 2000; Hunt & Bullen 2007), and this is supporting the genetic explanation. However, in Case et al's study, the African material showed also clear side preference which indicated to them

some mechanical explanation. Thus, Case et al. (2006) suggest that os acromiale might be a result of a combination of genetic and mechanical factors. However, the genetic component is more widely accepted to explain the phenomenon.

In general, os acromiale does not cause any problems. In cases of symptomatic os acromiale the patient is usually suffering from pain in the shoulder and other rotator cuff problems. If non-operative treatments do not ease the pain, os acromiale can be treated by surgery in which the separate piece of bone is removed or it is fused to the rest of the acromion (Edelson et al. 1993). Internal fixation (60%) has been reported to be the most common method of surgery whereas excision was used in 27% of the reported cases (Harris et al. 2011). The fixation can be done by using bone-grafting, pins or screws (Warner et al. 1998).

Button osteoma

Button osteoma is a benign tumor that can be usually seen as a solitary circular, sharply demarcated bony nodule on the outer surface of the cranium. It is a small button-like and slow-growing lesion consisting of dense lamellar bone (Figure 20). It is most commonly seen on frontal and parietals (Ortner 2003; Aufderheide & Rodriguez-Martin 1998). Eshed et al. (2002) studied a modern skeletal collection for button osteoma, and found the frequency to be 38% in the entire sample and no ancestry or sex differences. It seems to be age-dependent with increasing frequency until the sixth decade. They also suggested that this button lesion should not be called osteoma, because it is very different from other osteomas by its histology and demographics. They recommend

Figure 20. A right parietal showing two button osteomas. Photo permission: FAC.

using a term hamartoma (a malformation resembling neoplasms).

Button osteoma is usually asymptomatic, but can be visible. Its etiology is unknown but it has been suggested to be developmental, infectious or traumatic (Eshed et al. 2002).

Palatine torus and mandibular torus

Palatine torus and mandibular torus are bony exostoses found in the oral cavity. Palatine torus is located on the midline of palate (Figure 21), whereas mandibular torus can be found on the lingual side of the mandible at the premolar area bilaterally or unilaterally. The etiology of these exostoses is unclear, and explanations from abraded teeth (Reichart et al. 1988) to fish consumption (Eggen et al. 1994) have been offered. It seems that there is a genetic component since tori can be more prevalent in certain populations (Garcia-Garcia et al. 2010). Several studies have reported frequency data and as a consensus it seems that there are no differences in the prevalence of mandibular torus between males and females (Garcia-Garcia et al. 2010). Palatine torus, however, is more common in females than in males (Vidic 1966; Garcia-Garcia et al. 2010). The frequency of mandibular torus seems to be lower in general than the frequency of palatine torus. Garcia-Garcia et al. (2010) compiled data of several studies and the range

of frequencies of a mandibular torus was 0.54 - 64.4% and palatine torus 0.9 - 61.7%. Based on these studies the frequency is highest in African Americans and Thai population. Jainkittivong and Langlais (2000) studied Thai population and found that the frequency of tori increases with age similar to some other studies reported before (Larato 1972). Thus, they suggested the etiology to be a combination of genetic and environmental factors.

The exostoses in the oral cavity are usually asymptomatic and individual does not even know that he/she has it. They are usually found and diagnosed at a normal dentist appointment for something else. The problems that tori can cause are related to e.g. mastication, prosthetics and phonation. If treatment is needed, usually tori are removed in a surgery (Garcia-Garcia et al. 2010).

Enlarged nasal turbinate

This condition refers to the enlargement of the nasal turbinates (Figure 22), usually the middle one, and can also be called concha bullosa (Stallman et al. 2004). It is a common feature seen in the nasal cavity in clinical studies. The prevalence has been found to vary between different studies depending on the definitions used (for example, 44% in Stallman et al. 2004, 68% in Smith et al. 2010). It is usually asymptomatic and found incidentally in the CT-scans, but sometimes it can cause problems when it is too large (Cohen & Matthews 2008). Some studies have found enlarged turbinates to be associated with a deviated septum (Stallman et al. 2004), but not with sinus diseases (Stallman et al. 2004; Smith et al. 2010).

Words of caution

Comparing the results of clinical and anthropological research is not straightforward. It has to be kept in mind that the methods applied are different and thus the results can vary between living people and skeletal collections. For example, some congenital defects, like os acromiale, are easy to observe in bare bones but using radiographs some of them may go unnoticed depending on which radiographic views are used (Lee et al. 2004; Burbank et al. 2007). When palatine and mandible tori are studied, it might be more difficult to detect the elevated area in clinical studies on living

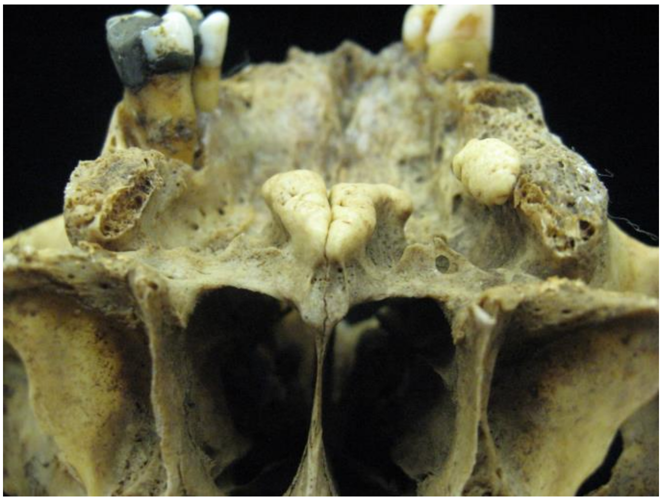

Figure 21. A large palatine torus. Photo permission: FAC.

Figure 22. An example of an enlarged nasal turbinate. Photo permission: FAC.

people with all the soft tissue than when we are looking at dry bone (Garcia-Garcia et al. 2010; Skrzat et al. 2003). Frequencies of fractures in dry bone and living subject studies can differ due to the simple fact that the living studies are usually based on trauma units in which acute fractures are studied, whereas in dry bone the most common type is healed fractures. Healed fractures can heal so well that they are difficult to observe in dry bone. Also x-rays may reveal more about the internal structure of the fracture site than just visual observation of the dry bone.

Osteoarthritis in living people is diagnosed by using patient's symptoms or imaging techniques. Naturally, in skeletal studies the symptoms are unknown and the criteria used in radiological diagnosis can be slightly different from dry bone diagnosis. Usually narrowing joint space and osteophytes are used in both diagnosis, but with current imaging technology also cartilage and other soft-tissue features are considered in living people (Braun & Gold 2012; Link et al. 2003). In addition, more cancer lesions metastasized to bone are seen when x-rays are used in comparison to visual examination of the bone alone (Rothschild & Rothschild 1995). Also other imaging methods, e.g. CT scans can show lesions in the bone marrow before the actual destruction occurs (Rosenthal 1997). These are some of the explanations for the possible discrepancies between clinical and skeletal frequency data.

Chapter 3.
Materials

The W. M. Bass Donated Skeletal Collection

In this study two different aspects of the same material are used: skeletal remains of donors and ante-mortem records of donors belonging to those remains. The W. M. Bass Donated Skeletal Collection is based on a body donation program which started in the early 1980s by Dr. William Bass in the Department of Anthropology at the University of Tennessee, Knoxville. The program was started for the purposes of studying the process of decomposition, and the skeletal remains that were left after decomposition were stored in a collection for skeletal research and teaching (Jantz & Jantz 2008). Currently this body donation program receives about 90 donations per year. The skeletal collection consists of over 1200 individuals (2013), including intact adult donations, cremations and fetal donations. The demographical distribution is quite biased towards older European-American males which form the core of the collection – about 70% of the donations are males. Approximately 90% of the donations are European-American, 7% African-American and 2% Hispanics (Shirley et al. 2011). Those above mentioned percentages are from 2010, and no significant changes have occurred since.

There are three different types of donations in the collection. 1) Self-/pre-donors are individuals who donate themselves to the program by completing a donation packet and signing the paperwork while they are still alive. In this context self-donor refers to a deceased individual who signed the paperwork him/herself, whereas pre-donor refers to a living individual who has signed the paperwork him/herself. 2) Family-donations are deceased individuals who have been donated by their family members. This means that the paperwork was filled and signed by the legal next of kin. 3. Medical examiner's office donations refer to deceased individuals that were either not identified, the family was not located, or that family did not claim the body. In the early years of the donation program medical examiner's office donations were much more common than they are today, and today the donated individuals must be identified.

Currently most of the individuals in the collections are family-donations but for the past few years self-donors have become more common and from the year 2011 they have been the main type of donations accepted into the program. For example, there were 574 donations between years 2006 and 2010, and 27.0 % of these donations were self-donors, 57.6 % family-donations, and 15.3 % medical examiner's office donations. The same percentages for the donations between 1982 and 2005 (N=612) were self-donors 11.6 %, 50.0 % family, and 38.6 % medical examiner/other.

The study sample for this dissertation was chosen from the donations that were donated between 2000 and 2008. The earlier donations were excluded because they have far less recorded information than the later donations in the collection. This is mostly due to the fact that no biological questionnaires were used systematically prior to 2000 and to the large number of medical examiner's office donations in the early years. Donations after 2008 were excluded because at the time this research was started, donations from the year 2009 were not in the collection yet. The sample size is 180 individuals: 45 self-donor females, 45 self-donor males, 45 family-donated females, and 45 family-donated males. The sample used was chosen by using Excel's random number generator. Due to the small number of individuals of other ancestries, only European-American individuals are included in the sample.

The age range of this sample is from 34 years to 93 years of age. The average age of females is 64 years, whereas the average age for males is 63 years. The family donated groups have a lower average age than the self-donor groups and female groups have higher average age than the male groups (Table 1, Figure 23 and 24). This distribution also reflects the age distribution of the entire collection. Naturally, the sample is concentrating on older individuals due to the demographics of the donated collection. This might raise a question as to how well this sample reflects actual forensic cases in which the individuals tend to be younger (Marks 1995; Komar 2003; Algee-Hewitt 2013). Nevertheless, in mass disasters including accidents and natural disasters the demographics of the deceased might not be as young as in forensic cases. For example, a study on victims of meteorological disasters (floods, typhoons, storms etc) in Korea showed that the death rate increased with age (Myung & Jang 2011). Almost 50% of the victims of Hurricane Katrina in Louisiana were 75 years or older (Brunkard et al. 2008). Also fire victims consist of a larger group of children and elderly people

Table 1. Basic demographics of the sample including minimum, maximum, mean, and median age.

	Self females	Family females	Females	Self males	Family males	Males
Min-max	44–93	36–87	36–93	39–89	34–88	34–89
Mean	67	62	64	64	60	63
Median	68	60	63	64	59	63

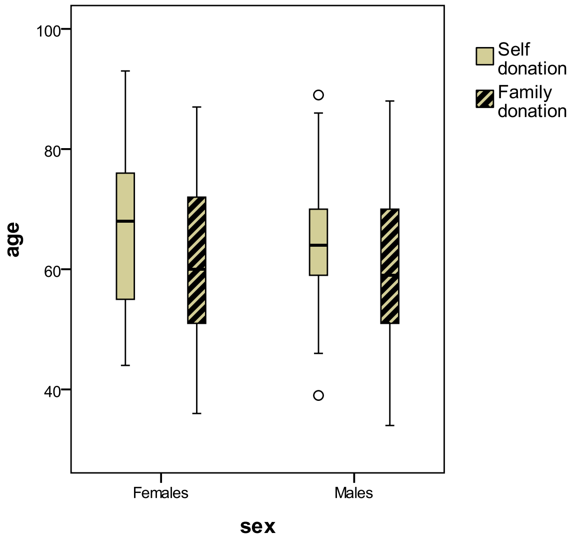

Figure 23. A box-plot presenting the average age by sex and donation type.

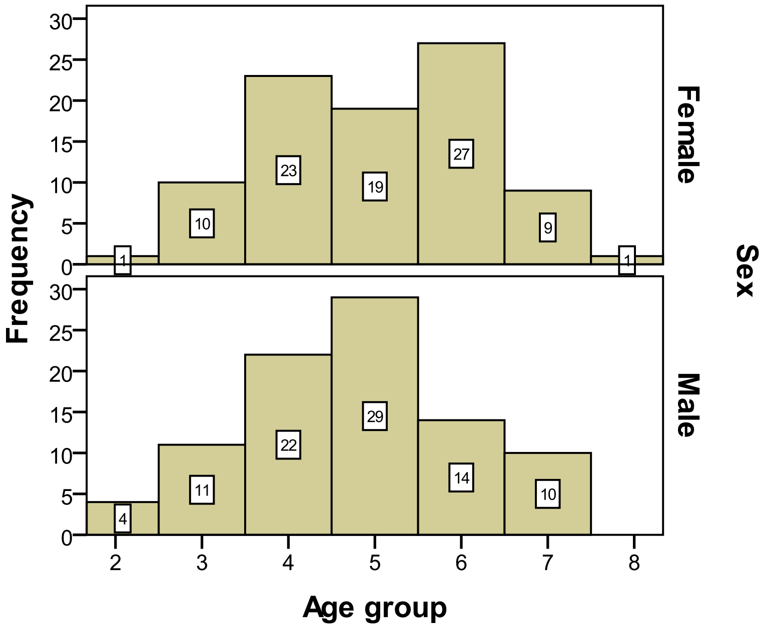

Figure 24. Age distribution of the study sample divided into age groups (N=180). Age groups: 2= 30-39, 3= 40-49, 4= 50-59, 5= 60-69, 6= 70-79, 7= 80-89, 8= 90-99.

than any other age groups (Barillo & Goode 1996). In addition, younger individuals tend to have teeth that could be used for dental identification, whereas older individuals tend to be edentulous and thus other means of identification would be needed.This study examined all the skeletal elements except hand and foot phalanges and coccyges. These exclusions were made because phalanges are the major group of missing elements in the Bass Donated Collection. A small number of individuals in the collection have a full set of phalanges, thus they are excluded even though fractures are common especially in hand phalanges (Court-Brown & Caesar 2006), and might be useful in identification. In addition, there were certain other circumstances (for example poor preservation, or an excessive number of missing or fragmentary elements) that made it impossible to use all the pre-selected individuals for the study. If most of the skeletal elements (allowing maximum of three long bones or other larger bones, or four vertebrae or six ribs to be missing) are present the skeleton is used for the study and all elements present are inventoried.

The presence or absence of bone is recorded as well as if the element is fragmentary. Fragmentary in this context means that there is a piece missing, or the pieces cannot be matched together. Also, it is recorded if the absence is congenital or post-mortem. For example, the twelfth rib is congenitally missing when no articular facets are present in T12. Teeth are not included in this study, because the majority of the W. M. Bass Donated Skeletal Collection individuals are edentulous. This also means that any pathological conditions clearly related to dentition (for example abscesses in the alveolar bone) are not included in the data. Altogether 134 skeletal elements in each individual are examined and this number includes 13 cranial bones (frontal, parietal bones, temporal bones, occipital, nasal bones, zygomatic bones, maxillae, mandible), 24 vertebrae, sacrum, manubrium, sternal body, 24 ribs, 16 carpal bones, 14 tarsal bones, 10 metacarpals, 10 metatarsals and paired scapulae, clavicles, os coxae, humeri, radii, ulnae, femora, tibiae, fibulae and patellae. However, there is some variation in this total number due to congenital absence, post-mortem loss and congenital extra elements. Using this bone count 24,120 skeletal elements would have been studied if all of the skeletons were complete. The total number of examined bones for this study is 22,253 (Details in table 2).

Table 2. Skeletal elements present in this study. Vertebrae, ribs, metacarpals, carpals, metatarsals and tarsals are summed together.

Element	Females Present	Absent	Fragmentary	Males Present	Absent	Fragmentary
Cranium	89	0	1	88	0	2
Manubrium	85	4	1	82	3	5
Sternal body	82	4	4	85	2	3
Scapula L	88	0	2	87	0	3
Scapula R	88	0	2	84	0	6
Clavicle L	90	0	0	88	1	1
Clavicle R	89	0	1	88	1	1
Humerus L	89	0	0	90	0	0
Humerus R	90	0	0	88	0	2
Radius L	89	1	0	88	1	1
Radius R	87	1	2	90	0	0
Ulna L	88	0	2	88	1	1
Ulna R	89	0	1	90	0	0
Sacrum	84	0	6	87	0	3
Os coxa L	89	1	0	88	2	0
Os coxa R	89	1	0	88	2	0
Femur L	89	1	0	89	0	1
Femur R	89	1	0	90	0	0
Tibia L	90	0	0	89	0	1
Tibia R	89	1	0	89	0	1
Fibula L	90	0	0	89	0	1
Fibula R	88	1	1	88	1	1
Patella L	84	6	0	83	6	1
Patella R	83	7	0	85	5	0
Cervicals	615/630			603/630		
Thoracics	1071/1080			1068/1080		
Lumbars	445/450			447/450		
L ribs	914/1080			969/1080		
R ribs	936/1080			969/1080		
L MCs	429/450			413/450		
R MCs	413/450			426/450		
L MTs	398/450			397/450		
R MTs	398/450			400/450		
L carpals	554/720			559/720		
R carpals	553/720			574/720		
L tarsals	572/630			581/630		
R tarsals	575/630			591/630		
	9981			10098		

The larger bones including cranial bones long bones, scapulae, clavicles, os coxae, and sacrum have 90-100% of the elements present, whereas the least number of elements present is seen, as expected, in carpals (approximately 77%). Also ribs and metatarsals have less than 90% of the elements present for this study.

Other characteristics of the study sample

The cause of death may also influence the type of changes observed in the skeleton, especially if aggressive acute or chronic diseases are involved. Cause of death of donated individuals is usually obtained from the death certificate. However, sometimes the cause is unknown or is “pending” investigation or toxicology when the donation is received by the donation program at the Forensic Anthropology Center. Table 3 presents the main causes of death in this study sample. Eight groups were established to summarize the data: 0= no cause of death in the file, 1= natural, 2= cancer, 3= cardiovascular, 4= accident, homicide, suicide, or fire, 5= overdose, alcohol-related deaths, 6= multiple causes including contributing factors, 7= COPD and other pulmonary diseases 8= other causes. The leading causes of death in this sample are cancer, natural death and cardiovascular diseases. Heart-related diseases and problems are the main cause of death for males, whereas cancer is the leading cause for females. Accident or other traumatic deaths are more common in males, but overdose is more common in females. If donation type is considered, it is interesting that cancer, natural death and cardiovascular diseases as the cause of death include 66% of the individuals in self-donors, whereas in family donations their percentage is lower, 43%. This difference is partly explained by the higher percentage of deaths caused by traumatic events and substance abuse, which are more common in family donations (21% vs self-donors 5%).

Another additional aspect of personal information that could affect the pathological conditions observed in the skeletons is occupation. The occupations are divided into groups following International Standard Classification of Occupations (Internatioal Labour Organization 2004). The classification system includes nine major categories and those are listed in Table 4. Categories 7-9 include production and Related Workers, Transport Equipment Operators and Labourers, respectively. In this study,

Table 3. Reported causes of death by sex and donation type.

COD	Females	Males	Total	Self	Family
Natural	19	15	34	22	12
Cancer	22	14	36	27	9
Cardiovascular	12	17	29	11	18
Accident/traumatic	3	12	15	4	11
Substance abuse	7	2	9	1	8
Multiple causes	6	4	10	3	7
COPD/pulmonary	6	6	12	7	5
Other	8	8	16	5	11
Not reported	7	12	19	10	9

Table 4. Distribution of the occupational categories.

Occupation	Self females	Family females	Self males	Family males	Total
Professional/ technical	12	12	8	11	43
Administrative/ managerial	7	5	1	2	15
Clerical	2	4	1	0	7
Sales	1	0	2	3	6
Service	15	16	5	2	38
Agricultural	0	0	1	0	1
Production/transport/laborer	6	2	18	22	48
Firefighter/police/army	0	0	5	0	5
Other	1	1	1	2	5

categories 7-9 are combined. Category Other has been added for those cases which do not seem to fit into any other categories. Another modification includes separation of firefighters and policemen from service workers into their own category with members of armed forces. This is done to separate those job types and their greater risk of physical injuries from other occupations which are included in service workers such as hairdressers or cooks.

Three occupational categories (professional/technical, service, or production/ transport/laborer) include approximately 77 % of the occupations reported. Twelve individuals did not have any occupation information. The majority of females in this sample were mostly service workers or professional workers, whereas males are mostly production/ transport/laborers or professional/technical workers. In addition to the occupation groups, the occupation was also used to divide the sample into two socio-economic groups by yearly income (less than $44,000 and more than $44,000). The median household income for Tennessee between 2000 and 2012 according to Census data (US Census Bureau 2014) was $44,000, and most of the donations in this sample are from TN. The division was done by using Occupational Employment Statistics from the Bureau of Labor Statistics website (Bureau of Labor Statistics 2014). Naturally, this division is not straightforward due to the type of the reported data, and it should be taken only as a crude socio-economic division. Based on these two categories: 84 individuals belonged to the lower income class and 77 to the upper income class. The remainder of individuals did not have occupation information that could be used for this purpose.

The body donation questionnaire also asks childhood socio-economic status with the options such as lower, lower middle, middle, upper middle and middle. In this sample only 39% of the individuals reported their status, and half of those were middle class, 24% lower class, 17% lower middle class and 9% upper class. This resembles the distribution in a sample of all the donations between 2000 and 2008.

The geographical distribution of the donations in this sample is concentrated on Tennessee and neighboring states: 73% of the donations are from Tennessee, 19% from other states (18 states represented, NC and GA with most donations), and rest of the sample do not have state information reported in the database.

