CREMAINS

THE VALUE OF QUANTITATIVE ANALYSIS FOR THE BIOANTHROPOLOGICAL RESEARCH OF BURNED HUMAN SKELETAL REMAINS

DAVID MIGUEL DA SILVEIRA GONÇALVES

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Faculdade de Ciências e Tecnologia - Universidade de Coimbra

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DEPARTAMENTO DE CIÊNCIAS DA VIDA
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UNIVERSIDADE DE COIMBRA

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Dedicated to Ana Catarina “Cati” Custódio,
A friend always missed.

On the cover

Excerpt from Prometheus Brings Fire to Mankind (Heinrich von Füger, 1817). Sammlungen des Fürsten von und zu Liechtenstein, Vaduz – Wien.

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ABSTRACT

The analysis of burned bone stumbles on the problems raised by the heat-induced changes that seriously interfere with the methods adopted by biological anthropologists. These changes especially affect the structure of bone leading to fragmentation, dimensional modification, warping and fracturing. As a result, quantitative analysis based on measurements and weighing are usually overlooked due to uncertainties regarding their ability to correctly process burned skeletal remains.

Although some pioneering research on this issue has been carried out in the Past, this remained sporadic and with little application from bioanthropologists. In addition, a significant part of that research was either developed on rather small samples of human bones or on samples of faunal bones. Also, some other investigation was carried out by extrapolating from the results obtained on unburned skeletons, which is an inadequate indirect approach. The present research tackled these problems by analysing present-day cremations on a modern crematorium in order to investigate three distinct issues. The first one regarded the relevance of heat-induced warping and thumbnail fracturing for the determination of the pre-cremation condition of the human remains. Secondly, the implication of heat-related dimensional change on sexual dimorphism and consequent sex determination from calcined bones was addressed. Finally