The information from self-donors also includes the date they signed the donation paperwork. Eleven individuals are missing this information in the database. The time between the paperwork was signed and the time of death ranged from months to nine years. Almost 50% of the donors donated their body to the program within a year before their death. This information can affect the reliability of the reported medical data, since there might be injuries, surgeries and diseases diagnosed after the date of donation.

Another factor that can affect the quantity and quality of the reported data on family-donations is the relationship of the donated individual and the informant donating the individual. As expected the legal next of kin is the most common type of family donor. Approximately 64% of the recorded informants for the family-donations have listed themselves as either the child or the spouse of the individual being donated. There are 50 female and 25 male informants, in addition to 15 informants whose sex could not be specified from the database.

The ante-mortem data for the individuals in the Bass Donated Collection comes mainly from the body donation questionnaire which the donor her/himself or family members fill out. This questionnaire can be found in Appendix I and also online http://fac.utk.edu/pdf/Questionnaire.pdf. This questionnaire collects personal information, height, weight, educational background, residence history, dental history and medical history (summary of the collected information can be seen in Figure 25). Personal information, such as name or social security number, is not available to researchers, and after the death the individuals will be referred to only by their donation number to protect the anonymity of donors in the program.

As the focus of this dissertation is on medical history (excluding dental history), this section will be explained in more detail. The medical history has check boxes for different conditions, mainly surgery-related and common illnesses. It is also requested that donors add the approximate year for these events/conditions. The check boxes are included in Figure 26.

In addition to these check boxes there is a blank space in which donors can describe the above mentioned conditions in their own words or give additional information about their health, for example medications or location and timing of the injuries. The general trends also in the longer medical descriptions are studied and they

Name	Height	Childhood socio-economic status statuts
Sex	Weight	Occupation
Age	Handedness	Residence history
Date and place of birth	Hair color	Dental history
Social security number	Blood type	Medical history
Race	Marital status	Habitual activities
Contact information	Number of children	Eye color
Parents' place of birth	Education	Tattoos and piercings

Figure 25. A summary of the content of the body donation questionnaire.

Surgery (general)	Diabetes
Fractures	Plastic surgery (type and location)
Auto accident (traumatic)	Cancer type and treatment
Spinal injuries	Smoker (how long)
Open heart surgery	Alcoholism
Amputations	Other (including childhood disorders)
Prosthetics	

Figure 26. A summary of the check boxes included in the questionnaire.

are categorized into major disease groups following the ICD9-coding system and Professional Guide to Pathophysiology (2006): neoplasms, infection, cardiovascular, respiratory, nervous, gastrointestinal, musculoskeletal, hematologic, immune, endocrine/metabolic, renal, sensory, genitourinary, and skin. Summaries of the reported medical data will be given in Results section.

The questionnaire also includes stature and weight information. There are many studies showing that self- or family-reported stature and weight data may not be that reliable. It has been documented that especially shorter males and older individuals overestimate their statures, whereas overweight females tend to report less weight than overweight males (e.g. Willey & Falsetti 1991; Rowland 1990; Braziuniene et al. 2007). Therefore, it is expected that the self-reported body size measurements in the database for the Bass Donated Collection are somewhat biased. They are however used to calculate BMI (body mass index) which is used as a variable to see if it affects any of the conditions reported or observed in this sample (Table 5). BMI is calculated by dividing the weight in kilograms by the squared height in meters. The average BMI in this sample is greater than 25 which indicates overweight individuals (World Health Organization 2014). Overweight and obese individuals are at risk for multiple health issues, especially cardiovascular diseases, diabetes and osteoarthritis, and the prevalence of pathological conditions might be different if the sample consisted mainly of individuals within normal body weight parameters. Since BMI can be influencing the pathological conditions expressed on the skeleton, it will be used in this research to analyze the factors contributing to the pathological conditions.

Table 5. Stature, weight and BMI information by sex.

	Stature cm		Weight kg		BMI	
	F (N=87)	M (N=86)	F (N=77)	M (N=75)	F (N=76)	M (N=75)
Average	162	176	78	87	29	28
Minimum	143	157	41	45	15	16
Maximum	180	193	181	181	60	57

Chapter 4.
Methods

Skeletal analysis

The skeletal analysis for this study was done macroscopically. All the bones except for the aforementioned hand and foot phalanges, coccyx and xiphoid were included. These small elements were excluded from the study because these elements can be lost at the Anthropological Research Facility. Individuals with some elements missing were included in the sample but the prevalence percentages are counted per observed elements, not number of individuals. Dental health was not recorded due to the large number of edentulous individuals in the Bass Donated Collection.

A macroscopic approach was chosen due to availability and the low cost of the method. However, a microscope is used in cases where bone lesions needed more detailed examination to verify their pathological or taphonomic nature. Other methods such as x-rays, CT-scans, histology and DNA are not used in this study. However, these could be incorporated into this type of research to give additional information about the conditions observed on the skeletons. Use of radiographs would have enabled better determination of fracture type and the state of healing (Roberts & Manchester 2005). Radiographs could have also made the description of the lytic lesions more consistent, especially since the margins of lesions and the structure of the new bone could have been examined more closely (Mays 2008).

The recording system used in this study included six sections: Inventory, Fractures, Bone lesions, Osteoarthritis, Surgical devices and Other conditions. The basics of the recording system are summarized here but the coding system in its entirety is in Appendix 2. The recording and coding system is based on the recording form made by D. W. Owsley/B. Bradtmiller for Smithsonian but it was also modified and additions were made following the data collection coding system as presented in "*Standards for Data Collection from Human Skeletal Remains*" (Buikstra & Ubelaker 1994). The collected data is included in this dissertation as five separate attachment files: Observed fractures (Observed fractures.pdf), Observed bone loss and formation (Observed bone loss and formation.pdf), Observed eburnation (Observed eburnation.pdf), Observed surgical devices (Observed surgical devices.pdf), Observed anomalies and degenerative

changes (Anomalies and degenerative changes.pdf). As mentioned above, Appendix 2 includes the key to the coding system.

Inventory

Four categories of inventory were included: present, absent, fragmentary and missing congenitally. Fragmentary means that there is a piece/pieces missing and the element could not be fully reconstructed.

Fractures

Only ante-mortem fractures and the number of fractures per bone were recorded. The location of fracture was recorded according to sections. Skull fractures were recorded within the specific bone, and long bones were divided into proximal, middle and distal shaft and proximal and distal joints. Also a separate code was used to indicate multiple locations within a skeletal element. Scapulae and vertebrae were divided into separate parts: glenoid cavity, blade, acromion, coracoid for scapula and body, spinous process, transverse process and arch for vertebra. Ribs were divided into vertebral end, middle and sternal end.

Remodeling was recorded as no healing, healing, healed and multiple remodeling types. Severity of the fracture was recorded as complete which means two or more pieces, or incomplete which means not in separate pieces. Fractures of vertebral bodies were classified into compression, single end-plate depression without wedging and with wedging and other. Union of the fracture was recorded as either complete or incomplete (including both non-union and partial union), but also as pseudoarthrosis (a false joint). In many cases of healed fractures it was not always possible to determine whether the fracture was complete or incomplete, and thus the code "unknown" was used as well. Alignment of the healed bone was described as good alignment, malalignment or both in the same element. In addition, surgical devices associated with the fracture were recorded. If there was uncertainty whether the bony changes are due to a fracture or another pathological condition, the defect was noted but not recorded in a certain category. Thus, the results are more likely underestimates rather than overestimates of existing healed fractures.

Bone lesions

Three general categories were recorded for bone lesions: bone loss, bone formation and both. Bone loss included in this study lytic lesions and surgical removal of bone. Also erosive lesions were studied, but they were only recorded around the joint areas, for example indicating a possible rheumatoid arthritis. The erosion of a joint surface itself was not included in this study, since osteoarthritis was assessed based on the presence of eburnation only. Bone formation included periosteal reaction, osteomyelitis and tumors, but enthesophytes or osteophytes were excluded from the study. The location for lesions was documented the same way as the location of fractures. Remodeling was recorded as active, healing, healed or mixed and severity of the lesions was coded as mild, moderate, severe and multiple. As mentioned above in the fracture section, if there was any uncertainty what about the etiology of these bony changes, they were noted but not recorded within a specific category. Thus, the observed number of bone lesions is likely a conservative estimate of the actual count of bone lesions.

Osteoarthritis

Eburnation is the only criteria used to record osteoarthritis in this study. Porosity, osteophytes or other minor changes were not recorded. This partial recording system was preferred since it has been suggested that eburnation alone can be used to diagnose osteoarthritis (Waldron 2009). In addition, research has shown that the inter-observer variation in coding those other changes is great, and there is too much variation in the scoring methods (Waldron & Rogers 1991; Bridges 1993; Weiss & Jurmain 2007). This recording system makes more sense for practical reasons as well; if all the arthritic changes were recorded, data collection would have taken much longer time.

The location of eburnation was recorded as proximal/distal joint of long bones, facets/body of vertebrae and as surface or margin. The degree of eburnation was documented as slight, polish only, polish with grooves or multiple types. The extent of the affected area was recorded as mild, moderate and severe. For vertebral articular facets the extent was based on which facets were affected. Eburnation in the hand and foot bones was recorded only by the bone, not a specific articular surface.

Surgical devices

For surgical devices the location was recorded following the same system as in fractures and bone lesions. In addition, the type of the device was documented (replacement, plate, rod, wire, screw, suture, staple, pin, other, or multiple). Only the major type of the device is recorded. For example, a plate which has four screws was only recorded as a plate, not as a plate and screws. The material of the device was recorded as metal, plastic, thread, metal and plastic, metal and thread, or other.

Other conditions

For other conditions a pre-determined list of diseases/skeletal changes or anomalies were recorded as present or absent. The conditions included degenerative changes such as sacroiliac fusion, Schmorl's depressions, temporal-mandibular joint problems and pathological fusions. Other conditions included anomalies and congenital defects such as cleft vertebra, spina bifida occulta, congenital fusion, sternal aperture, bifurcated ribs, cervical ribs (including separate rib and bony extensions, Figure 27), os acromiale, button osteoma, spondylolysis, palatine and mandibular tori and enlarged nasal turbinate.

If the element was missing or was not well preserved the condition was considered not observable. The location of these conditions/anomalies was recorded as bone, side, vertebrae/rib number and a small description was written if necessary. Also the severity of the condition was recorded; for example partial or complete spondylolysis/spina bifida. In general, limited information was recorded in this section and more detailed studies on specific conditions can be conducted in the future.

Figure 27. An example of a seventh cervical with a bony extension of the left transverse process.

Differential diagnosis

In paleopathology differential diagnosis is used to diagnose pathological lesions and conditions observed in bones. Differential diagnosis starts with examining the demographics of the individual, mainly sex and age. Any abnormalities observed in bone are recorded, including documentation on which bones are affected and the specific location on the bone. In addition the type of lesion and the activity level are recorded. After completing the observations, a list of possible conditions that could have caused these changes is made. The last phase of differential diagnosis excludes the conditions that contradict the observations and in the end there should be a condition or conditions that are the most likely explanations for those skeletal changes (Lovell 2000).

Even though the required information for differential diagnosis was collected in this study, the final two phases of the diagnosis were not carried out. This study is not attempting to diagnose the observed lesions or changes, but rather to document and describe them. Thus, the basic categories: fractures, surgical devices, lesions and eburnation will be used throughout the dissertation. Nevertheless, some level of diagnosis may be required when the observed conditions are being matched with the reported conditions.

Statistical methods

The data collected in this research is categorical, mainly nominal and ordinal. Nominal data includes categories such as presence and absence, or locations of fractures (1= proximal shaft, 2= middle shaft, 3= distal shaft). Nominal variables are just numbers without a specific order. Ordinal variables are in order, and demonstrate that one value is more advance than another. For example, the values used for coding severity of the eburnation (1= mild, 2= moderate, 3= severe) tell us that mild eburnation is less severe than moderate or severe eburnation, although there is no way of knowing how much more severe category moderate is compared to mild.

Chi-square tests are usually used to compare different groups when dealing with categorical data, and they are very common in paleopathological and clinical literature (e.g. Nikita et al. 2013; Holloway et al. 2011; Valerio et al. 2012; Smith et al. 2010; Jurmain et al. 2009; Klaus et al. 2009). Pearson's chi-square test compares the frequencies observed in the sample to the frequencies that would be expected by chance. Chi-square works well in large samples with high frequencies, but its use in smaller samples with low frequencies results in low accuracy. Therefore, with samples that have any cells with expected frequencies less than five, one should use Fisher's Exact test (See for example Field 2013).

Since the data collected for this research is categorical, chi-square test could have been used, but instead of using it, logistic regression was chosen. Unlike chi-square, which compares only two variables at a time, logistic regression allows the use of multiple variables, and this helps to reduce the number of comparisons. Using logistic regression, variables such as sex, age, donation type or BMI can each be added into the equation. Logistic regression can also be used when the outcome variable is categorical, and the predictors can be continuous or categorical. In this study, binary logistic regression was used to predict mainly the presence/absence of conditions based on certain variables. Logistic regression also gives odds ratio, which shows how a change in a predictor will affect the outcome variable. If the odds ratio is over 1, the likelihood of the outcome variable to occur is increasing, when the value of the predictor variable also increases. If the odds ratio is less than 1, the likelihood of the outcome variable to occur decreases when the predictor variable increases (See Field 2013). All the statistical analyses were conducted by using IBM SPSS Statistics 21.

Matching the reported and observed conditions

Medicine and clinical settings use reported medical histories to evaluate individual's health and the possible risks for acquiring certain diseases, such as cancer. These data are then used to decide on possible treatment, and as motivation for changing, for example, life style, and diet (See Stavrou et al. 2011; Navarro et al. 2006; Ming et al. 2004).

In this dissertation, agreement of reported and observed pathological conditions were analyzed by following two principles: agreement and disagreement, and sensitivity and specificity. Agreement simply means cases in which a reported condition was observed or a condition that was not reported and was not observed. Disagreement is the opposite, meaning the cases in which the observed and reported data contradict.

In order to test the accuracy of the reported data researchers have used sensitivity and specificity. Sensitivity is generally defined as the proportion of individuals who reported having a certain condition among the individuals who were actually diagnosed with the condition (true positive). Specificity (true negative) is the proportion of the individuals who did not report a certain condition among the individuals who were not diagnosed with the condition (Chang et al. 2006; Molenaar et al. 2006). Therefore, in this study, sensitivity means the proportion of the individuals who correctly reported a certain condition among the individuals who actually presented this condition in their skeletal remains. Specificity, following the same principle, means the proportion of individuals who did not report a certain condition among the individuals who also did not present this condition in their skeletal remains (See Table 6).

It is important to remember that this method typically requires a gold standard as a reference point. Professional clinical diagnoses do not necessarily represent the absolute truth and they can be incorrect as well (Smith et al. 2008). Naturally, in this study there is no gold standard, since one type of data is reported and prone to mistakes, and the other type is macroscopic observations on skeletal elements which may not be able to detect all the conditions. However, this study considers the observed skeletal data as the "gold standard".

Combinations of observed conditions

The collected frequency data were coded manually in multiple ways to detect the most common patterns of observed pathological conditions. This was done in a similar manner as Adams (2002) coded his dental data. The data was divided into the major body segments for this study. In the future the coding can be done based on single elements. The data were coded for presence and absence (1= present, 0= absent) in the body segments by the conditions. For example, an individual with fractures in ribs only would be coded as 0000001, and an individual with fractures in lower limbs and ribs would be coded as 0000101. These combinations will show which body segments are commonly seen affected in a single individual. In addition, to show which conditions are commonly seen in one person, the individuals exhibiting any of the conditions or their combinations were coded by using a code for the condition or combinations of them: F= fracture, D= device, L= lesions, E= eburnation or FD, FDL, FDLE etc.

Table 6. Agreement of reported and observed data.

	Reported	Observed
True positive	Disease	Disease
False negative	No disease	Disease
True negative	No disease	No disease
False positive	Disease	No disease

Chapter 5.
Results

Antemortem data

The antemortem medical histories of this sample were examined and results are presented here, including both the check-box data and the longer descriptions. Fourteen individuals in the sample do not have any of the 13 check-boxes checked, and 13 of them are family donations. This can be due to non-existing and/or undiagnosed conditions or lack of reporting. The number of checked boxes varies generally from one to six. Self-donors (80 %) most commonly report two to four boxes. Family members most frequently filled in two boxes, which contributes to about 38% of all the boxes checked.

The frequencies of reported check boxes by sex and donation type are shown in Table 7. The most common boxes checked are Other, Surgery, Smoker, Fractures and Cancer. Other and Surgery remain the two most commonly reported checkboxes when sexes and donation types are considered separately, with the next most common box checked as either cancer or fractures (excluding smoker). Cancer is more commonly reported for females and self-donations, whereas fractures are more commonly reported for males and family donations.

Other sex differences are seen in reported information on open heart surgery and alcoholism, in which males have these conditions reported more often than females. The odds ratio shows that males have a higher odds to report open heart surgery (sig. 0.04, odds ratio 3.4) and alcoholism (sig. 0.002, odds ratio 5.9) than females. Alcoholism is also more likely to be reported for a family donation than for a self-donor (sig 0.034, odds ratio 3.1). Another check box that shows differences between donation types is smoking. Family-donation decreases the likelihood of reporting smoking (sig. 0.011, odds ratio 0.4), which again could be due to non-smoking or underreporting. A higher BMI is found to increase the likelihood of reporting diabetes (sig. <0.0001, odds ratio 1.1) and other conditions which are not specified in the check boxes (sig. 0.009, odds ratio 1.1). Significant age differences in the reported conditions are not observed when other factors, especially sex and donation type are controlled.

Table 7. Frequencies of reported check boxes by sex and donation type. * significant sex difference, ** significant age difference, *** significant donation type difference, **** significant BMI difference, p-value < 0.05.

	Self females	**Family females**	**Self males**	**Family males**	**Total**
Surgery *,***	32	17	18	17	84
Open heart*	1	3	7	5	16
Amputation	1	1	4	1	7
Prosthetics	1	2	0	1	4
Plastic surgery	3	2	0	2	7
Fractures	14	12	15	10	51
Auto accident	3	1	4	6	14
Spinal injury	5	1	2	3	11
Diabetes****	11	12	10	7	40
Cancer***	17	13	15	6	51
Other****	32	28	33	26	119
Smoker***	19	12	15	8	54
Alcoholism*,***	2	2	4	15	23

Details of reported fractures

Fractures are one of the most common pathological conditions reported in this sample. Fifty-five donations have a specified location information on their fractures. These include 16 self-donor females, 17 self-donor males, 12 family-donated females and 10 family-donated males. These individuals have one to seven fractures reported, excluding individuals who have just reported "multiple/several fractures" or "18 fractures" without specification. The location descriptions show a wide variation in the terminology used in them. Sometimes the exact bone name is reported, such as "left zygomatic" or "right clavicle", but it is also common to report only "left leg" or "right arm", or sometimes, especially in the case of family-donations, only "leg" or "ankle" are reported. This naturally will cause some problems with the interpretation of which bones are actually fractured. A reported leg fracture can be either right or left, but also in the femur, tibia or fibula. A reported ankle fracture can be either left or right, but also in the tibia, fibula or talus. Thus, all the reported fractures are presented using the descriptions of the informants in Table A-1 and A-2 in Appendix 3.

There is a total of 82 reported fractures with some kind of location information that those above mentioned 55 individuals reported. Reported fractures are grouped into nine body segments based on their location: the cranium, upper limbs, lower limbs (including patella), spine, ribs, pelvis, other trunk (sternum, clavicles, scapulae), hands and feet (Table 8). All the reports on ankle or wrist fractures are included in the lower limb or upper limb segment, respectively, instead of with the feet and hands. As expected the most commonly reported fracture sites are arms (N=23) and legs (N=25), followed by spinal fractures (N=9). Since the frequencies are so low, no significant differences are observed between sex, age or donation type.

General medical history

Other reported medical history includes descriptions of possible surgeries, diseases and other conditions. The informant might have also added a year when the disease was diagnosed or surgery was done. Sometimes this descriptive information is explaining the check boxes in more detail but often the information is something additional. Twenty-three individuals do not have any other medical history reported and 18 of these are family donations. The reported data are categorized into disease

Table 8. Frequencies of reported fractures by sex and donation type.

	Self females	Family females	Self males	Family males	Total
Cranium	1	0	1	2	4
Trunk	1	0	1	1	3
Spine	5	1	2	1	9
Ribs	1	1	3	0	5
Upper limb	6	7	8	2	23
Lower limb	6	4	11	4	25
Pelvis	4	0	0	0	4
Feet	4	0	1	0	5
Hands	1	1	2	0	4
Total	29	14	29	10	82

categories for a symmary (grouped by using Professional Guide to Pathophysiology 2007 and ICD9-coding system). The grouping is: 1) Infectious, 2) Neoplasms, 3) Endocrine/metabolic diseases, 4) Cardiovascular system, 5) Respiratory system, 6) Nervous system, 7) Gastrointestinal system, 8) Genitourinary system, 9) Skin/subcutaneous tissue, 10) Musculoskeletal system, 11) Sensory system, 12) Immune system, 13) Hematological system, and 14) Mental illnesses. This grouping is very crude, since the informants use variant terms in their descriptions, and the terminology requires some occasional interpretation. Naturally, not all the diseases and conditions reported will be seen in the skeleton, thus the general groupings are shown in Table 9 and only the ones impacting skeleton will be analyzed in depth.

The most commonly reported category is diseases and problems affecting the cardiovascular system. Seventy-four individuals are reported to have some kind of cardiovascular condition (for example coronary artery disease, hypertension, myocardial infarction). Individuals could have multiple reported conditions in one category but only the individual is counted, not the number of conditions. Sixty-four individuals have reported injuries, surgeries or other conditions of the musculoskeletal system. These include, for example, fractures, replacements, back pain, and arthritis. Neoplasms, diseases or other problems of the gastrointestinal or respiratory system have all approximately the same number of individuals (46, 44, and 40 respectively). Neoplasms include the reported cancers and tumor removals. Gastrointestinal conditions include for example appendectomy, hernia, cirrhosis and gallbladder problems. The respiratory system is most often affected by chronic obstructive pulmonary diseases (COPD), which include asthma, emphysema and chronic bronchitis. Endocrine/metabolic diseases include mainly diabetes, and the genitourinary system involves mostly hysterectomy, kidney problems and bladder repairs. The category of mental illnesses includes mainly depression and substance abuse. Examples of conditions listed as impacting the nervous system are dementia and Parkinson’s disease; and cataracts and blindness are included in the sensory system. The rest of the groups (infectious, skin/subcutaneous, immune and hematological systems) include six or fewer individuals.

When these disease category data in the W. M. Bass Donated collection are compared to the general US population data the major disease groups are the same. In

Table 9. Frequencies of reported medical conditions by sex and donation type. * significant sex difference, ** significant age difference, *** significant donation type difference, **** significant BMI difference, p-value < 0.05 Wald statistic .

	Self females	Family females	Self males	Family males	Total
Infectious	1	0	0	2	3
Neoplasms *	17	13	11	5	46
Endocrine/metabolic****	10	8	7	4	29
Cardiovascular**,****	18	20	19	16	73
Respiratory	10	11	13	6	40
Nervous	1	4	4	3	12
Gastrointestinal	14	11	11	8	44
Genitourinary *	16	9	2	2	29
Skin/subcutaneous	2	0	1	1	4
Musculoskeletal****	19	15	17	13	64
Sensory	3	3	4	3	13
Immune	2	2	1	1	6
Hematological	0	0	0	1	1
Mental**	5	5	4	7	21

2008 based on the National Health Interview Survey (reported and modified in The Burden of Musculoskeletal diseases 2008) the most commonly reported conditions were affecting musculoskeletal system (110 million), and they were followed by diseases of circulatory (69 million) and respiratory (55 million) systems. Reported cancer in this current sample seem to be more common than in the general population data (18 million). This could be a result of a high number of cancer-related cause of deaths.

Logistic regression is used to detect significant differences in these conditions. Sex differences are found in reporting neoplasms and genitourinary conditions. In both cases males are less likely to report having these conditions (neoplasms sig. 0.016, odds ratio 0.419; genitourinary sig. 0.002, odds ratio 0.04). Age differences are seen in numbers of reporting cardiovascular diseases and mental issues. Older individuals are more likely to report a cardiovascular condition (sig. 0.04, odds ratio 1.026), whereas younger individuals are more likely to report mental problems (sig. 0.004, odds ratio 0.938). When BMI is included in the equation for cardiovascular diseases, both higher age and higher BMI increases the likelihood of reporting cardiovascular conditions.

As already noted earlier, a higher BMI is associated with a higher number of individuals reporting diabetes, and the same is true with the endocrine-nutritional-metabolic disease group (sig. 0.028, odds ratio 1.048). Another disease group that is more likely reported by individuals with a higher BMI is musculoskeletal conditions (sig. 0.037, odds ratio 1.039).

Diseases and conditions affecting skeleton

There are several diseases and conditions which affect bones directly or indirectly. In this sample 64 individuals are reported to have some kind of musculoskeletal condition or surgical procedure that impacted the skeleton (Table 10). Conditions already counted in the check boxes, like amputations, cancers or open heart surgeries are not taken into account in this section. However, there are individuals who did not check the box for open heart surgery, but reported to have a heart transplant, which requires open heart surgery. This is counted in this section. Also, joint replacements and fracture fixation mentioned separately are counted since the check boxes include only general prosthetics (replacements).

Table 10. Reported conditions affecting musculoskeletal system.

	Self females	Family females	Self males	Family Males	Total
Arthritis	3	5	4	3	15
Joint problems	1	3	0	2	6
Rheumatoid arthritis	1	0	1	0	2
Spine problems	2	0	2	2	6
Disc disease	2	0	1	0	3
Osteoporosis	1	1	0	0	2
Gout	1	0	0	0	1
Dislocation	0	0	1	0	1
Metastasis	3	0	0	0	3
Deviated septum	1	0	0	0	1
Bunionectomy	2	0	0	0	2
Facial	1	0	0	2	3
Bone removal	3	3	1	0	7
Joint replacement	1	2	2	0	5
Fracture fixation	2	0	2	0	4
Heart surgery	2	2	1	0	5
Tumor removal	2	1	3	0	6
Spine surgery	2	0	3	2	7
Obesity	1	2	1	0	4

Most of the reported musculoskeletal conditions are joint related problems or surgeries. Some of the conditions, like “arthritis”, “rheumatoid arthritis”, “gout”, “osteoporosis” are reported as such, but some other descriptions are more variable and summarizing these categories requires more interpretation. For example, joint problems include descriptions like “bad knees”, “broken shoulder” and “chronic problems with ankle”. Spine problems include “back pain”, “spinal problems”, “spondylolisthesis” and “crooked back”. “Disc disease” could be included in spine problems but was given its own category since it was mentioned separately. Metastasis includes mentions of metastases to bone. Bone removal includes “kneecap removed”, “heel spur removed”, “spur removed from shoulder”, and “a wrist bone removed”. Tumor removal includes descriptions that might not have actually affected the bone, but sometimes it is hard to tell. Descriptions like “brain tumor removed” or “tumor taken off right internal ear” surely had some bone involvement, but the same cannot be said about “tumor removed from right neck”. Spine surgery includes any mentions of “laminectomy”, “back surgery” or “disk replacement in neck using hip bone”. Heart surgery category includes descriptions like “heart surgery”, “heart valve replacement”, and “heart transplant”.

The most common reported musculoskeletal condition is arthritis, followed by spine surgery and bone removal. In general some kind of spine problems (reported as back problems, disc disease or spine surgery) are reported in 16 cases. Reported frequencies in these categories are generally so small that no age, sex or donation type differences are found.

Observed conditions

In this current research the skeletal conditions studied are healed fractures, surgical devices, osteoarthritis, bone lesions (both lytic and periosteal reaction) and other skeletal anomalies and changes. The observed frequencies of these conditions are reported in this section in several different ways. First, the number of individuals exhibiting any of these conditions will be reported. Also the maximum number of observed conditions (for example fractures) per individual are reported. Skeletal elements are reported as individual bones but also as bone groups. The bone groups are generally the same for each condition type, but some variation exists due to different

information recorded during the data collection. The following bone groups are used: cranium (includes all cranial bones including the mandible), spine (includes all the vertebrae), ribs (includes all the ribs), upper limb (includes all the upper limb long bones), lower limb (includes all the lower limb long bones and also patella), pelvis (includes sacrum and os coxae), trunk (includes manubrium, sternal body, scapula and clavicle), metacarpals and metatarsals. Carpals and tarsals are excluded from the data analysis due to too many missing elements.

Observed healed fractures

Out of 180 individuals 147 exhibit one or more fractures somewhere in their skeleton (excluding carpals and tarsals). Seventy-five of these are males, and 72 are females. Only five individuals have no fractures observed anywhere in their skeleton and the rest of the sample (N=28) have no fractures on the elements observed, but they might have one or more elements missing. The number of fractures per individuals varies from one to 52 fractures. Table 11 shows the numbers of individuals by sex with one fracture, two fractures, 3-15 fractures and over 16 fractures. It can be seen that more females have one or two fractures than males, and males tend to have more than two fractures.

Logistic regression is used to test whether there are sex or age differences if the fracture counts are divided into two groups: 1) one or two fractures, 2) more than two fractures. There is a significant sex difference (sig. 0.021) which indicates that being a male increases the likelihood of having more than two fractures by 2.3 times. There is no significant age difference (sig. 0.076).

The most frequent fractures are seen in the ribs (102 individuals), spine (66 individuals) and cranium (40 individuals). Some significant sex and age differences are found when the body segments are considered separately (Table 12). When individuals with only cranial fractures are compared, a significant sex difference is found when age is controlled. Logistic regression shows that being a male increases the likelihood of having a cranial fracture by 2.5, and this is significant (sig. 0.017). Also the upper trunk (scapulae, clavicles, sternum) shows a statistically significant sex difference (sig. 0.048), which means that males are 3.9 times more likely to have a fracture in this area

Table 11. The total fracture counts in males and females.

Fracture count	Females	Males	Total
1	17	9	26
2	13	10	23
3-15	41	43	84
over 16	1	13	14

Table 12. Fractures by body segments. Sample size, number of individuals with a fracture/s, and maximum number of fractures per individual. * significant sex difference, ** significant age difference, p-value < 0.05 Wald statistic. Fracture counts are based on the number of bones fractures, thus f. ex. multiple cranial fractures can be caused by a single event.

	N		Individuals with fractures		Max count			N		Individuals with fractures		Max count	
	F	M	F	M	F	M		F	M	F	M	F	M
Cranial*	84	85	13	27	3	7	Spine	79	76	37	29	13	14
Upper trunk*	78	78	3	10	1	3	Ribs**	59	72	46	56	30	39
Upper limb	84	87	15	18	2	4	Metacarpals*	67	66	4	14	2	2
Pelvis	84	85	12	8	3	2	Metatarsals	60	56	11	9	5	2
Lower limb	79	81	15	20	2	4							

than females. Metacarpals as well are more often fractured in males than females (being a male increases the likelihood of having a metacarpal fracture by 4.2, sig. 0.018). A significant age difference is found in the number of individuals having rib fractures. Increasing age increases the likelihood of having rib fractures (sig. 0.034, odds ratio 1.039). All the other body segments show no significant differences between sexes or age.

In addition to these typical demographics, socio-economic class (lower class= less than $44,000 yearly income and higher class= more than $44,000 yearly income, see Methods) is used as a variable. Generally socio-economic class does not seem to affect the fracture frequencies, but the odds for having a metacarpal fracture are greater if the individual is from the lower socio-economic class (sig. 0.010, odds ratio 0.127) and from a younger end of the age range (sig. 0.031, odds ratio 0.948). The list of occupations was also divided into “hard physical work” and “less physical work” to see whether the physicality of the work is influencing the fractures or not. However, no differences between hard physical work and less physical work are seen.

After looking at the fracture data by body segments individual bones are analyzed. All the observed bones and the frequency of healed fractures in a specific element are shown in Tables A-3 – A8 in Appendix 3. Table 13 shows the bones that have ten or more individuals with a fracture or significant sex or age differences. As can be seen, the most common elements to exhibit healed fractures are: the nasal, radius, mid-thoracic and lumbars, and all ribs, but especially ribs between four and ten. Nasal fractures are more common in males than in females, but only the left side shows a statistically significant difference (sig. 0.043) indicating that being a male increases the likelihood of nasal fracture by 2.4 times. Other single bones in which a significant increase in likelihood of fracture in males is seen, are the right fibula (4.9 times), ribs 4-7 and 12th on the left side, and ribs 5 and 6 on the right side (2.5 – 10.1 times). The only element in which being a male decreases the likelihood of a fracture is the sacrum (sig. 0.035). When sex is controlled only three bones show age differences. These are the left radius (sig. 0.014), left pubis (sig. 0.023) and left 9th rib (sig. 0.025), and all of them are more commonly seen in individuals with increasing age.

Table 13. All the elements that have ten or more individuals with a fracture. In addition, elements with significant sex or age differences are included. * sex difference, ** age difference, p-value < 0.05 Wald statistic.

	N		Individuals			N		Individuals	
	F	M	F	M		F	M	F	M
Nasal L *	85	89	9	20	T5	89	89	7	4
Nasal R	85	88	9	16	T6	90	88	7	5
Radius L **	89	88	5	5	T7	90	87	4	9
Radius R	87	90	9	7	T8	90	87	6	6
Tibia R	89	86	4	7	T9	89	87	3	7
Fibula R*	86	87	2	9	L1	89	89	9	9
MC5 R	81	85	3	8	L3	88	88	6	4
Sacrum *	84	86	8	1	L4	87	90	5	5
Pubis L **	90	90	2	2					
Rib 2 L	76	82	4	11	Rib 2 R	81	82	5	8
Rib 3 L	75	78	8	10	Rib 3 R	80	81	11	10
Rib 4 L *	72	76	7	16	Rib 4 R	77	81	9	16
Rib 5 L *	74	77	8	22	Rib 5 R *	75	82	7	18
Rib 6 L *	73	80	8	19	Rib 6 R *	72	72	8	21
Rib 7 L *	77	85	8	21	Rib 7 R	80	81	10	16
Rib 8 L	75	83	14	15	Rib 8 R	79	82	11	14
Rib 9 L **	76	86	11	18	Rib 9 R	82	81	10	17
Rib 10 L	81	85	11	16	Rib 10 R	80	85	6	9
Rib 11 L	81	86	0	10	Rib 11 R	80	87	5	10
Rib 12 L *	74	75	1	9					

Observed surgical devices and procedures

In this sample 123 surgical devices are observed in sixty-five individuals. If multiple wires are observed in one area, for example five sternal wires, they are counted as one. Table 14 shows the frequencies of different types of surgical devices. The most common material found attached to the skeleton is wire (in 48 elements). This is mainly due to the high number of open heart surgeries, especially in males. Wire is also used in other cases of fracture repair, especially in the cranium. Metal plates are observed in 26 elements. These are mainly seen in the long bones. Replacements are seen in 18 elements with the majority of these being femoral head replacements. Other surgical devices seen in a lower quantity are intramedullary rods, screws, pins, sutures, and clamps. When multiple devices are observed in one element, they are usually combinations of plate/pin and suture or wire and plate. Other devices observed are metal dental roots, a mesh, and cement in vertebrae. Twenty-nine individuals have only one surgical device, but almost as many, twenty-five, have two devices. Two surgical fixation devices or other devices are more common in males than in females. The biggest count of separate devices in one person is six in males and five in females. More details on the device types by skeletal elements are presented in Tables A-9 – A11 in Appendix 3.

The most common body segment to have surgical implants (replacements and fracture fixation) is the lower limb bones (Table 15). Twenty-three individuals have one or more implants in their lower limb bones, followed by 21 individuals with surgical devices in their trunk segment (mainly open heart surgery).

Logistic regression is used to see whether there are sex or age differences in the frequencies of surgical devices in certain body segments. Only the trunk, which includes the clavicle, scapula and sternum, and lower limb bones show statistically significant age differences. Increasing age also increases the likelihood of having surgical devices in the trunk area by 1.052 times (sig. 0.015). These surgical devices are mainly wires used to repair sterna in open heart surgeries. The same trend is true for lower limb surgical devices (sig. 0.015, odds ratio 1.048), and this is mainly due to the large number of joint replacements of the hip and knee. When individual bones are considered, only the right femur and tibia show age differences (sig. 0.036, odds ratio 1.058; sig. 0.042, odds ratio 1.145 respectively).

Table 14. Frequencies of observed surgical devices by type and sex.

	Females	Males	Total
Replacement	11	7	18
Plate	9	17	26
Rod	3	1	4
Wire	15	33	48
Screw	5	3	8
Suture	0	3	3
Pin	2	3	5
Clamp	0	1	1
Multiple	4	1	5
Other	3	2	5
Total	52	71	123

Table 15. Frequencies of surgical devices by body segment.

	N		Individuals		Max count	
	F	M	F	M	F	M
Cranium	89	89	3	10	2	4
Trunk	84	84	8	13	2	2
Upper limb	87	89	2	4	1	2
Pelvis	90	90	2	0	2	0
Lower limb	80	80	13	10	3	6
Spine	88	86	4	2	1	1
Metacarpals	68	64	0	1	0	1
Metatarsals	63	55	3	1	1	1

When the devices observed in the long bones are divided into six locations: proximal 1/3 of the shaft, middle 1/3 of the shaft, distal 1/3 of the shaft, proximal joint, distal joint and more than one, the most common site for a surgical device is the proximal shaft (N=13), and the second most common site is the proximal joint (N=11).

Any surgical procedure observed in the skeletons are listed in Table 16. Fracture fixation, open heart surgery and bone removal are the most common types of surgical procedures.

Observed lesions

The observed skeletal lesions are divided into two main categories: bone loss and bone formation. Bone loss includes mainly active and healed lytic lesions, but also surgical bone removal. Bone loss due to osteoarthritic or other degenerative bone changes are not included in this study. The bone formation category includes periosteal reaction and neoplasms. In the beginning of data collection, active, healing and healed periosteal reactions were recorded, but however, it was soon discovered that healed periosteal reactions would be very common in this sample. Thus, only periosteal lesions with active and clearly sclerotic appearance are included in this analysis.

Table 16. All the surgical procedures observed in the sample.

	Females	Males
Craniotomy/burr holes	1	5
Facial reconstruction	3	3
Fracture fixation	13	16
Replacement	5	2
Bone removal	10	5
Amputation	2	4
Spinal surgery	6	5
Open heart	8	14
Other	3	2

Ninety-seven individuals out of those 120 individuals that have either all skeletal elements present or show lesions on at least one surface of a body segment missing other elements, show a skeletal lesion on at least one of their bones (49 females, 48 males). Bone formation (usually periosteal reaction) is more common than bone loss. Fifty-three individuals have a lesion of bone loss somewhere in their skeleton, whereas 78 show an active or sclerotic periosteal reaction (Table 17) and several of these have a combination of both. There are no statistically significant sex or age differences in the total number of individuals exhibiting any lesions, bone loss or bone formation. The most common areas to find any kind of skeletal lesions in this sample are ribs, lower limbs, cranium and pelvis. Rib lesions are mostly periosteal lesions, but also lytic lesions are observed. The low number of lytic lesions might be affected by the difficulty of observing these lesions in fragmentary ribs but also by the more conservative data collection on lytic lesions (if lesion was not clearly lytic, it was not recorded). In most of the body segments the periosteal lesions seem to be more common than lytic lesions, except in upper trunk and pelvis these two types are almost as common. Again, this difference could be influenced somewhat by the difficulty of observing and diagnosing lytic lesions, but also the conditions causing lytic lesions tend to be more severe (cancer metastasized to bone) than conditions causing periosteal lesions (infection, trauma), and thus, not as common.

Skeletal lesions in individual bones are presented in Tables A-12 – A-14 in Appendix 3. There are no significant sex or age differences observed in any types of lesions combined or lytic and periosteal lesions separately.

Even though healed periosteal reactions were not recorded in detail during the data collection, notes on these lesions on femora and tibiae were taken. One hundred and two individuals have healed periosteal reaction on either their femora or tibiae (Table 18). Most commonly these lesions are seen in the lateral surface of the proximal-middle of the femur shaft or middle-distal tibial shaft on the medial surface. Logistic regression is used to detect any differences that might be caused by sex, age or BMI. In both the femora and tibiae when age and sex are controlled, increasing BMI increases the likelihood of healed periosteal lesions (femora sig. 0.001, odds ratio 1.1; tibiae sig. 0.009, odds ratio 1.1). Also 74 individuals showed periosteal lesions along the shafts of

Table 17. Frequencies of individuals exhibiting skeletal lesions, both bone loss and bone formation by body segments, and maximum count of observed lesions in the specific segment.

Bone loss							Bone Formation						
	N		Individuals with lesions		Max count			N		Individuals with lesions		Max count	
	F	M	F	M	F	M		F	M	F	M	F	M
Cranium	89	89	4	8	3	2	Cranium	89	89	6	11	4	3
Trunk	86	84	8	3	3	2	Trunk	86	84	8	4	3	2
Upper limb	86	88	2	3	4	1	Upper limb	86	88	2	7	4	2
Pelvis	90	88	6	8	2	2	Pelvis	90	88	6	9	3	4
Lower limb	88	89	5	2	2	1	Lower limb	88	89	16	15	5	6
Spine	77	73	9	8	6	4	Spine	77	73	1	1	1	4
Ribs	56	62	6	6	15	2	Ribs	56	62	15	18	21	18

Table 18. A number of individuals with healed periosteal reaction in lower limbs.

	N		Individuals with reaction			N		Individuals with reaction	
	F	M	F	M		F	M	F	M
Femur L	89	90	33	38	Femur R	89	90	36	40
Tibia L	89	89	31	36	Tibia R	89	89	25	34
Fem+Tib	89	89	48	54					

their metatarsals. An earlier study associated these metatarsal lesions with diabetes (Williams et al. 1988), but in this sample no association was found.

Observed osteoarthritis

In this sample 127 individuals show signs of eburnation related to osteoarthritis. Fourteen individuals exhibit no eburnation in any of the observed joint surfaces, and 39 individuals show no eburnation on the elements present but they are missing some bones, and thus, not included in this analysis. Eburnation is recorded for 67 females, and 60 males. The counts of skeletal elements affected by eburnation vary from one to 30. There is no significant sex difference found in the number of individuals with eburnation, but as expected there is a statistically significant age difference when logistic regression is used and sex is controlled (sig. 0.002); increasing age increases the number of individuals with eburnation. In addition, the counts of these polished surfaces are divided into two groups as follows: 1) one to 10 surfaces, 2) over 11 surfaces. Not only are there more elderly individuals with eburnation, but also more joint surfaces are affected in older individuals than in the younger individuals (sig. 0.001).

Also the frequencies of eburnation in different body segments are studied (Table 19). The body segments used in this section are: the cranium (temporomandibular joint), spine (vertebrae), upper limb (glenoid cavity, humerus, radius, ulna), pelvis (sacrum, os coxae), lower limb (femur, tibia, patella), metacarpals and metatarsals.

The most common body segments exhibiting eburnation are the spine (118 individuals), metacarpals (49 individuals) and pelvis (35 individuals). A maximum number of affected vertebra in a person is 21. There are no statistically significant differences between males and females but, as expected, age differences are present. Increasing age increases the odds of having eburnation in joint surfaces in the spine, pelvis, and upper limb joints. The same pattern is seen in the metacarpals and metatarsals. However, joints in the lower limbs do not show age differences in eburnation. Carpals and tarsals are excluded from further statistical analysis due to too many missing elements, but 57 individuals (31 females, 26 males) have one or more carpals with an eburnated surface, and 12 (6 females, 6 males) have one or more tarsals with an eburnated surface.

Table 19. Eburnation by body segments. Sample size, number of individuals with eburnation, and maximum number of elements or joint surfaces affected per individual. ** significant age difference, *** BMI, p-value < 0.05 Wald statistic.

	N		Individuals with eburnation		Max count			N		Individuals with eburnation		Max count	
	F	M	F	M	F	M		F	M	F	M	F	M
Cranium	89	89	2	1	4	1	Lower limb***	81	81	14	7	4	5
Spine**	83	81	63	55	20	21	Metacarpals**	73	66	24	25	7	5
Pelvis**	88	85	22	13	2	1	Metatarsals**	65	61	10	16	3	3
Upper limb**	87	89	13	13	7	6							

If the body segments are further divided into separate joints, it can be seen that the shoulder and wrist are more affected than the elbow (Table 20). Also those joints are more affected by age. In the lower limb, the knee is the most common joint to exhibit osteoarthritic changes. However, this is not significantly related to old age. Other factors that might affect osteoarthritis are BMI and hard physical work. Increasing BMI is found to increase the likelihood of eburnation in lower limbs (sig. 0.026, odds ratio 1.061) when age and sex are controlled but the quality of work does not seem to impact the presence of OA.

Frequencies of eburnation in individual bone elements are show in Tables A-15 – A-17 in Appendix 3. As already mentioned, there are no sex differences in the frequency of the osteoarthrisis. All of the cervical vertebrae and lumbar vertebrae show age effect, whereas five thoracics (T4, T8, T10-12) do not exhibit significant age differences. Other elements showing significant age differences, are both scapulae and humeri, both radii, left ulna, both patellae, both greater multangulars, both sides of first and second metacarpals, and both first metatarsals. The most common sites for eburnation are cervicals, lower lumbars, and the joint between first metacarpal and greater multangular. The bigger joints are also affected, especially the shoulder, wrist and knee. Elbow and hip joints are less affected by osteoarthritis but it should be noted that there are multiple femoral head replacements in this sample and they might have been implanted to fix eburnation.

Other observed conditions

The last category of observed skeletal conditions includes both congenital anomalies (i.e. cleft vertebrae, cervical ribs) and degenerative changes (Schmorl's depressions, pathological fusions). Congenital anomalies might be asymptomatic and an individual might not even know he/she has this skeletal feature. In these cases the skeletal feature is generally an incidental finding in medical examination, i.e. x-rays, related to other problems. Some of these anomalies can cause symptoms that will lead to the discovery of the skeletal abnormality. For example, a cervical rib can cause problems with blood circulation in the neck (Chang et al. 2013). Congenital anomalies and degenerative changes are analyzed separately due to their different etiology.

Table 20. Frequencies of individuals with joints showing eburnation. Vertebrae are number of vertebrae not joints. ** significant age difference, p-value < 0.05 Wald statistic.

	N		Individuals with eburnation		Max surface number			N		Individuals with eburnation		Max surface number	
	F	M	F	M	F	M		F	M	F	M	F	M
TMJ L	89	89	2	1	2	1	Hip L	89	90	2	0	2	0
TMJ R	89	89	1	1	2	2	Hip R	89	90	2	0	2	0
Shoulder L**	89	90	5	3	2	2	Knee L	83	84	8	3	3	2
Shoulder R**	90	90	7	4	2	2	Knee R	82	84	7	5	2	3
Elbow L	88	89	3	3	2	2	Ankle L	87	86	0	0	0	0
Elbow R	89	90	1	2	2	2	Ankle R	87	88	1	2	1	2
Wrist L**	64	67	9	9	4	3	Cervicals	616	608	185	164		
Wrist R**	65	68	7	12	3	3	Thoracics	1075	1076	147	96		
Thumb L**	70	68	17	15	2	2	Lumbars	447	448	117	94		
Thumb R**	65	72	13	17	2	2							

Congenital anomalies included in the study are divided into specific body segments: the cranium (button osteoma, mandibular torus, palatine torus, enlarged nasal turbinate), spine (spina bifida, cleft vertebra), ribs (cervical rib, bifid rib) and upper trunk (os acromiale, sternal aperture). Degenerative changes included in this section are sacroiliac fusion, other pathological fusions (mainly vertebrae) and Schmorl's depressions in vertebral bodies. In addition to these congenital fusions (any bones, but mainly vertebrae) and spondylolysis were analyzed as separate features.

In this sample 112 individuals show one or more skeletal anomalies in the cranium, spine, ribs or trunk (scapula, sternal body). Sixty-two out of these are females, and 50 males. Twenty-two individuals have essential skeletal elements missing and thus are excluded from this analysis. Table 21 shows the frequencies of these congenital anomalies. The most common anomaly is a palatine torus, which is found in 30% of the individuals. Cervical ribs are found in 23 individuals (13%) and mandibular tori in 21 (12%). In this study, cervical rib variants range from a full separate rib to a bony extension of the transverse process, thus the frequency is high. If only separate ribs were counted, the percentage would be 1.1%. None of these anomalies show age differences in their prevalence, but enlarged nasal turbinates are less likely to be present in males than in females (logistic regression sig. 0.021, odds ratio 0.213).

When the degenerative changes are analyzed, logistic regression shows significant sex difference in sacroiliac fusion and Schmorl's depressions. Being a male increases the likelihood of showing sacroiliac joint fusion by 8.8 times (sig. 0.005, odds ratio 8.754). Also Schmorl's depressions are 2.5 times more likely seen in males than in females (sig. 0.003, odds ratio 2.482). Pathological vertebral fusions are also more common in males than in females (sig. 0.010, odds ratio 2.520), and also a significant age difference is observed (sig. 0.000, odds ratio 1.082). Including BMI into the equation shows that pathological fusions after controlling age and sex are more common in individuals with high BMI (sig. 0.010, odds ratio 1.056).

Some characteristics of these anomalies and degenerative changes are analyzed further. For example, the most common location (vertebra type, right or left) and severity (complete or partial) of the traits are studied. This information can also be useful when considering how common certain types of anomalies are and can they be

Table 21. Frequencies of the skeletal anomalies and pathological degenerative changes. * significant sex difference, ** significant age difference, p-value < 0.05.

	N		Individuals with anomalies/changes			N		Individuals with anomalies/changes	
	F	M	F	M		F	M	F	M
Button osteoma	89	89	10	7	Bifid rib			0	2
Mandibular torus	89	89	9	12	Cleft vertebra			9	4
Palatine torus	89	90	30	24	Spina bifida	90	90	6	9
Nasal turbinate*	71	71	12	3	Sternal aperture	86	88	5	5
Cervical rib	90	88	16	7	Os acromiale	90	90	3	1
Sacroiliac fusion*	90	90	2	14					
Pathological fusions*,**			25	36					
Schmorl's depressions*	87	88	34	54					

used in identification. For example, 69% of the cleft vertebrae are seen in cervicals and only one lumbar is recorded to be cleft. Also, 93% of the enlarged nasal turbinates are unilateral, thus an individual with bilateral enlarged nasal turbinates seems to be quite rare. The descriptive information is presented in Table 22.

Matching the reported and observed conditions

Since the self- and family-reported descriptions of the surgeries, diseases, injuries and other conditions are so varied, summarizing the results is complicated. Naturally, only the conditions that are likely to be seen in the skeletal remains and also easily observed were chosen. This includes surgeries, fractures, open heart surgeries, amputations, prosthetics and arthritis. Cancer is not included since it may not leave signs on bone, and also not all lytic lesions are necessarily caused by cancer. Fractures are further divided into body segments. These percentages and frequencies are based on the number of individuals showing and reporting these conditions/procedures and not the number of actual observed/reported conditions.

Agreement between reported and observed data is analyzed by using two different methods. First, only agreement and disagreement is looked at by comparing the reported and observed conditions. Agreement includes cases in which a condition is reported and observed and in which a condition is neither reported nor observed. Disagreement includes cases in which a condition is reported but is not observed and a condition is observed but not reported. Secondly, the nature of the agreement and disagreement is studied by dividing them into true positives/negatives and false positives/negatives. This latter approach is used in studies when there is “a gold standard”, i.e. a reliable test, that will be the true condition and the reported data is compared against it. In this study, there is no gold standard (see Smith et al. 2008; Okura et al. 2004), since reported data cannot definitely be considered reliable but also the macroscopic assessment is not the true state of the disease since not all the conditions can be seen on the bone and also the bony changes may not be associated with the disease.

Table 22. Details of the anomaly locations and severity. Sample sizes for different vertebral groups marked as (Female/Male).

	N		Individuals with anomalies/changes			
	F	M	Right	Left	Both	
Mandibular tori	89	89	2	1	18	
Nasal turbinate	71	71	9	5	1	
Os acromiale	90	90	0	2	2	
Sacroiliac fusion	90	90	7	6	3	
			Cervical	Thoracic	Lumbar	Multiple
Cleft vertebra			9 (81/77)	3 (85/87)	1 (87/88)	
Congenital fusion			2 (80/78)	2 (85/87)	1 (87/88)	
Pathological fusion			10 (82/81)	28 (85/87)	2 (87/89)	21 (85/87)
Schmorl's depressions			0 (80/77)	47 (87/88)	2 (88/89)	39 (87/88)
			Complete	Partial		
Spina bifida	90	90	2	13		
Spondylolysis	88	89	8	2		
Cervical rib	90	88	2	21		

Nevertheless, in order to gain understanding of which conditions are reported but not observed and vice versa, the macroscopic assessment is used as the “gold standard” and the reported data is compared against it. This gives four different variables: 1) True positive which means the conditions is both reported and observed on the skeleton; 2) False negative which means that the condition is observed but not reported; 3) True negative which means that the conditions is neither reported nor observed; 4) False positive which means that the condition is reported but not observed (See Table 6). Several assumptions are made when these data are analyzed this way. First of all, the reported data is from questionnaires that only ask individuals to report the conditions they have. So if the box is not checked, this is recorded as the individual did not have or was not aware of having this condition. However, in reality this could also mean that the individual just ignored this box.

Table 23 shows the agreement of the reported and observed data in percentages. The data is divided by sex and donation type. Since the study includes family donations, the sample is also divided by the sex of the informant (informants most commonly wife/husband, daughter/son, sister/brother etc). In self-donations this refers to the donor’s sex, but for the family donations the sex of the informant is used. When the sample is divided like this, there are 95 female informants and 70 male informants, and 15 donations which do not have informant’s sex available. Both of the sex divisions are shown in the table since the sex of the actual donation can affect the type of conditions the individuals had, and the sex of the informant can affect the quality and quantity of the reported data.

General agreement is high (over 90%) for surgeries such as open heart surgery (94.4%), prosthetics (97.2%) and amputations (96.7%), but low for arthritis (16.0%) and fractures (38.9%). Agreement is also low for the general surgery category (55.0%), but this can be explained by the fact that many of the surgeries reported involve soft tissue and leave no signs on the bones. This could also explain the lower agreement in females since a large number of females reported surgeries such as hysterectomy. Reporting accuracy does not differ greatly between family and self-donation when those major surgical procedures are considered, but greater agreement is found between observations and self-reported data on fractures (46.6% vs. 31.1%) and arthritis (18.2% vs. 13.4%).

Table 23. Agreement (percentages) between reported and observed data. Female and male include the sex of the donation, female and male informant include the sex of the informant reporting the medical history if known. Significant differences * sex, ** age, *** donation type, p-value < 0.05 Wald statistic.

	Female	Male	Female informant	Male informant	Self	Family	Total
Surgery	50.0	60.0	50.5	58.6	57.8	52.2	55.0
Open heart	92.2	96.7	93.7	94.3	94.4	94.4	94.4
Prosthetics**	97.8	96.7	98.0	95.7	97.8	96.7	97.2
Amputation	97.8	95.6	100.0	98.5	97.8	95.6	96.7
Fractures***	34.4	43.3	38.9	41.4	46.6	31.1	38.9
Arthritis	17.8	14.1	13.2	17.9	18.2	13.4	16.0

Some sex differences can be seen in the agreement percentages. Reports on fractures seem to agree better with observed conditions in males (43.3 %) than in females (34.4 %). The same is seen when the sex of the informant is taken into account but with a smaller difference (38.9 % vs. 41.4 %).

Reported fractures by body segments are also compared to the observed fractures (Table 24). The highest agreement is found in areas such as the trunk (91.0%), pelvis (88.8%), hands (84.2%), feet (80.2%) and upper limbs (80.1%). The lowest agreement is seen in the ribs (26.0%). Usually rib fractures are observed but not reported. The same is true with spinal fractures whose agreement is low as well (58.1%). In general, self-reported fracture information is more reliable than family-reported data, except when fractures in the spine (60.8% vs. 55.6%) and feet (82.1% vs. 78.3%) are considered. The agreement in fractures seems to be higher in those reports in which the informant is a male. Only fractures of the spine, lower limbs and hands show higher agreement in reports by females.

Since the general agreement/disagreement is a binary variable, logistic regression is used to see if any of the variables (sex, age, donation type) influence the agreement. Most of the data show no differences, but for example general fracture reporting and fractures in the cranium, ribs and hands show differences. Reported and observed fractures seem to disagree more in family reports than in reports by self-donors (sig. 0.031, 1.989 odds ratio). When body segments are considered separately, cranial fractures show a difference between the sexes; being a male increases the likelihood of disagreement by 2.2 times. This usually means that the fractures are observed but not reported and most of the cranial fractures are seen in males. Also fractures in the hand bones show the same sex effect. The likelihood of disagreement is 3.961 times higher in males (sig. 0.013). None of the differences are significant when the sex of the informant is used as a variable. Reports on fractured ribs are more likely to disagree with the observed fractures when the individual is older (sig. 0.020, odds ratio 1.042). Age

Table 24. Agreement (percentages) between reported and observed fractures by body segments. Female and male include the sex of the donation, female and male informant include the sex of the informant reporting the medical history if known. Significant differences * sex, ** age, *** donation type, p-value < 0.05 Wald statistic.

	Female	Male	Female informant	Male informant	Self	Family	Total
Cranium*	83.3	69.4	73.3	79.4	81.0	71.8	76.3
Trunk	94.9	87.2	88.8	93.8	91.5	90.5	91.0
Upper limb	76.2	83.9	80.9	82.6	82.4	77.9	80.1
Spine	53.2	63.2	61.2	55.9	55.6	60.8	58.1
Ribs**	25.4	26.4	25.4	25.0	27.3	24.6	26.0
Pelvis	86.9	90.6	88.3	91.3	92.0	85.4	88.8
Lower limb	83.5	72.0	82.4	73.4	80.2	75.0	77.6
Feet	76.7	83.9	78.5	83.7	78.3	82.1	80.2
Hands*	92.5	75.8	88.7	80.7	87.5	80.3	84.2

differences are also seen in reporting prosthetics. The likelihood of disagreement increases with older age (sig. 0.060, odds ratio 1.157).

The frequencies of true positives, true negatives, false positives and false negatives are presented in Tables A-18 and A-19 in Appendix 3, and Table 25 shows the sensitivity and specificity percentages by sex and donation type. As explained in the Methods, sensitivity is calculated as the number of individuals with correctly reported existing conditions/the number of all the individuals with observed existing conditions. Similarly, specificity is calculated as the number of individuals with correctly reported non-existing conditions/the number of all the individuals with non-existing conditions. Thus, sensitivity and specificity gives an idea where the discrepancies are in the matched data (e.g. low sensitivity usually means that more observations were made than reported, and low specificity means that more reports were made than observed). Skeletally obvious surgeries like amputations, open heart surgeries and prosthetics are usually observed if they are reported. They are also pretty rarely observed without any reports in the medical history.

Fractures are commonly observed (in this sample 147 individuals) on the skeletal remains but not reported as often (in this sample for 57 individuals) in the medical history. The same trend can be seen in the case of arthritis which is observed (in 127 individuals) far more often than it is reported (for 15 individuals). Surprisingly, quite a large number of limb fractures (N=20) are reported but not observed. This discrepancy might be due to well-healed fractures without external skeletal signs of the event. A more common situation is underreporting of fractures. Rib fractures are typically underreported. For example, 97 individuals in this sample have at least one rib fracture, but no rib fractures are reported. The same is true for vertebral fractures (observed in 61 individuals without any reports). These differences can be explained in several ways: these fractures happened after the self-donor signed the paperwork, or the donor or family was not aware of the fracture. The possible explanations for any discrepancies in the reported and observed data will be discussed in more detail in Chapter 6.

The general conditions and surgical procedures show total sensitivity percentages lower than 64 %, with open heart surgery having the highest sensitivity (63.4 %). The lowest sensitivity is seen in arthritis (8.5%) followed by fractures (30.2%). Sensitivity

Table 25. Sensitivity and specificity percentages for major pathological conditions/surgical procedures. Female and male include the sex of the donation, female and male informant include the sex of the informant reporting the medical history if known.

Sensitivity							
	Female	Male	Female informant	Male informant	Self	Family	Total
Surgery	56.3	48.7	64.9	40.0	67.6	37.8	52.1
Open heart	33.3	84.6	57.1	75.0	60.0	63.6	63.6
Prosthetics	60.0		66.7	25.0	33.3	50.0	42.9
Amputation	50.0	66.7	100.0	100.0	50.0	66.7	60.0
Fractures	27.4	32.9	30.4	33.3	37.0	23.7	30.2
Arthritis	7.8	9.1	5.9	9.8	8.8	8.1	8.5
Specificity							
	Female	Male	Female informant	Male informant	Self	Family	Total
Surgery	46.6	68.6	41.4	72.5	51.8	62.3	56.9
Open heart	100.0	98.7	100.0	96.8	98.7	98.7	98.7
Prosthetics	100.0	98.9	98.9	100.0	100.0	98.8	99.4
Amputation	100.0	98.8	100.0	100.0	98.5	100.0	99.4
Fractures	64.7	100.0	81.3	76.9	88.2	71.4	80.6
Arthritis	77.8	80.0	75.0	80.0	88.9	60.0	78.6

is higher in self-donations for surgery, fractures and arthritis, whereas the major surgical events have a higher sensitivity in family-donations. Sex differences are also seen, but they depend on the condition and no clear pattern is seen.

In general, sensitivity is higher in males. Specificity percentages of the major surgeries are close to 100%, but much lower for general surgeries, fractures and arthritis. Fracture data divided into body segments shows low sensitivity, which is expected based on the sensitivity of the general fracture data (Table 26). The highest percentages are for upper and lower limbs (27.3% and 27.8% respectively). The lowest sensitivity is found in the ribs (4.9%), cranium (5.0%) and pelvis (5.0%). In general, higher sensitivity is seen in self-donor reports, especially for the limbs and spine. When sex differences are assessed, they seem to depend on the body segment without a clear general trend. All the total specificity percentages are over 92%. The specificity percentages seem to be similar regardless of the donation type, except for the spine and lower limb. For those segments specificity is higher in family donations than in self-donations. Sex differences are small as well, except for limbs and spine.

Table 10 in the antemortem section provided information on the reported diseases and conditions affecting the musculoskeletal system. The results of these observed conditions were not presented in the observed section because some of the conditions require more detailed analysis and interpretations of the skeletal elements. Many of these skeletal observations could be linked to the reported condition only after looking at the reported medical history. Not all of the reported conditions included earlier are necessarily seen in the skeleton. For example, it was not clear whether some of the tumor removals referred to bone or soft tissue. Some skeletal elements exhibit irregularities which could be results of the reported conditions or procedures, but that is not certain. Since the frequencies are so low, only the total number of reported and observed conditions are shown in Table 27. Surgical procedures and devices that were included in the check boxes (open heart surgery, prosthetics) are excluded from this table. Almost 80 % of the reported musculoskeletal conditions are observed or possibly observed, and only seven percent are not seen in the remains. The fact that these conditions, four arthritis cases and one spinal problem case, were not observed can be explained by missing elements or soft tissue involvement. Eburnation could have been present on the missing elements or hand and feet phalanges that were not examined for

Table 26. Sensitivity and specificity percentages for fractures by body segment. Female and male include the sex of the donation, female and male informant include the sex of the informant reporting the medical history if known.

Sensitivity							
	Female	Male	Female informant	Male informant	Self	Family	Total
Cranium		7.4		12.5	6.3	4.2	5.0
Trunk		10.0		25.0	14.3		7.7
Upper limbs	20.0	33.3	31.3	28.6	33.3	22.2	27.3
Spine	8.1	6.9	8.8	4.0	10.8	3.4	7.6
Ribs	4.3	5.4	3.8	7.1	7.7	2.0	4.9
Pelvis	8.2		9.1		12.5		5.0
Lower limbs	33.3	23.8	44.4	14.3	33.3	25.0	27.8
Specificity							
	Female	Male	Female informant	Male informant	Self	Family	Total
Cranium	98.6	98.3	96.9	100.0	98.5	98.3	98.4
Trunk	98.7	98.5	98.6	98.3	98.7	98.5	98.6
Upper Limb	88.4	97.1	91.8	96.4	92.9	92.6	92.8
Spine	92.9	97.9	96.1	94.1	93.2	97.8	95.5
Ribs	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pelvis	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Lower limbs	95.3	88.5	92.5	90.0	88.4	96.4	92.0
Feet	93.9	100.0	94.4	100.0	94.0	100.0	96.9
Hands	98.4	96.2	100.0	93.3	96.9	98.0	97.4

Table 27. The reported pathological conditions and surgical procedures affecting the musculoskeletal system and their matching observations.

	Individuals with reported	Individuals with observed	Possibly observed	Not observed	Report not clear
Arthritis	15	11		4	
Joint problems	6	2	2		2
Rheumatoid arthritis	2	2			
Spine problems	9	5	3	1	
Osteoporosis	2	1			1
Gout	1	1			
Dislocation	1	1			
Metastasis	3	1			2
Deviated septum	1	1			
Bunionectomy	2	2			
Facial reconstruction	3	3			
Bone removal	7	2	3		2
Fracture fixation	5	5			
Tumor removal	5	3	1		1
Spine surgery	7	3	3		1

this study, and spinal problems could have involved more vertebral disc than the bone. Also, arthritis here is assumed to mean osteoarthritis. There are cases in which no macroscopic changes in a skeleton were observed, but it was not possible to say that the condition or procedure did not occur at some point.

Observed combinations of pathological conditions and applications for personal identification as likelihood ratios

This section summarizes the common combinations of observed pathological conditions. There are several issues that complicate this summary. First, not all the skeletons examined are complete. Due to the missing elements hands and feet are totally excluded from this analysis. Nevertheless, there will be cases in which one or more ribs or vertebrae are missing or they are fragmentary, and thus the sample sizes used in these analyses are going to differ.

Also the numbers of individuals within these conditions will be different in this section than they were in the frequency-section. This is due to the fact that when the number of individuals with fractures was examined, individuals with fragmentary ribs showing evidence of fractures were counted, but now in combination with other conditions, fragmentary ribs can be excluded due to the lack of evidence of the other conditions. For example, there are three ribs missing, but one existing rib exhibits a fracture, thus the individual is counted as having a fracture, but if that individual does not have any fractures, he/she will be excluded, since it is not known whether the missing elements exhibit a fracture or not.

Additionally, not all conditions were recorded for all the body segments during the data collection. For example, eburnation was not recorded for ribs, or for the elements in the trunk other than scapulae.

Table 28 shows combinations of any conditions (fractures, devices, lesions, and osteoarthritis) observed on any skeletal elements. Eleven different patterns are observed in these 104 individuals, and four of them are seen only in one individual each. The sample size is small since many individuals who did not show any conditions, but had

Table 28. Number of individuals showing different combinations of any pathological conditions. F= fracture, D= surgical device, L= skeletal lesion, E= eburnation . Females N=53, males N=51.

F	D	L	E	Female	Male
1	1	1	1	11	12
1	0	1	1	11	12
1	0	0	1	12	10
1	1	0	1	10	11
1	0	1	0	4	2
1	0	0	0	3	0
1	1	0	0	0	2
0	0	0	1	1	0
1	1	1	0	1	0
0	1	0	1	0	1
0	1	1	1	0	1

one or more elements missing, were excluded. This also impacts the observed patterns, since there is no pattern indicating a skeleton without any of these conditions, even though that is probably the most common pattern in reality. The most common combinations include fractures and eburnation. Twenty-three individuals show a combination of one or more fractures and one or more articular surface areas with eburnation, and another 23 show a combination of one or more fractures, lesions and eburnation.

These major pathological conditions (fractures, devices, lesions and osteoarthritis) are also divided further into body segments. As mentioned earlier not all the conditions were recorded for all body segments, thus the number of body segments will vary depending on the pathological condition.

Surgical devices show 12 different patterns as to how they are divided into body segments (Table 29, Table A-21 lists the patterns with only one individual). Six of these patterns are seen only in one individual each. Four of these patterns include devices in different body segments. These include combinations of devices in all the body segments, and a device in a lower limb bone is most often associated with a device in another body segment. The most common pattern shows the lack of surgical devices with all the segments scored as zero. Single surgical devices are most often seen in lower limb bones and trunk.

Sixteen different patterns are observed for osteoarthritis (Table 30, Table A-22 patterns with less than four individuals). Six of these are seen only in one individual each. This is the only condition in which the pattern for no observations is less common than a pattern with observations. Forty-nine individuals show eburnation somewhere in their vertebral column and nowhere else. The next common pattern includes eburnation in spine and pelvis. Twelve out of 16 patterns include multiple body segments, and all of them include spine.

Skeletal lesions presented here are divided into bone loss and bone formation (Table 31 and 32, Table A-23 and A-24, patterns with only one individual). Seventeen different patterns are recorded for lytic lesions, and eleven of these are seen only in one individual each. The sample size for this condition is small, so frequencies for patterns are low too. The patterns that are seen only in one indivual include multiple affected

Table 29. Surgical devices by body segments. C= cranium, T= trunk, A=upper limb, P= pelvis, L= lower limb, S=spine. Females N=55, males N=61.

C	T	A	P	L	S	Females	Males
0	0	0	0	0	0	37	33
0	0	0	0	1	0	6	7
0	1	0	0	0	0	3	9
1	0	0	0	0	0	3	7
0	0	1	0	0	0	1	2

Table 30. Osteoarthritis by body segments. C= cranium, A=upper limb, P= pelvis, L= lower limb, S=spine. Females N=64, males N=65.

C	A	P	L	S	Female	Male
0	0	0	0	0	13	17
0	0	0	0	1	24	25
0	0	1	0	1	11	8
0	1	1	0	1	3	4
0	1	0	1	1	4	0

Table 31. Lytic lesions by body segment. C= cranium, A=upper limb, P= pelvis, L= lower limb, S=spine, R=ribs. Females N=29, males N=43.

C	T	A	P	L	S	R	Female	Male
0	0	0	0	0	0	0	15	26
0	0	0	0	0	0	1	2	2
0	0	0	0	0	1	0	3	1
0	0	0	1	0	0	0	2	2
1	0	0	0	0	0	0	1	3
0	0	0	0	1	0	0	2	1

Table 32. Bone formation lesions by body segment. C= cranium, T= trunk, A=upper limb, P= pelvis, L= lower limb, S=spine, R= ribs. Females N=30, males N=40.

C	T	A	P	L	S	R	Females	Males
0	0	0	0	0	0	0	14	18
0	0	0	0	0	0	1	5	5
0	0	0	0	1	0	0	2	3
0	1	0	0	0	0	1	2	0
0	0	0	0	1	0	1	1	1
0	1	0	0	1	0	0	0	2
1	0	0	0	0	0	1	0	2

body segments. The most common body segments in these combinations are vertebrae and ribs. Also cranium, trunk and pelvis are seen in several combinations. The most typical pattern observed shows lytic lesions only in ribs.

Bone formation lesions are observed in 22 different patterns, and 15 of these are observed only in one individual. The most common pattern includes lesions only in the ribs. Fifteen patterns include multiple body segments with bone formation, and the most common segments in these combinations are ribs, lower limb, pelvis and cranium.

Twenty-six individuals do not show antemortem fractures in the body segments analyzed here (cranium, trunk, upper limb, pelvis, lower limb, spine and ribs). Forty-one different types of fracture combinations are seen in this sample. Six of them have fractures only in one body segment and the rest have two to six segments affected. Eighteen combinations are present in only one individual. These usually include fractures in four different body segments. The most common combination of fractures in two or more body segments includes at least one facture in the ribs and vertebrae (19 individuals). The most common solitary healed fracture is seen in the ribs (N=26), and the second is in the vertebrae (N=8). The combinations seen in three or more individuals are listed in Table 33, and the rest of the patterns can be seen in Table A-25.

Because long bones are commonly found in forensic cases and healed fractures in them could be used for identification, combinations of long bone fractures are listed in Table 34**.** One hundred and ten individuals do not show macroscopic signs of healed fractures in the lower limb bones. Twenty-eight different combinations with fractures are observed in the sample of 80 females and 83 males. Eleven combinations include only one fractured bone and the most commonly fractured element is the right radius (6 individuals) followed by right fibula (5 individuals). The most common combination of long bone fractures is the right tibia and fibula (3 individuals). Seventeen combinations are seen in only one individual (Table A-26).

Table 33. Number of individuals showing one or more healed fractures in specific body segments. C= cranium, T= trunk, A=upper limb, P= pelvis, L= lower limb, S=spine, R= ribs. Females N=75, males N=81.

C	T	A	P	L	S	R	Female	Male
0	0	0	0	0	0	0	13	13
0	0	0	0	0	0	1	11	15
0	0	0	0	0	1	1	10	9
0	0	0	0	0	1	0	4	4
0	0	1	0	0	1	1	5	2
0	0	0	1	0	0	0	5	1
0	0	0	0	1	0	1	3	2
1	0	0	0	0	0	0	3	2
0	0	0	0	1	1	1	2	2
0	0	0	0	1	0	0	3	0
1	0	0	0	0	1	1	1	2
1	0	0	0	0	0	1	0	3
1	0	0	0	1	0	1	0	3

Table 34. Observed healed fractures by long bones. H= humerus, R= radius, U= ulna, F= femur, T= tibia, Fi= fibula, r= right side. Females N=80, males N=83.

H	Hr	R	Rr	U	Ur	F	Fr	T	Tr	Fi	Fir	Female	Male
0	0	0	0	0	0	0	0	0	0	0	0	55	55
0	0	0	1	0	0	0	0	0	0	0	0	4	2
0	0	0	0	0	0	0	0	0	0	0	1	1	4
0	1	0	0	0	0	0	0	0	0	0	0	2	2
0	0	1	0	0	0	0	0	0	0	0	0	1	3
0	0	0	0	0	0	0	0	0	1	0	1	1	2
0	0	0	0	0	0	1	0	0	0	0	0	1	2
0	0	0	0	0	0	0	0	0	1	0	0	2	1

Since rib fractures are so common, all the ribs are examined for common combinations of fractures. There are 42 combinations for fractured left ribs and 40 for right ribs (Tables A-27 and A-28). The sample size is small, since only individuals with all the ribs present were included. Eight of these combinations on the left side and nine on the right side included only one fractured rib. One individual has 11 left ribs fractured of which seven have multiple fractures, and 10 right ribs of which six have multiple fractures. The same combinations are rarely seen in multiple individuals. For example, only seven (left side) and eight (right side) combinations are shared by two or three individuals, leaving 35 and 32 patterns seen only in one individual. But the sample size is so small that more data needs to be collected to make these combinations useful.

Not all the ribs are necessarily found in forensic cases. In order to make individual ribs useful in comparisons to medical reports or x-rays, a more specific analysis of rib fractures by their location is done separately for each rib. This analysis looks at all the ribs separately and lists the number of fractures in each locations (head 1/3, middle 1/3, and sternal 1/3) or if multiple (Table 35). In general, ribs 5-9 have the most fractures. There are slightly more fractures on the left side than on the right. Males have more fractures than females, as reported earlier. The most common location for a healed fracture is the sternal end of the rib (254 fractures). Fractures in the vertebral end of the rib are quite rare (35 fractures). Seventy-two ribs have more than one fracture. Thus, the rib fractures that are going to be most useful in personal identification due to their rarity would be located in the vertebral end of the rib and preferably in the first two and last two ribs.

Long bones are often found and exhibit a fair amount of fractures, surgical fixations and osteoarthritis. The last combination analyzed in this study is the patterns of having any of the four condition groups (fractures, surgical devices, osteoarthritis, lesions both lytic and formation together) on any of the long bones. The conditions are coded as F=fractures, D=device, E=eburnation and L=lesions. There can be multiple conditions on single skeletal element, thus the letter code can include multiple letters: for example, bone with a code FDL has a fracture, a device and a lesion. Twenty individuals are excluded from the analysis due to missing elements. Thus, 160 individuals exhibit 80 different patterns. Sixty-four individuals do not have any conditions observed on their long bones, and twelve other patterns are seen in multiple

Table 35. Observed rib fractures by their locations. Sternal= 1/3 from the sternal end, middle= 1/3 of the middle rib, vertebral= 1/3 from the vertebral end, multiple= multiple fractures with multiple locations.

	N		Sternal		Middle		Vertebral		Multiple		Total	
	F	M	F	M	F	M	F	M	F	M	F	M
Rib1 L	83	86	0	0	0	0	0	2	0	0	0	2
Rib1 R	87	87	1	0	0	0	0	2	0	0	1	2
Rib2 L	76	82	2	9	0	2	0	0	2	0	4	11
Rib2 R	81	82	5	5	0	2	0	0	0	1	5	8
Rib3 L	75	78	4	6	3	2	1	1	0	1	8	10
Rib3 R	80	80	9	5	1	2	0	1	1	2	11	10
Rib4 L	72	76	3	6	3	6	0	2	1	2	7	16
Rib4 R	77	81	7	11	1	1	0	1	1	3	9	16
Rib5 L	74	77	5	8	1	8	0	1	2	5	8	22
Rib5 R	75	82	5	15	2	1	0	1	0	1	7	18
Rib6 L	73	80	5	8	3	5	0	1	0	5	8	19
Rib6 R	72	72	5	13	2	3	0	2	1	3	8	21
Rib7 L	77	85	5	10	3	3	0	1	0	7	8	21
Rib7 R	80	80	5	11	5	3	0	0	0	2	10	16
Rib8 L	75	83	10	7	4	3	0	1	0	4	14	15
Rib8 R	79	82	5	9	6	3	0	1	0	1	11	14
Rib9 L	76	86	9	6	2	5	0	2	0	5	11	18
Rib9 R	81	82	7	8	3	1	0	2	0	6	10	17
Rib10 L	81	85	8	4	1	5	1	2	1	5	11	16
Rib10 R	80	85	2	1	1	4	1	0	2	4	6	9
Rib11 L	81	86	0	2	0	5	0	2	0	1	0	10
Rib11 R	80	87	1	4	2	4	2	1	0	1	5	10
Rib12 L	74	75	0	2	1	5	0	1	0	1	1	9
Rib12 R	76	72	0	2	1	1	2	1	0	1	3	5
Total			103	152	45	74	7	28	11	61		

individuals. This means that 66 patterns are present only on one individual. If more specific location or device type is included in the pattern, there would be even more combinations. Table 36 shows the patterns seen in multiple individuals and Table A-29 lists rest of the observed patterns. More data should be collected to see the frequencies of these combinations in a wider population.

Examples of likelihood ratios

Steadman et al. (2006) calculated likelihood ratios for a correct identification based on several skeletal traits (e.g. age, sex, stature, dental formula, fractures). As an example, this current material was used to calculate likelihood ratios based on healed fractures and surgical devices.

Nasal fractures are common in this sample, and the likelihood ratio for a healed right nasal is 9.4 (85/9) for females, and 5.5 (88/16) for males. Fractures in right tibia are little less common and their likelihood ratios are 22.3 (89/4) and 12.3 (86/7) for females and males respectively. If a healed fracture on right humerus is used for likelihood calculations, the likelihood ratios increase: females 45 (90/2), and males 30 (90/3). Even higher likelihood ratios are obtained when right first metatarsal is used: females 39, but males no healed fractures observed. As Steadman et al. (2006) points out combining several fractures is not a good idea, since we do not know whether these fractures are independent or not (whether they were caused by the same event). The same applies also with healed fractures and fracture fixation devices. Thus, no fracture or fracture and plate combinations are calculated. However, a likelihood ratio of 82 (83/1) for females and 29.3 (88/3) for males is obtained by using a combination of open heart surgery wires and a healed right nasal fracture. Right ulna with healed fractures is seen in one female (likelihood ratio 89, 89/1) and in three males (likelihood ratio 30, 90/3). A femur head replacement on the right side is seen only in three individuals resulting in likelihood ratios of 44.5 for females (89/2) and 89 (89/1) for males. When the healed right ulna fractures and right femur head replacements are combined, there are no individuals in this sample with both of these conditions. The raw data in the attachments can be used to calculate more likelihood ratios according to what is needed by the reader.

Table 36. The most commonly observed conditions and combinations in the long bones. Females N=76, Males N=84.

H	Hr	R	Rr	U	Ur	F	Fr	T	Tr	Fi	Fir	Female	Male
0	0	0	0	0	0	0	0	0	0	0	0	29	35
0	0	0	0	0	0	0	0	0	0	0	F	1	3
0	0	0	0	0	0	0	0	0	L	0	0	3	1
0	0	0	F	0	0	0	0	0	0	0	0	2	1
0	0	0	0	0	0	0	0	0	F	0	0	1	1
0	F	0	0	0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	F	0	F	0	2	1
0	0	0	0	0	0	0	0	D	0	0	0	1	1
0	0	0	0	0	0	0	0	L	L	0	0	1	1
0	0	0	0	0	0	L	L	0	0	0	0	2	0
0	0	0	0	0	0	L	L	L	0	0	0	0	2
0	0	0	0	0	0	E	E	0	0	0	0	1	1
0	0	E	E	E	E	0	0	0	0	0	0	2	0

Chapter 6.
Discussion

In order to discuss the results and their application to forensic anthropology, the research questions of this study are reviewed here. This dissertation is mainly concerned with two topics: the prevalence of pathological conditions and the quality of reported medical histories. The questions presented in the Chapter 1 are the following:

1) How accurate is the medical history data reported with the donations?

What kind of conditions are usually reported?
Which conditions are usually not reported but o0bserved?
Which conditions are usually reported but not observed?
Are there differences between self and family-reported data?
How the questionnaires for the donation program could be improved?

2) What are the frequencies of the observed fractures, surgical interventions and other pathological conditions?

Are there differences between sexes and age groups?
Are certain combinations of conditions more common than others?
Can these conditions and combinations be used for personal identification?

The discussion here will follow the order in which the results were presented and questions will be answered when appropriate.

Discussion on reported pathological conditions

The analyzed reported data includes check boxes and longer descriptions of medical histories including fracture information. One hundred and sixty-six individuals have one or more check boxes checked. The most common medical conditions/procedures reported are surgery, fractures, cancer, other condition and smoking. There are some differences found when sex, age, donation type and BMI are taken into account. Sex differences are seen in the number of individuals reporting open heart surgery and alcoholism. These conditions are more common in males, which is true also in living populations (see Langley 2003). Donation type seems to matter in cases of reporting alcoholism and smoking. More alcoholism is reported by family members and more individuals who are self-donors are reported to be smokers. The

validity of self-reported alcohol consumption is an important part of alcohol studies in which the self-reported data can be compared to family reports, official records, interviews and laboratory tests (Midanik 1988). Many factors have been found to affect the validity of self-reported information and thus the findings are varied. In this case findings from Watson et al. (1984) might apply. In their study they found that collaterals reported more uncontrolled drinking than the alcoholist him/herself. BMI seems to affect the number of reported cases of diabetes and other unspecified conditions. The number of individuals with diabetes or other conditions increased in both cases when BMI increased. This is not surprising since being overweight brings several other complications and diabetes has been found to be related to obesity (e.g. Leong & Wilding 1999).

When the longer descriptive medical histories are analyzed the most common reported disease categories are cardiovascular, musculoskeletal and neoplasms (cancer). Cancer and genitourinary conditions are reported more often in females than in males. Most of the conditions affecting genitourinary systems in this study are hysterectomies reported by females. Some cancers have been found to have higher sensitivity in self-reported medical histories. One of these is breast cancer (Navarro et al. 2006), and thus female donations might have a higher reporting rate for cancer in this sample. In addition to sex differences, some age differences are found. More cardiovascular conditions are reported for individuals with increasing age and this reflects the general trend of cardiovascular diseases. On the other hand, mental health issues are more frequently reported for younger individuals. The trend seen in mental health is in accordance with a previous study documenting a decreasing number of self-reported mental health problems with increasing age (Chandola et al. 2007). Older individuals tend to report more physical symptoms but ignore psychiatric problems (Centers for Disease Control and Prevention and National Association of Chronic Disease Directors 2008). There are several factors that can influence reporting of mental health issues and other diseases (e.g. cultural beliefs, see Cole et al. 2009), but these are beyond the focus of this study.

As already mentioned BMI affects the numbers of reported diabetes, and thus the entire endocrine-metabolic disease group. It is also noted that increasing BMI increases the likelihood of reporting conditions affecting the musculoskeletal system. This is

probably due to the large number of joint problems (including osteoarthritis) reported in the medical histories.

Fractures with some kind of location in the skeleton are reported for 55 individuals. Limb bone fractures are most frequently reported in the medical histories, followed by vertebral fractures. The location information is very non-specific and thus might not be very useful in locating the fracture in actual skeleton. Other diseases or conditions affecting the musculoskeletal system that are often reported are arthritis, spine problems and surgical procedures including especially spine surgeries, joint replacements and bone removal.

Thus it can be said based on the results that diseases and conditions mostly found in the reported medical histories are such that have required treatment or major surgical procedures. There are several types of surgeries and conditions listed that have not affected the skeletal remains, for example tonsillectomy, appendectomy, hypertension or gastrointestinal conditions. Fractures are also commonly reported and the questionnaire emphasizes them by providing a separate check box for fractures but also suggest adding descriptions of timing and locations of traumatic injuries.

Discussion on observed pathological conditions

The skeletal remains were examined for any pathological conditions. The results of healed fractures, surgical devices, osteoarthritis, bone lesions, skeletal anomalies and degenerative changes are discussed in this section.

Fractures

One hundred and forty-seven individuals show one or more healed fractures in their skeleton. The highest number of fractures in one individual is 52. The most common body segments for healed fractures are the ribs, spine and cranium. Sex differences are present when the count of fractures in a person is examined: males more often have more than two fractures than females. Males also have more fractures in the cranium, trunk and metacarpals. An age difference is found only in ribs, when increasing age increases the likelihood of having rib fractures.

When individual bones are analyzed, the most commonly fractured bones are the nasals, radius, mid-thoracics and lumbars, and ribs. There are some sex differences that show that males tend to have more fractures on left nasals, right fibula, left ribs 4-7 and 12, right ribs 5 and 6. Sacral fractures are more common in females.

There are only three bones that exhibit age differences and those are the left radius, left pubis, and left 9th rib which are more frequently fractured in older individuals. Radial fractures, especially in the distal shaft, are associated with osteoporosis and thus it is known that its prevalence increases with increased age.

Even though males usually have more fractures, some of the older women in this sample have a high number of fractures (max. 52 fractures). It is important to remember that a history with previous fractures will increase the risk of new fractures. This is especially true in the case of osteoporotic fractures. Prior vertebral fractures specifically are a risk factor for new fractures, not only for other vertebral but also hip fractures (Klotzbuecher et al. 2000).

Surgical devices

Sixty-five individuals in this sample have one or more surgical devices. The most common types of devices seen are wire, plates and replacements, and these can usually be seen in lower limb or trunk. There were no sex differences, but age seemed to increase the odds of having surgical devices in the trunk area and lower limbs. In this aging population it is not surprising to see several open heart surgeries and joint replacements. It has been reported that in 2004 over one million joint replacements were made in the USA (The Burden of Musculoskeletal Diseases in the United States 2008). Also 84 million Americans are reported to have some type of cardiovascular disease (Johns Hopkins Medicine), and for example the number of cardiac valve replacements in 2006 was almost 100 000 (Etzioni & Starnes 2011).

Lesions

Pathological lesions included in the study are bone loss and bone formation. As expected bone formation, i.e. periosteal lesions are more common than bone loss lesions. The areas mostly affected by the lesions are the ribs, lower limbs, cranium and

pelvis. No significant association between age or sex and lesions were seen. Healed periosteal lesions are so commonly seen in skeletons that they were not documented in detail. Nevertheless, it was noted that multiple individuals showed signs of these lesions. In the tibia the healed lesions are located on the medial surface and could be infection or trauma-related. In multiple femora it was noticed that the healed periosteal lesions were located in the lateral surface of the proximal-middle shaft of the femur. This does not seem a likely place for infection and thus it's etiology in greater body mass was considered. Increasing BMI was found to increase the odds of having healed periosteal lesions in both the femora and tibia. This could be the extra bone that has been found in cross-sectional properties in the lower limb bones of obese individuals (see Reeves 2014). However, since it is well-known periosteal lesions can be rarely associated with a specific pathological condition, and they are difficult to detect on x-rays (Weston 2008), these lesions are not going to be useful for identification purposes, if no antemortem records exist.

Osteoarthritis

Osteoarthritis was widely observed in this sample. The most commonly affected joints in this study were the spine, hands, shoulder, wrist and knee. Usually the weight bearing joints, the hip and knee, and hands are among the most affected joints in clinical settings (Litwic et al. 2013; Buckwalter et al. 2004). In this study the arm joints seem to be more involved than normal and more affected than the hip joint. The fact that eburnation is not observed in the hip joint more often here, can be partly due to the large number of femoral head replacements that might have been implanted to fix OA. As expected, the presence of eburnation was associated with increasing age in most of the joints. In addition, eburnation was found to be associated with BMI in the lower limb. This is expected since obesity is known to be one of the risk factors for osteoarthritis, especially in the knee (Sharma et al. 2000; Lementowski & Zelicof 2008). The high prevalence of OA is not surprising since the sample consists of older individuals and it has been estimated that 27 million American exhibit osteoarthritis in at least one of their joints (Lawrence et al. 2008). Also the large number of joint replacements in the USA is mainly due to severe arthritis (The Burden of Musculoskeletal Diseases in the United States 2008).

Discussion on matching the reported and observed conditions

This study aims at answering several questions concerning the reliability of the reported medical history data. This study is interested in the conditions that are reported but not observed and also conditions that are observed but rarely reported. It was hypothesized that females would report their medical history more accurately than males and that self-donors would have more accurate reports than those who were donated by a family member.

As expected, major surgeries and medical procedures are very likely reported correctly. These include open heart surgery, prosthetics and amputations which usually had a high agreement between the reported and observed data. Some clinical studies have suggested high agreement for reporting prosthetics previously (Liu et al. 2007; Parimi et al. 2010). It was also noted that the difference in reporting accuracy between self- and family-donations was small in these major events. This could be explained by the fact that large-scale surgeries requiring hospitalization and recovery are going to be remembered even by the family members. For example, Okura et al. (2004) showed that self-reported medical histories are useful and reliable in cases of major conditions which are life-threatening (stroke) or chronic conditions that require daily care (diabetes). General surgeries are often reported but not observed on the skeletal remains. This discrepancy is easily explained by a large number of surgeries that are not visible in the skeletal record.

General agreement was very low for arthritis and low for fractures. In both cases these conditions were frequently observed but not as often reported. These two conditions were usually more accurately reported by the donor him/herself than by the family members. Sometimes individuals might not even know that a fracture occurred, or since it necessarily does not require as extensive treatment or recovery time as major surgeries they can be easily forgotten by elderly donors and their families. Sex differences in agreement seemed to vary depending on the body segment analyzed so no clear trend is seen here. The highest sensitivity was seen in fractures of the upper and lower limbs, whereas fractures of the ribs, cranium and pelvis were not as accurately reported. Previous studies on self-reported fractures have shown that the validity of the data depends on the fracture site. Reports of fractures of the hip, lower leg, forearm, and

upper arm were in good agreement with the clinical/medical record examination, but spinal, and hand fractures were less so (Chen et al. 2004).

Results of this current study partly correspond to Chen et al.'s findings (limb bones), but also show variability just like previous research. For example, a study on Norwegian data found high validity on self-reported hip fractures, whereas wrist fractures had a lower agreement (Joakimsen et al. 2001). In contrast to this Norwegian study a Finnish study found wrist fractures to be very accurately self-reported by perimenopausal women, but reports on fractures in the toes, fingers and ribs were less accurate (Honkanen et al. 1999). There are fewer studies on family reports on fractures but they have been found to be less accurate than self-reports (Chen et al. 2004).

The low agreement on reported and observed OA is not surprising. Other studies have noticed that patients might not remember what type of rheumatic disease they have been diagnosed with, and thus the prevalence of OA could be underestimated (Busija et al. 2010) or they never had it diagnosed due to the fact that slight pathological changes may not be observed in radiographs and thus the prevalence from the radiographic studies are lower than in studies concentrating on bone surface (Arden & Nevitt 2006). It has been noticed that the reported diseases that were most often in agreement with medical reports are usually familiar chronic diseases that have clear diagnosis, whereas those that disagree are more ambiguous, fluctuating, and not so well known among the lay population (Haapanen et al. 1997). Diabetes has been found to be accurately reported (Huerta et al. 2009; Bush et al. 1989), whereas arthritis and other musculoskeletal diseases have shown some confusion in their reporting (Haapanen et al. 1997, Kehoe et al. 1994).

Other musculoskeletal conditions that are commonly seen in the Bass Donated collection in general are pathological fusions of vertebrae. Some of these might be due to osteophytes, but there are also several individuals with diffuse idiopathic skeletal hyperostosis (DISH) and ankylosing spondylitis (AS). However, there is no report of DISH or AS in the reported medical histories. This is an interesting discrepancy between the reported and observed conditions and might be because the individuals exhibiting these spinal changes do not have a diagnosis for it. Previous studies have shown that rheumatology outpatients reported conditions like AS and rheumatoid

arthritis (RA) accurately unlike regular OA. RA and AS seem to cause more difficulties in everyday life, and thus self-reports on those are more accurate (Rasooly et al. 1995).

In conclusion to answer whether there are conditions that are commonly observed but not reported and vice versa, this study finds that the conditions that are not often reported but are frequently observed include fractures and osteoarthritis. Especially rib and cranial fractures are seen more often than they are reported. No typical medical condition or procedure affecting the skeletal system was found to be often reported but not observed. In addition, some differences in the reported data between donation types are found: The differences in the reporting accuracy between donation types are small in the major conditions but greater when fractures and arthritis are considered (self-donor data more accurate). Sex differences depend on the condition, and no clear trend is seen.

Discussion on combinations

This study examines not only the individual conditions seen on skeletal remains but also their possible combinations in a person. The aim is to tell whether or not these combinations can be used in personal identification and what they can tell us about the skeletal health of modern Americans.

It is evident that the use of combinations of several conditions will be more efficient to distinguish individuals from each other than just using a single condition. When only a basic grouping of individuals into those exhibiting any of these pathological conditions and those not is used, there are only 11 patterns and most of the individuals shared four main patterns. Thus, this kind of division is too basic and will not be useful in narrowing down the possible match in identification. But these combinations reflect the fact that most elderly individuals will have at least one fracture somewhere in their body indicating accidental injuries or osteoporotic fractures. It is also very common to exhibit eburnation somewhere in the joint surfaces, which indicates old age, but also loading of the joints (activity and/or obesity). Naturally, surgical devices and their frequencies are related to fractures and osteoarthritis since these devices are typically used to fix fractures or joints destroyed by OA. Acute skeletal lesions are not as common as the conditions mentioned above. However, healed

periosteal lesions are very common, and some of them, especially in the proximal femora, might be obesity-related.

All the conditions were divided further into body segments and these combinations showed that there are several different patterns. Depending on the condition, the number of patterns with only one individual varied from six to eighteen. Most of the combinations seen only in one person include multiple body segments and thus makes the variability of the patterns greater. This indicates that the combinations rather than individual conditions should be used if personal identification based on skeletal pathological conditions is considered. Komar & Lathrop (2006) state that even the combinations of pathological conditions are not sufficiently unique. The examples they use to show that there are multiple people sharing certain combinations in their sample, include very common features like fractures in the nasals, tibiae, and ribs and open heart surgeries. Naturally the usefulness of these combinations depends on what features and elements are included in the combination. Also which combinations can be used depend on which skeletal elements are found and present for the analysis.

If it is an individual forensic case that these combinations are applied to, also the contextual information matters. There is a reason why this matching identity was proposed (list of missing people, location etc), and as Steadman et al. (2006) suggest using a database with these combinations could be used as a reference to how many other individuals would match these criteria in a larger population. There will very likely be other individuals with the same combinations of conditions in the general population, but are they also on the list of missing people or are they expected to be found in that location where the remains were found. The situation will naturally be different when there are multiple victims with similar biological profiles and similar pathological conditions at the same time. In those cases, distinction might not be possible based on the conditions. For example, a firefighter who died at the WTC attack was misidentified as another firefighter from the same company based on a congenital anomaly observed in the neck. The false identification was based on comparison of the remains and antemortem x-rays in association with circumstancial evidence such as location of the body and a gold chain around neck. However, DNA associated the remains with another firefighter who had been in the same place, wearing similar chain, and exhibiting similar anatomical feature at the same time (Kleinfield 2001).

Even though the current sample is too small to tell which combinations will be sufficiently rare and good for identification purposes, it can tell which combinations are already too common in this sample and thus not necessarily useful. Based on the study ribs and vertebral bodies are the most commonly observed locations for healed fractures. They are also often seen in combination with other fractures. More specific data on locations are needed to make these fracture data useful. In an elderly population replacements and fracture fixations in lower limbs and wires fixing open heart surgery are common, and without AM-radiographs or other details, combinations with other kinds of surgical devices or pathological conditions are required to reduce the frequency of individuals sharing this pattern.

Osteoarthritis is very common in this elderly sample and often seen in multiple joints with vertebral surfaces being one of the components. Lytic lesions do not show a typical combination of lesion sites, whereas active or sclerotic periosteal reactions are usually seen in ribs and in combination with other sites. Healed periosteal reaction is most often seen in lower limb bones.

Limitations and future directions

This study has its limitations. Personal identification in forensic anthropology requires ante- and postmortem data that can be compared. The identification cannot be made unless there is an assumption of who the individual is and some kind of medical records are located. For example, in Calcutta, India, a large number of autopsied bodies remain unidentified. This is due to the large number of homeless people who are very likely away from their family leaving nobody to report them missing (Chattopadhyay et al. 2013). Even if the individual is reported missing, the quality and quantity of the ante-mortem data is crucial. This study compared self- and family-reported medical histories to evaluate what kind of pathological conditions people tend to report and what kind of data is most accurate.

However, the reported data documented for the Bass Donated collection is not totally comparable to missing people reports. First of all, half of the sample was self-reports which will not be available for the missing persons reports. Secondly,

individuals (self-donors, or family-members) usually fill in the questionnaires at home and no additional questions are addressed.

Self-reports were included in the study to see how reliable the medical history data is from the collection documentation and research planning point of view. There are studies on self-reported medical histories in clinical medicine, but they also differ from the Bass Donated collection questionnaire. Those studies tend to use questionnaires that are more straight-forward, asking if you have been diagnosed with the following conditions: e.g. diabetes, hypertension, cancer, and the answering options are “yes” or “no” (e.g. Huerta et al. 2009).

The questionnaires for the Bass Donated collection include some check boxes but additional information can be written in the form and what is written depends on whatever the donor recalls or thinks is useful. This blank space makes the reports and the terminology used in them very varied and difficult to standardize. Hennessey (2008) discusses typical problems in data collection in mass fatalities. He points out that the questions used in the questionnaires should be clear to avoid misunderstandings and check boxes should be used to avoid nonstandardized answers. If open questions are used, they and the corresponding answers should be in a form that can be easily coded (Samuels 2008).

It is also very likely that a personal interview rather than a questionnaire would result in more detailed reported data. This is especially true when reporting minor conditions/diseases. Bergmann et al. (2004) compared self-reported data between a baseline interview and a follow-up questionnaire, and they found that the agreement on reports of cancer, diabetes and myocardial infarction was high but much lower with diseases with less definitive diagnosis or definition. Naturally, personal interviews are not a feasible option for the Bass Donated data collection.

Another limitation of the study is that the results can be applied to a very limited section of a population. The sample is small and concentrates on older individuals. More individuals should be added to the sample, especially younger individuals in order to make the data applicable for forensic cases. Also other ancestries should be added to the sample. Nevertheless, both of these additions may require use of identified individuals from forensic collections instead of donated collections. This study can serve as a pilot study to guide what kind of data should be collected for a larger

pathological conditions/surgical procedures database. In the long run this database could serve as a beginning for a computer program like OdontoSearch.

This current research was done by an anthropologist without medical training, thus some surgeries with slight modification of bone might have not been correctly interpreted. It is important that different disciplines collaborate in personal identification (e.g. Lorkiewicz-Muszynska et al. 2013; Skinner et al. 2010; Tinoco 2010; Scheuer & Black 2007; Cunha et al. 2006), especially if medical conditions or surgical evidence are present (Milroy 2007; Clarkson & Schaefer 2007). In the future collaboration with medical specialists should be considered to evaluate the material. In addition, x-rays should be used, especially when lytic lesions are examined, but also for elements that were reported to have fractures but none was observed.

Another aspect which would be worth investigating is a possible secular change in the prevalence of these pathological conditions. By comparing the current sample to an older skeletal collection it might be easier to tease out different factors (e.g. type of work, activities and diet-related health issues) influencing skeletal health, and make more robust interpretations on the quality of life of these individuals.

Practical implications of this study for data collection and identification

This study is an essential step for a validation of the collected information for the Bass Donated Collection. Medical data can be used to select research samples (e.g. cancer, diabetes) and thus, it is important that the information associated with the skeletal remains is as reliable as possible. The following recommendations would improve the quality of data reported by donors.

Based on this and previous studies (Hennessey 2008) the reported data is more detailed if the questions are clear and specific. In order to improve the medical history data collected for the Bass Donated collection some changes in the questionnaire should be made. For example, instead of having a blank space for a medical history description, check boxes could be used especially for musculoskeletal conditions that can be observed in the skeletal remains. Due to the large number of different rheumatic diseases and their impact on the skeleton, it would be useful to add a check box for rheumatic diseases followed by a line where donors could specify what the condition

actually is. In addition, a sketch outlining a human body might be useful for the donors to mark the locations of fractures or surgeries (as is used in the OCME NYC's missing person reports, personal communication with Dr. Benjamin Figura 2012). This would help to standardize the wide variety of locations reported in the additional information.

Conclusions

The research questions and the results have been discussed above, but the gist of the conclusions is summarized here. There are differences in the odds of presenting certain pathological conditions between sex, age and BMI. Males have more fractures in three body segments, cranium, upper trunk and metacarpals, than females. Individual bones showing more fractures in males are left nasal, right fibula and certain ribs on both sides, whereas sacrum is more often fractured in females. More fractures are seen in ribs, left radius and left pubis in older individuals. Surgical devices indicate only age differences, i.e. more devices observed in trunk and lower limbs in older individuals. These devices are mainly related to open heart surgeries and joint replacements which tend to be associated with advancing age.

Observed lytic or periosteal lesions show no age or sex differences but healed periosteal lesions are more common in femora and tibiae of individuals with higher BMI. As expected, osteoarthritis is more common in older individuals in most body segments, especially in shoulder, wrist and thumb. Also increasing BMI is increasing the odds of showing eburnation in lower limbs. Degenerative changes, including sacroiliac fusion, Schmorl's depressions and pathological fusions, show sex differences, since they are found to be more common in males. Pathological fusions seem to be influenced by age and BMI as well; their prevalence increases with increasing age and BMI. Skeletal anomalies do not seem to be influenced by sex or age, except females show more often enlarged nasal turbinates than males.

The accuracy of the reported medical histories depends on the reported conditions. Major surgical procedures such as replacement or open heart surgeries are quite reliably reported, whereas smaller procedures or conditions are not. Thus, the assumptions behind the questions asked in this research are found to be valid only partially. The assumption of major health problems being reported more accurately than minor ones is

supported by the study, and also self-reports are found to be slightly more accurate on minor conditions than family reports as assumed. The accuracy of the medical reports is not found to be consistent enough to support the assumption that female reports are more accurate than male reports. Pathological conditions and their patterns may be useful in personal identification depending on the observed condition, skeletal elements and also on the type of the medical history present for comparison. The more elements are included, the more variation in combinations can be seen. Larger samples concentrating on healed fractures and surgical procedures are necessary to create a systematic database.

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Appendices

APPENDIX 1.

Forensic Anthropology Center
University of Tennessee, Knoxville
Body Donation Questionnaire
Please complete the following information by filling in the blank and/or circling an option.
If you need more space, additional sheets may be attached.
All of the information will be considered confidential.

Name ________________ / ________________ / ____________ **Sex:** male___ female___
Last / First / Middle

Social Security #______ —_____—_______ **Race:** White / Black / Hispanic / Other______________
(circle one)

Date of Birth____/____/_____ **Age** ____ **Place of Birth (city/state)**______________________

Home Address ____

City ______________________ **County**_________________ **State** ____ **Zip** _________

Phone Number______________________ **Inside City Limits:** yes ___ no___

Mother's Name (include maiden) ___________________________ **Place of Birth**______________

Father's Name ____________________________________ **Place of Birth**______________

Driver's License Height _______ **Weight** _______ **Recent Weight Loss:** yes ___ no___

Handedness: Right ___ Left___ **Shoe size** ____ **Blood Type** _______ **Hair Color**_________
(natural)

Marital Status: (circle one) Never Married Married Widowed Divorced Unknown Other

Spouse: _________________ / _____________ / ____________ Living__ Deceased__ Unknown__
Last (include maiden) / First / Middle

Number of Children: ______

Highest Education Level (indicate number of years) **Military Service:** yes ___ no___
Elem/Second (0-12): ______ College (1-4; 5+): ______

Childhood Socio-Economic Status: (circle one) Lower Lower Middle Middle Upper Middle Upper

Usual (life-long) Occupation _________________ **Business/Industry** ___________________

Residence History (list additional locations as necessary)

Childhood Hometown (0-15 years of age):
City _______________ State ____ Start Date ____ End Date _____
City _______________ State ____ Start Date ____ End Date _____
City _______________ State ____ Start Date ____ End Date _____

Location as an Adult (any place you have lived for more than 1 year)
City _______________ State ____ Start Date ____ End Date _____
City _______________ State ____ Start Date ____ End Date _____
City _______________ State ____ Start Date ____ End Date _____
City _______________ State ____ Start Date ____ End Date _____

PLEASE CONTINUE ON NEXT PAGE

Version 5: 12_2009

Name ________________ /________________ / ______________
Last First Middle

Dental History – Check all that apply

☐ **Extensive Dental work**
☐ **Lower Dentures: When**________
☐ **Upper Dentures: When**________
☐ **Upper and Lower Dentures: When**________
☐ **Partial Plate**
☐ **Braces**

☐ **Most/all teeth**
☐ **Bridge**
☐ **Gum Disease**
☐ **Dental Disease**
☐ **Other** ____________________

Teeth Missing
☐ **Few**
☐ **Many**
☐ **All**

Medical History (please indicate the approximate year for each). Please do not provide just a Doctor's name.

☐ Surgery (general) ____________________

☐ Fractures ____________________

☐ Auto Accident (traumatic)

☐ Spinal Injuries

☐ Open Heart Surgery
☐ Amputations

☐ Prosthetics (e.g. Hip or knee replacement)
When:______________

☐ Plastic Surgery (indicate type and location) ____________________

☐ Cancer (type) ____________________
Treatment: ____________________
Length of Illness: ____________________

☐ Smoker If yes, how long?____________________

☐ Alcoholism

☐ Diabetes Type:__________

☐ Other (Including childhood disorders) ____________________

Medical History (continued) –

Please describe the above and any other information you feel may be important, including current medications, timing of injuries, the locations of traumatic injuries, or a family history of an illness, etc. Please attach additional pages as necessary.

Habitual Activities

(i.e., jogging, repetitive motions, life-long occupation activities, etc.) -

PLEASE CONTINUE ON NEXT PAGE

Version 5: 12_2009

Name ____________________ / ________________ / _______________
Last First Middle

Eye Color	☐	Blue	☐	Green	☐	Gray	☐	Brown	☐	Hazel	☐	Other ________

Tattoo(s)	☐ Yes	If yes,	Description:	____________________
	☐ No		Body Location:	____________________
Body Piercing(s)	☐ Yes	If yes,	Description:	____________________
	☐ No		Body Location:	

Next of Kin Information

Name ____________________________________ Relationship ______________________________

Address ____________________________________ Phone number ______________________________

City ________________ State ____ Zipcode _________ email: __________________________

Informant Information (if other than donor or Next of Kin)

Name ____________________________________ Relationship ______________________________

Address ____________________________________ Phone number ______________________________

City ________________ State ____ Zipcode _________ email: __________________________

DO NOT CONTINUE IF YOU ARE A LIVING DONOR

Location of death (if applicable) **Date of Death** _____________

Institution/Hospital ____

Address ____

City ________________ County ___________ State ____ Zip code ________

Thank you for taking the time to fill out this questionnaire.
If we can be of further assistance, please feel free to contact us.

Return completed forms to:
Dr. Lee Meadows Jantz
Department of Anthropology
250 South Stadium Hall, Knoxville, TN 37996-0720
email: donateinfo@utk.edu
phone: (865) 974-4408

Version 6:8_2012

APPENDIX 2.

Coding system

Fractures (all the bones, except hands and feet phalanges)

Inventory
1= present
2= absent
3= fragmentary
4= congenitally missing

Fracture
1= antemortem
2= perimortem/postmortem

Vertebral body
1= compression
2= single end-plate depression without wedging
3= single end-plate depression with wedging
4= biconcave body
5= more than above
6= other

Location

Long bones
1= proximal 1/3 shaft
2= middle 1/3
3= distal 1/3
4= proximal joint
5= distal joint
6= more than one above

Clavicle
1= medial 1/3
2= lateral 1/3
3= middle

Skull
bone

Mandible
1= body
2= ramus

Scapula
1= glenoid cavity
2= blade
3= acromion
4= coracoid

Sacrum
segment number

Vertebrae
1= body

	2= spinous process
	3= transverse process
	4= arch
Ribs	1= sternal end 1/3
	2= middle 1/3
	3= vertebral end 1/3
Remodeling	1= no healing
	2= healing
	3= healed
	4= multiple types
Severity	1= incomplete (not in two pieces)
	2= complete (two or more pieces)
	3= both
	4= unknown
Union	1= incomplete union
	2= pseudoarthrosis
	3= complete union
	4= multiple
Alignment	1= good alignment
	2= malalignment
	3= both
Surgical device	1=present

Bone lesions (all the bones, except hands and feet)

General	1= bone loss
	2= bone formation
	3= both
Type	Loss
	1= resorptive lesion (lytic)
	2= porosis (pinpoint to coalesced)
	3= osteopenia/osteoporosis
	4= surgical

5= erosion

Formation
1= periosteal reaction
2= osteomyelitis
3= neoplasm (tumor)
4= ossified connective tissue (myositis ossificans)
5= periosteal + osteomyelitis
6= periosteal + lytic/porous

Location

Long bones
1= proximal 1/3 shaft
2= middle 1/3
3= distal 1/3
4= proximal joint
5= distal joint
6= more than one above

Skull	bone
Mandible	1= body
	2= ramus
Scapula	1= glenoid cavity
	2= blade
	3= acromion
	4= coracoid
	5= other
	6= multiple
Sacrum	segment number
Os coxa	1= anterior surface
	2= posterior surface
	3= both
Vertebrae	1= body
	2= spinous process
	3= transverse process
	4= arch
Ribs	1= sternal end 1/3
	2= middle 1/3
	3= vertebral end 1/3

	4= multiple
Clavicle	1= medial 1/3
	2= lateral 1/3
	3= middle 1/3
Aspect	1= superior
	2= inferior
	3= both superior and inferior
	4= medial
	5= lateral
	6= both medial and lateral
	7= posterior/dorsal
	8= anterior/ventral
	9= circumferential
	10= multiple
Remodeling	1= active
	2= healed
	3= both
	4= sclerotic
Involvement	1= localized
	2= widespread
Severity	1= mild, small discrete area involving less than ¼ of the bone/bone surface
	2= moderate, area involving less than ½ of the bone/bone surface
	3= severe, area involving more than ½ of the bone/bone surface
	4= multiple

Osteoarthritis (TMJ, vertebrae, sacrum, innomates, long bones, patella)

Eburnation	
Location	1= surface
	2= margin
	3= both
Vertebrae	
Location1	1= facets

	2= body
	3= both
Location2	1= end-plate
	2= margin
	3= both
Sacrum	
Location1	1= promontory
	2= facets
	3= both
Location2	1= surface
	2= margin
	3= both
Degree	1= barely discernible
	2= polish only
	3= polish with grooves
Extent	1= <1/3 of the surface
	2= 1/3-2/3
	3= >2/3

Extent in vertebrae

1= one upper facet affected
2= both upper facets affected
3= one lower facet affected
4= both lower facets affected
5= both upper and lower facets affected

Hands and feet scored as 1= present

Surgical devices (All bones, except hands and feet)

Location

Long bones	1= proximal 1/3 shaft
	2= middle 1/3
	3= distal 1/3
	4= proximal joint
	5= distal joint
	6= more than one above
Skull	bone
Scapula	1= glenoid cavity
	2= blade

	3= acromion 4= coracoid
Sacrum	segment number
Vertebrae	1= body 2= spinous process 3= transverse process 4= arch
Ribs	1= sternal end 1/3 2= middle 1/3 3= vertebral end 1/3
Type	1= replacement 2= plate 3= rod 4= wire 5= screw 6= suture 7= staple 8= pin 9= clamp 10= multiple 11= other
Material	1= metal 2= plastic 3= thread 4= metal and plastic 5= other 6= metal and thread

Model data reported in comments if specific data can be seen

Number of screws and holes in the plates/etc

Other conditions; skeletal anomalies, degenerative changes

1= present
2= not observable

Comments: description of the conditions including location (bone, side, vertebrae/rib number), inferior/superior surface, severity of the condition

Sacroiliac fusion
Schmorl’s nodes

Pathological fusions
Congenital fusions
Bifid ribs
Cleft vertebrae
Spina bifida
Spondylolysis
Sternal aperture
Os acromiale
Button osteoma
Mandibular torus
Palatine torus
Enlarged nasal turbinate

APPENDIX 3.

Table A- 1. Reported fractures by location.

	Self females	Family females	Self males	Family males	Total
Cranium	1	0	1	2	4
R leg	1	0	2	2	5
L leg	0	0	1	1	2
R arm	2	0	0	1	3
L arm	2	1	3	0	6
R lower leg	0	1	1	0	2
R lower arm	0	0	1	0	1
L lower arm	0	0	1	0	1
R humerus	1	0	0	0	1
L foot	2	0	0	0	2
L humerus	0	0	1	0	1
R ankle	1	0	0	0	1
L ankle	2	0	0	0	2
R foot	1	0	0	0	1
L wrist	0	0	2	0	2
R clavicle	0	0	1	0	1
R patella	0	0	1	0	1
L ribs	0	0	1	0	1
Spine	5	1	2	1	9
Coccyx	2	0	0	0	2
R pelvis	1	0	0	0	1
L pelvis	1	0	0	0	1
Total	22	3	18	7	50

Table A- 2. Reported fractures without detailed location.

	Self females	Family females	Self males	Family males	Total
Shoulder	0	2	0	0	2
Ribs	1	1	2	0	4
Leg	2	0	0	3	5
Wrist	1	2	0	0	3
Toe	1	0	1	0	2
Finger	1	1	2	0	4
Clavicle	1	0	0	1	2
Unclear	0	1	4	1	6
Hip	0	0	2	0	2
Ankle	0	2	1	1	4
Arm	0	2	0	1	3
Knee	0	1	0	0	1
Total	7	12	12	7	38

Table A- 3. Observed fractures in cranium.

	N		Individuals with fx		Maximum count			N		Individuals with fx		Maximum count	
	F	M	F	M	F	M		F	M	F	M	F	M
Frontal	89	88	0	2	0	1	Occipital	88	89	0	0	0	0
Parietal L	88	87	0	2	0	1	Maxilla L	89	87	2	7	1	1
Parietal R	88	88	0	2	0	1	Maxilla R	89	86	1	4	1	1
Temporal L	88	88	0	1	0	1	Nasal L*	85	89	9	20	1	2
Temporal R	89	86	0	1	0	1	Nasal R	85	88	9	16	1	2
Zygomatic L	88	88	0	2	0	1	Mandible L	89	89	0	1	0	1
Zygomatic R	89	88	0	0	0	0	Mandible R	89	89	0	2	0	1

Table A- 4. Observed fractures in trunk and pelvis.

	N		Individuals with fx		Maximum count			N		Individuals with fx		Maximum count	
	F	M	F	M	F	M		F	M	F	M	F	M
Manubrium	86	83	1	0	1	0	Ilium L	90	9	0	0	0	0
Sternal body	81	85	2	3	1	1	Ilium R	90	9	0	1	0	1
Scapula L	88	86	0	2	0	1	Ischium L	90	9	1	2	1	1
Scapula R	88	85	0	3	0	1	Ischium R	90	9	1	0	1	0
Clavicle L	90	88	0	2	0	1	Pubis L	90	9	2	2	1	1
Clavicle R	89	88	0	4	0	1	Pubis R	90	9	2	3	1	1
Sacrum	84	86	8	1	1	1	Acetabulum L	90	9	0	0	0	0
							Acetabulum R	90	9	1	1	1	1

Table A- 5. Observed fractures in long bones.

	N		Individuals with fx		Maximum count			N		Individuals with fx		Maximum count	
	F	M	F	M	F	M		F	M	F	M	F	M
Humerus L	89	89	2	5	1	1	Femur L	89	88	2	4	1	1
Humerus R	90	90	2	3	1	1	Femur R	89	89	3	1		
Radius L	89	88	5	5	1	1	Tibia L	90	89	1	3		
Radius R	87	90	9	7	1	1	Tibia R	89	86	4	7		
Ulna L	88	88	1	4	1	1	Fibula L	90	88	2	3		
Ulna R	89	90	1	5	1	1	Fibula R	86	87	2	9	1	2
							Patella L	84	83	2	1		
							Patella R	83	85	0	2		

Table A- 6. Observed fractures in metacarpals and metatarsals.

	N		Individuals with fx		Maximum count			N		Individuals with fx		Maximum count	
	F	M	F	M	F	M		F	M	F	M	F	M
MC1 L	85	83	0	2	0	1	MT1 L	81	84	2	0	1	0
MC2 L	88	85	1	0	1	0	MT2 L	83	84	4	2	1	1
MC3 L	87	84	0	1	0	1	MT3 L	84	81	4	0	1	0
MC4 L	87	83	0	1	0	1	MT4 L	76	78	2	0	1	0
MC5 L	83	78	1	2	1	1	MT5 L	74	71	5	2	2	1
MC1 R	82	86	0	1	0	1	MT1 R	78	81	2	0	1	0
MC2 R	81	87	0	0	0	0	MT2 R	81	81	1	1	1	1
MC3 R	86	84	0	0	0	0	MT3 R	81	79	0	1	0	1
MC4 R	83	84	0	0	0	0	MT4 R	79	79	0	0	0	0
MC5 R	81	85	3	8	1	1	MT5 R	79	79	4	4	1	1

Table A- 7. Observed fractures in the vertebrae.

	N		Individuals with fx		Maximum count			N		Individuals with fx		Maximum count	
	F	M	F	M	F	M		F	M	F	M	F	M
C1	85	88	0	0	0	0	T6	90	88	7	5	1	1
C2	86	87	0	0	0	0	T7	90	87	4	9	1	1
C3	90	87	0	0	0	0	T8	90	87	6	6	1	1
C4	86	85	0	1	0	1	T9	89	87	3	7	1	1
C5	87	86	1	1	1	1	T10	88	89	4	3	1	1
C6	88	87	1	1	1	1	T11	89	89	5	3	1	1
C7	90	89	1	2	1	1	T12	89	88	6	3	1	1
T1	89	90	2	0	1	0	L1	89	89	9	9	1	1
T2	89	90	5	1	1	1	L2	90	88	1	3	1	1
T3	89	90	7	2	1	1	L3	88	88	6	4	1	1
T4	89	90	6	3	1	1	L4	87	90	5	5	1	1
T5	89	89	7	4	1	1	L5	90	89	3	4	1	1

Table A- 8. Observed fractures in the ribs.

	N		Individuals with fx		Maximum count			N		Individuals with fx		Maximum count	
	F	M	F	M	F	M		F	M	F	M	F	M
Rib 1 L	83	86	0	2	1	1	Rib 1 R	87	87	1	2	1	1
Rib 2 L	76	82	4	11	2	1	Rib 2 R	81	82	5	8	1	2
Rib 3 L	75	78	8	10	1	1	Rib 3 R	80	81	11	10	2	3
Rib 4 L	72	76	7	16	3	2	Rib 4 R	77	81	9	16	3	2
Rib 5 L	74	77	8	22	2	3	Rib 5 R	75	82	7	18	1	3
Rib 6 L	73	80	8	19	2	3	Rib 6 R	72	72	8	21	3	3
Rib 7 L	77	85	8	21	2	3	Rib 7 R	80	81	10	16	1	2
Rib 8 L	75	83	14	15	2	3	Rib 8 R	79	82	11	14	1	2
Rib 9 L	76	86	11	18	2	3	Rib 9 R	82	81	10	17	2	3
Rib 10 L	81	85	11	16	2	3	Rib 10 R	80	85	6	9	2	3
Rib 11 L	81	86	0	10	0	2	Rib 11 R	80	87	5	10	1	2
Rib 12 L	74	75	1	9	1	2	Rib 12 R	76	72	3	5	1	2

Table A- 9. Observed surgical devices in the cranium

	Females	Males		Females	Males
Frontal	N=89	N=90	MaxillaL	N=89	N=90
Wire	0	1	Plate	1	1
Multiple	0	1	Wire	0	1
ParietalL	N=89	N=90	Other	0	2
Plate	0	1	MaxillaR	N=89	N=90
Wire	0	1	Plate	1	1
ParietalR	N=89	N=90	Wire	0	1
Clamp	0	1	MandibleL	N=89	N=89
Wire	0	1	Plate	0	1
ZygomaticL	N=88	N=90	Wire	0	1
Plate	0	2	MandibleR	N=89	N=89
ZygomaticR	N=89	N=89	Plate	0	1
Plate	0	1	Wire	0	1
Wire	1	0	Other	1	0

Table A- 10. Surgical devices in long bones.

	Females	Males		Females	Males
HumerusL	N=89	N=90	FemurR	N=89	N=90
Suture	0	1	Replace	3	2
HumerusR	N=90	N=90	Plate	1	1
Suture	0	1	Rod	1	0
Pin	1		Screw	0	2
RadiusL	N=89	N=89	Pin	1	0
RadiusR	N=89	N=90	TibiaL	N=90	N=89
Plate	0	1	Replace	1	1
Pin	0	1	Screw	1	1
UlnaL	N=90	N=89	TibiaR	N=89	N=89
Plate	0	1	Replace	1	0
UlnaR	N=90	N=90	Screw	1	1
Plate	1	1	FibulaL	N=90	N=89
FemurL	N=89	N=90	FibulaR	N=89	N=87
Replace	3	1	Plate	0	1
Plate	2	3			
Rod	1	0			
Pin	0	1			

Table A- 11. Surgical devices in trunk, pelvis, spine, patella, metacarpals and metatarsals.

	Females	Males		Females	Males
Manubrium	N=86	N=87	AcetabulumL	N=90	N=90
Wire	7	13	Replace	1	0
Multiple	1	0	AcetabulumR	N=90	N=90
Sternalbody	N=86	N=88	Replace	1	0
Wire	6	13	PatellaL	N=84	N=84
Multiple	1	0	Replace	0	1
PubisL	N=90	N=90	Wire	1	0
Multiple	1	0	PatellaR	N=83	N=85
PubisR	N=90	N=90	Replace	1	1
Multiple	1	0	L MCs	N=78	N=74
Cervicals	N=81	N=78	Pin	0	1
Plate	2	1	L MTs	N=68	N=65
Rod	0	1	Screw	1	0
Thoracics	N=85	N=87	R MTs	N=75	N=73
Other	1	0	Plate	1	0
Lumbars	N=87	N=88	Screw	2	0
Rod	1	0	Suture	0	1
Other	1	0			

Table A- 12. Observed lesions in the cranium.

	N		Loss		Formation		Both	
	F	M	F	M	F	M	F	M
Frontal	89	90	0	1	1	0	0	0
Parietal L	89	90	1	1	0	0	0	0
Parietal R	89	90	1	3	0	1	0	0
Occipital	89	90	3	0	0	0	0	0
Temporal L	89	90	0	1	0	0	0	0
Temporal R	89	90	0	1	0	0	0	0
Zygomatic L	88	90	0	0	0	1	0	0
Zygomatic R	89	89	0	0	0	1	0	0
Maxilla L	89	90	0	0	2	3	1	1
Maxilla R	89	90	0	0	1	2	0	0
Mandible L	89	89	1	1	2	1	0	0
Mandible R	89	89	0	0	4	4	0	0

Table A- 13. Observed lesions in the trunk and pelvis.

	N		Loss		Formation		Both	
	F	M	F	M	F	M	F	M
Manubrium	86	87	0	0	4	4	0	0
Sternal body	86	88	1	1	0	0	0	0
Scapula L	90	89	2	0	4	2	1	0
Scapula R	90	89	4	1	4	1	1	1
Clavicle L	90	89	1	0	1	1	0	0
Clavicle R	90	89	2	0	1	0	0	0
Sacrum								
Ilium L	90	90	4	5	4	4	0	1
Ilium R	90	90	2	2	3	2	1	0
Ischium L	90	90	0	0	0	2	0	0
Ischium R	90	90	0	1	0	0	0	1
Pubis L	90	90	0	0	0	1	0	0
Pubis R	90	90	0	0	1	0	0	0
Acetabulum L	90	90	0	0	0	1	0	1
Acetabulum R	90	90	1	0	0	0	0	0

Table A- 14. Observed lesions in the long bones.

	N		Loss		Formation		Both	
	F	M	F	M	F	M	F	M
Humerus L	89	90	1	2	0	1	0	0
Humerus R	90	90	2	0	0	4	0	0
Radius L	89	89	2	0	2	1	0	1
Radius R	88	89	2	0	2	1	0	0
Ulna L	90	89	0	0	1	0	0	0
Ulna R	90	90	0	0	1	0	0	0
Femur L	89	90	1	0	6	5	0	0
Femur R	89	90	4	0	4	6	1	1
Tibia L	90	89	0	0	10	7	0	0
Tibia R	89	89	0	1	10	6	0	0
Fibula L	90	89	0	0	3	3	0	0
Fibula R	89	87	0	1	3	3	0	0

Table A- 15. Observed lesions in the ribs.

	N		Loss		Formation		Both	
	F	M	F	M	F	M	F	M
Rib1 L	86	86	0	0	1	1	0	0
Rib2 L	79	82	1	0	1	0	1	1
Rib3 L	78	82	2	0	1	4	1	0
Rib4 L	77	78	1	0	3	5	1	0
Rib5 L	80	81	1	0	5	6	1	0
Rib6 L	82	83	2	0	6	7	0	0
Rib7 L	80	84	2	0	3	7	1	1
Rib8 L	81	84	4	0	2	8	0	0
Rib9 L	81	86	2	0	3	7	0	0
Rib10 L	89	89	0	0	1	5	0	0
Rib11 L	87	88	1	0	1	3	0	0
Rib12 L	76	77	0	0	0	0	0	0
Rib1 R	88	90	0	0	0	0	0	0
Rib2 R	85	87	1	0	1	1	0	0
Rib3 R	83	86	3	1	1	2	0	0
Rib4 R	81	86	3	2	4	3	0	0
Rib5 R	81	85	1	1	6	8	1	0
Rib6 R	78	74	0	0	8	10	2	0
Rib7 R	82	87	1	0	9	9	0	1
Rib8 R	85	87	1	1	11	9	0	0
Rib9 R	86	88	1	0	7	9	0	0
Rib10 R	86	85	1	0	5	6	0	0
Rib11 R	85	87	0	0	3	4	0	0
Rib12 R	77	74	0	0	1	0	0	0

Table A- 16. Observed eburnation in the cranium and vertebrae.

	N		Individuals with OA			N		Individuals with OA	
	F	M	F	M		F	M	F	M
Temporal L	89	90	2	1	T5**	90	90	11	8
Temporal R	89	90	1	1	T6**	90	90	10	3
Mandible L	89	89	1	1	T7**	90	90	7	6
Mandible R	89	89	1	1	T8	90	89	7	5
C1**	88	86	19	22	T9**	89	88	9	8
C2**	87	88	25	31	T10	89	90	8	8
C3**	90	87	32	30	T11	90	90	13	8
C4**	86	86	33	28	T12	90	89	10	7
C5**	87	86	28	22	L1**	90	90	10	4
C6**	88	87	22	11	L2**	90	89	14	9
C7**	90	88	26	20	L3**	90	90	19	21
T1**	89	90	25	19	L4**	89	90	35	31
T2**	89	90	14	8	L5**	88	89	39	29
T3	89	90	15	6	S1**	90	90	20	13
T4	90	90	18	10					

Table A- 17. Observed eburnation in the trunk, pelvis and long bones. P= proximal, D= distal.

	N		Individuals with ebur			N		Individuals with ebur	
	F	M	F	M		F	M	F	M
Glenoid L**	90	90	5	3	Acetabulum L	90	90	1	0
Glenoid R**	90	90	6	3	Acetabulum R	90	90	2	0
Humerus P L**	89	90	5	2	Femur P L	89	90	2	0
Humerus P R**	90	90	6	4	Femur P R	89	90	2	0
Humerus D L	89	90	3	3	Femur D L	89	90	8	3
Humerus D R	90	90	1	2	Femur D R	89	90	8	5
Radius P L	89	89	1	3	Tibia P L	90	89	6	1
Radius P R	89	90	1	2	Tibia P R	89	89	5	5
Radius D L**	89	89	3	5	Tibia D L	89	89	0	0
Radius D R**	89	90	3	7	Tibia D R	89	89	0	1
Ulna P L	90	89	2	0	Patella L**	84	84	4	1
Ulna P R	90	90	0	0	Patella R**	83	85	3	1
Ulna D L**	90	89	4	4					
Ulna D R	90	90	1	5					

Table A- 18. Observed eburnation in the metacarpals, metatarsals and greater multangulars.

	N		Individuals with eburnation			N		Individuals with eburnation	
	F	M	F	M		F	M	F	M
MC1 L**	84	83	18	18	MT1 L**	82	84	6	9
MC2 L**	88	85	2	2	MT2 L	83	84	1	0
MC3 L	88	84	3	3	MT3 L	85	81	0	0
MC4 L	88	83	1	1	MT4 L	77	78	0	1
MC5 L	84	83	1	0	MT5 L	78	76	0	1
MC1 R**	83	86	16	17	MT1 R**	80	82	7	10
MC2 R**	81	87	5	4	MT2 R	83	83	0	0
MC3 R	86	84	4	4	MT3 R	83	81	0	0
MC4 R	83	85	1	0	MT4 R**	83	81	2	1
MC5 R	81	86	1	0	MT5 R	81	80	3	0
G multangular L**	71	72	17	15					
G multangular R**	68	72	11	13					

Table A- 19. Matched reported and observed main conditions.

	Donation type	N		True positive		False negative		True negative		False positive	
		F	M	F	M	F	M	F	M	F	M
Surgery	Self	45	45	12	11	2	9	11	18	20	7
	Family	45	45	6	8	12	11	16	17	11	9
Open heart	Self	45	45	1	6	2	2	42	36	0	1
	Family	45	45	2	5	4	0	38	40	1	0
Prosthetics	Self	45	45	1	0	0	2	44	43	0	0
	Family	45	45	2	0	2	0	41	44	0	1
Amputation	Self	45	44	1	2	0	0	44	41	0	1
	Family	44	44	0	0	1	1	43	43	0	0
Fractures	Self	45	45	12	15	24	22	7	8	2	0
	Family	45	45	8	10	29	29	4	6	4	0
Arthritis	Self	39	38	2	4	32	30	4	4	1	0
	Family	34	33	3	2	27	30	3	0	1	1

Table A- 20. Matched reported and observed fractures.

	Donation type	N		True positive		False negative		True negative		False positive	
		F	M	F	M	F	M	F	M	F	M
Cranium	Self	41	43	0	1	6	9	34	33	1	0
	Family	43	42	0	1	7	16	34	24	0	1
Trunk	Self	39	43	0	1	3	3	35	39	1	0
	Family	39	35	0	0	0	6	39	28	0	1
Upper limb	Self	41	44	1	4	6	4	31	34	3	2
	Family	43	43	2	2	6	8	30	33	5	0
Spine	Self	42	39	3	1	15	18	22	19	2	1
	Family	37	37	0	1	19	9	17	27	1	0
Ribs	Self	30	36	1	3	23	25	6	8	0	0
	Family	29	36	1	0	21	28	7	8	0	0
Pelvis	Self	42	45	1	0	4	3	37	42	0	0
	Family	42	40	0	0	7	5	35	35	0	0
Lower limb	Self	40	41	2	2	3	5	32	29	3	5
	Family	39	41	3	3	7	11	29	25	0	2
Feet	Self	31	29	0	0	5	5	23	24	3	0
	Family	29	27	0	0	6	4	23	23	0	0
Hands	Self	38	34	0	0	2	5	36	27	0	2
	Family	29	32	0	0	2	9	26	23	1	0

Table A- 21. Surgical devices by body segments. C= cranium, T= trunk, A= upper limb, P= pelvis, L= lower limb, S= spine. Continuation of Table 29.

C	T	A	P	L	S	Females	Males
0	1	0	0	0	1	1	1
0	0	0	1	0	0	1	0
0	0	0	0	0	1	1	0
0	0	0	1	1	1	1	0
0	1	0	0	1	0	1	0
0	0	0	0	1	1	0	1
1	0	1	0	0	0	0	1

Table A- 22. Osteoarthritis by body segments. C= cranium, T= trunk, A= upper limb, P= pelvis, L= lower limb, S= spine. Continuation of Table 30.

C	A	P	L	S	Females	Males
0	0	0	1	1	2	1
0	0	1	1	1	3	0
0	1	0	0	1	0	3
0	1	0	1	1	0	3
0	1	1	1	1	2	0
0	1	0	1	0	1	0
1	0	1	0	1	1	0
0	0	0	1	0	0	1
0	1	0	0	0	0	1
1	1	0	1	1	0	1
0	1	1	1	1	0	1

Table A- 23. Lytic lesions by body segments. C= cranium, T= trunk, A= upper limb, P= pelvis, L= lower limb, S= spine, R= ribs. Continuation of Table 31.

C	T	A	P	L	S	R	Females	Males
0	1	0	0	0	0	0	0	1
0	0	0	1	0	1	0	1	0
0	1	0	0	0	1	1	1	0
0	1	1	0	0	0	0	1	0
1	1	0	1	0	0	1	1	0
0	0	1	0	0	0	1	0	1
1	1	0	1	0	0	0	0	1
1	0	0	1	0	0	0	0	1
1	0	0	0	0	1	1	0	1
0	0	0	0	1	1	0	0	1
1	0	0	1	0	1	1	0	1

Table A- 24. Bone formation lesions by body segments. C= cranium, T= trunk, A= upper limb, P= pelvis, L= lower limb, S= spine, R= ribs. Continuation of Table 32.

C	T	A	P	L	S	R	Females	Males
0	0	0	0	0	1	0	1	0
0	0	0	1	0	0	0	1	0
0	1	0	0	0	0	0	1	0
0	1	0	0	1	0	1	1	0
1	0	0	0	0	0	0	1	0
1	1	1	1	1	0	1	1	0
1	1	0	0	1	0	1	0	1
0	0	1	0	0	0	1	0	1
1	0	1	0	1	0	0	0	1
1	0	0	1	0	1	1	0	1
0	0	0	1	0	0	1	0	1
1	0	0	1	0	0	1	0	1
1	0	0	0	1	0	0	0	1
0	0	0	1	1	0	0	0	1
0	0	1	1	1	0	0	0	1

Table A- 25. Healed fractures by body segments. C= cranium, T= trunk, A= upper limb, P= pelvis, L= lower limb, S= spine, R= ribs. Continuation of Table 33.

C	T	A	P	L	S	R	Females	Males
0	0	1	0	0	0	0	1	1
0	0	1	0	0	0	1	2	0
0	0	1	0	1	1	0	1	1
0	1	0	0	0	1	1	1	1
1	0	0	0	0	0	1	2	0
1	0	1	0	1	0	1	0	2
0	0	0	0	1	1	0	0	2
1	1	0	0	0	0	1	0	2
1	0	1	1	1	1	1	1	1
1	1	0	1	1	1	1	1	1
0	0	1	0	0	1	0	1	0
0	0	1	1	0	1	1	1	0
1	0	0	0	1	1	1	1	0
1	0	0	1	0	1	1	1	0
1	0	0	1	1	0	1	1	0
1	0	1	0	0	1	1	1	0
1	1	0	0	0	1	1	0	1
0	0	1	0	1	1	1	0	1
1	0	1	1	1	0	1	0	1
1	1	1	0	1	0	1	0	1
0	1	1	1	1	1	1	0	1
1	0	1	0	1	0	0	0	1
1	0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	0	1
1	1	0	1	0	0	1	0	1
1	1	0	0	1	0	1	0	1
1	0	1	1	0	0	1	0	1
0	1	1	0	0	1	1	0	1

Table A- 26. Healed fractures by long bones. Continuation of Table 34.

H	Hr	R	Rr	U	Ur	F	Fr	T	Tr	Fi	Fir	Females	Males
0	0	0	0	0	0	0	0	1	0	0	0	2	0
0	0	0	0	0	0	0	0	1	0	1	0	2	0
0	0	0	0	0	0	0	1	0	0	0	0	2	0
0	0	0	1	0	1	0	0	0	0	0	0	1	1
0	0	0	1	0	0	0	1	0	0	0	0	1	0
0	0	0	0	1	0	0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0	0	0	0	0	1	0
0	0	1	1	0	0	0	0	0	0	0	0	1	0
1	0	0	1	0	0	0	0	0	0	0	0	1	0
1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	0	0	0	1	0	0	0	0	1	0	1	0	1
1	0	1	0	1	0	0	0	0	1	0	0	0	1
0	0	0	0	0	1	0	0	1	0	0	0	0	1
1	1	1	1	0	0	1	0	1	0	0	0	0	1
1	0	0	1	0	1	0	0	0	1	0	1	0	1
1	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	1	0	0	1
1	0	0	0	1	0	0	0	1	1	1	0	0	1
0	0	0	0	0	0	0	1	1	0	0	1	0	1
0	0	0	0	1	0	0	0	0	0	0	0	0	1
0	0	0	1	0	0	0	0	0	0	0	1	0	1

Table A- 27. Healed fracture counts in the left ribs. Females N=38, males N=59.

1	2	3	4	5	6	7	8	9	10	11	12	Females	Males
0	0	0	0	0	0	0	0	0	0	0	0	23	26
0	0	1	0	0	0	0	0	0	0	0	0	2	1
0	0	0	0	0	0	0	1	1	1	0	0	2	0
0	0	0	0	1	0	0	0	0	0	0	0	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	2
0	0	1	1	0	0	0	0	0	0	0	0	0	2
0	0	0	1	1	1	1	0	0	0	0	0	0	2
0	0	0	0	0	0	0	1	1	0	0	0	1	0
0	0	0	0	0	0	1	0	0	0	0	0	1	0
0	0	0	0	0	0	1	1	0	0	0	0	1	0
0	0	0	0	1	0	1	1	0	0	0	0	1	0
0	0	0	0	1	1	1	1	0	1	0	0	1	0
0	0	0	1	0	0	0	0	0	0	0	0	1	0
0	0	1	1	1	0	0	0	0	0	0	0	1	0
0	0	1	1	1	1	1	1	2	1	0	0	1	0
0	1	0	0	0	0	0	0	0	0	0	0	1	0
0	1	1	1	2	1	1	1	1	0	0	0	1	0
0	1	1	1	1	1	0	0	1	0	0	0	0	1
0	1	1	1	2	3	3	2	2	3	2	1	0	1
0	0	0	0	0	0	0	0	0	0	0	1	0	1
0	0	0	0	1	1	1	0	0	0	0	0	0	1
0	0	0	0	2	1	2	1	1	1	0	0	0	1
0	1	1	1	1	1	1	0	0	0	0	0	0	1
0	0	0	0	1	1	1	1	1	0	0	0	0	1
0	0	0	0	1	2	2	2	2	0	0	0	0	1
0	1	1	0	0	0	0	0	0	0	0	0	0	1
0	1	0	1	0	2	3	1	2	3	2	0	0	1
0	1	1	2	3	3	2	1	1	1	0	2	0	1
0	0	0	0	0	1	1	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	1	0	1	0	0	1
0	0	0	1	1	0	0	1	1	1	1	1	0	1
0	0	0	1	1	1	1	0	0	1	0	1	0	1
0	0	0	0	0	0	0	0	1	1	0	0	0	1
0	0	0	1	0	0	1	0	0	0	0	0	0	1
0	1	0	0	1	0	0	1	0	0	0	0	0	1

Table A-27 continues.

1	2	3	4	5	6	7	8	9	10	11	12	Females	Males
0	0	0	0	0	0	0	0	1	1	1	1	0	1
0	1	1	1	3	2	3	3	2	1	0	0	0	1
0	0	0	0	1	0	0	0	0	0	0	1	0	1
0	0	0	1	1	1	0	0	1	1	1	0	0	1
0	1	1	1	1	2	1	1	0	0	0	0	0	1
0	0	1	0	0	0	0	0	1	0	0	0	0	1
0	1	0	0	1	0	2	3	3	2	0	1	0	1

Table A- 28. Healed fracture counts in the right ribs. Females N=44, male N=61.

1	2	3	4	5	6	7	8	9	10	11	12	Females	Males
0	0	0	0	0	0	0	0	0	0	0	0	27	31
0	0	0	0	1	0	0	0	0	0	0	0	2	1
0	0	0	0	0	0	0	0	0	0	1	0	1	1
0	0	0	0	0	0	0	1	0	0	0	0	1	1
0	0	0	0	0	0	0	1	1	0	0	0	1	1
0	0	0	0	0	1	0	0	0	0	0	0	1	1
0	0	1	1	0	0	0	0	0	0	0	0	2	0
0	0	0	1	0	0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	0	0	1	1	1	1	0
0	0	0	0	0	0	0	0	1	1	0	0	1	0
0	0	0	0	0	0	0	1	2	2	1	0	1	0
0	0	0	0	0	0	1	1	1	1	0	0	1	0
0	0	0	0	0	1	0	0	1	0	0	0	1	0
0	0	1	1	1	1	1	1	0	0	0	0	1	0
0	1	0	0	0	0	0	0	0	0	0	0	1	0
0	1	1	1	0	1	0	1	0	0	0	0	1	0
1	0	0	0	0	0	0	0	0	0	0	0	1	0
0	1	1	0	0	0	0	0	0	1	0	1	0	1
0	0	3	2	1	3	2	1	2	2	1	1	0	1
0	0	1	0	0	0	0	0	0	0	0	0	0	1
0	0	0	1	1	0	0	0	0	0	0	0	0	1
0	0	0	1	0	1	2	2	3	1	2	0	0	1
1	1	1	1	1	1	0	1	0	0	0	0	0	1
0	0	1	1	1	1	1	1	1	0	0	1	0	1
0	1	1	0	0	0	1	0	3	3	2	0	0	1
0	0	0	1	1	0	0	0	1	0	1	0	0	1

Table A-28 continues.

1	2	3	4	5	6	7	8	9	10	11	12	Females	Males
0	0	0	0	1	1	0	0	0	0	0	0	0	1
0	0	0	0	0	1	1	1	3	2	1	1	0	1
0	0	0	0	0	0	0	0	1	0	0	0	0	1
0	0	1	0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	3	1	0	0	0	1
0	0	0	1	1	3	0	0	0	0	1	0	0	1
0	0	0	1	1	1	1	1	2	3	1	2	0	1
0	1	0	0	0	3	2	0	0	0	0	0	0	1
0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	1	0	0	0	1	0	0	0	0	0	0	0	1
0	0	0	1	1	1	1	1	0	0	1	0	0	1
0	1	2	1	0	1	0	0	0	0	0	0	0	1
1	2	1	2	3	1	2	0	0	0	0	0	0	1
0	1	0	1	2	1	1	0	0	0	0	0	0	1

Table A- 29. All observed conditions and combinations in the long bones. Continuation of Table 36.

H	Hr	R	Rr	U	Ur	F	Fr	T	Tr	Fi	Fir	Females	Males
0	0	0	0	0	0	0	0	0	FD	0	0	1	0
0	0	0	0	0	0	0	0	0	0	F	0	0	1
0	0	0	0	0	0	0	0	0	F	0	FD	0	1
0	0	0	0	0	0	0	0	0	L	0	L	0	1
0	0	0	0	0	0	0	0	F	0	0	0	1	0
0	0	0	0	0	0	0	0	FDL	L	0	0	1	0
0	0	0	0	0	0	0	0	L	FL	L	FL	1	0
0	0	0	0	0	0	0	FD	0	0	0	0	1	0
0	0	0	0	0	0	0	L	0	0	F	0	0	1
0	0	0	0	0	0	0	E	0	E	0	0	1	0
0	0	0	0	0	0	D	0	D	0	0	0	1	0
0	0	0	0	0	0	D	D	D	D	0	0	0	1
0	0	0	0	0	0	D	L	0	0	0	0	1	0
0	0	0	0	0	0	FD	0	0	0	0	0	0	1
0	0	0	0	0	0	FDL	0	L	0	0	0	1	0
0	0	0	0	0	0	L	0	L	L	0	0	0	1
0	0	0	0	0	0	L	FDL	0	0	0	0	1	0
0	0	0	0	0	0	E	0	0	0	0	F	0	1
0	0	0	0	0	0	E	0	EL	L	0	0	0	1
0	0	0	0	0	0	E	E	E	E	0	0	1	0
0	0	0	0	0	F	E	DE	FDE	E	E	E	0	1
0	0	0	0	0	E	0	0	0	F	0	F	0	1
0	0	0	0	F	0	0	0	F	0	0	0	1	0
0	0	0	0	F	0	0	0	L	0	0	0	0	1
0	0	0	F	0	0	0	0	L	0	L	0	1	0
0	0	0	F	0	0	0	0	L	L	0	0	1	0
0	0	0	F	0	0	0	L	0	L	L	F	0	1
0	0	0	E	0	0	0	0	0	0	0	0	1	0
0	0	F	0	0	0	0	0	0	0	0	0	0	1
0	0	F	0	0	0	0	0	0	L	L	L	0	1
0	0	F	0	0	0	0	0	L	L	0	0	0	1
0	0	F	0	0	0	0	D	0	0	0	0	1	0
0	0	L	0	0	0	FD	0	L	L	0	L	0	1
0	0	L	0	FD	0	0	0	0	F	0	F	0	1
0	0	E	FE	0	0	0	0	0	0	0	0	0	1
0	0	E	E	0	0	E	E	0	E	0	0	0	1
0	0	E	E	E	0	0	0	0	0	0	0	1	0

Table A-29 continues.

H	Hr	R	Rr	U	Ur	F	Fr	T	Tr	Fi	Fir	Females	Males
0	F	0	0	0	0	0	0	L	L	L	L	1	0
0	F	0	0	0	0	E	E	E	E	0	0	0	1
0	L	0	0	0	0	0	F	0	F	0	FD	0	1
0	L	0	E	0	0	L	LE	0	E	0	0	0	1
0	E	0	0	0	0	0	0	0	0	0	0	1	0
0	E	0	F	0	0	0	FD	L	0	0	0	1	0
0	E	FL	FL	0	0	0	0	0	0	0	0	1	0
0	E	E	E	E	0	L	E	L	L	L	L	1	0
DE	D	E	0	0	0	0	0	0	0	0	0	0	1
F	0	0	0	0	0	0	0	0	0	0	0	0	1
F	0	0	0	F	0	0	L	F	F	F	0	0	1
F	0	0	F	0	0	0	L	0	0	0	0	1	0
F	0	0	FD	0	F	0	0	0	F	0	F	0	1
F	0	F	0	F	0	0	0	0	L	0	0	0	1
F	0	F	F	0	0	0	0	0	0	0	0	1	0
F	F	F	F	0	0	FD	E	F	E	0	0	0	1
L	0	0	0	0	0	0	0	0	0	0	0	0	1
L	L	0	0	0	0	0	0	0	0	L	0	0	1
L	L	L	L	0	0	0	0	0	0	0	0	1	0
E	0	0	0	0	0	LE	LE	LE	E	0	0	1	0
E	0	0	0	E	0	E	0	E	0	0	0	0	1
E	0	L	L	L	L	L	LE	L	L	L	L	1	0
E	0	E	0	0	0	0	0	0	0	0	0	1	0
E	0	E	LE	E	E	0	0	0	0	0	0	0	1
E	E	0	0	0	0	E	0	0	0	0	0	0	1
E	E	0	FD	E	FD	0	0	0	0	0	0	0	1
E	E	FE	E	0	0	FD	0	0	E	0	0	1	0
E	E	E	E	0	0	0	E	0	0	0	0	1	0
E	LE	0	0	0	0	E	DE	0	E	0	0	0	1

VITA

Heli Maijanen was born in Kiiminki, Finland. She did her BA and MA in archaeology at the University of Oulu, Finland. In 2005 she began her Ph.D. studies at the University of Oulu and came to the University of Tennessee, Knoxville, in 2006 to collect data for her dissertation from the W. M. Bass Donated Skeletal collection. In 2008 she started her doctoral studies at UTK concentrating on biological anthropology. Studies at UTK provided her with plenty of hands-on experience, knowledgeable mentors and a great circle of colleagues. She received her Ph.D. in archaeology from the University of Oulu in December 2011 and Ph.D. in biological anthropology from the University of Tennessee in August 2014.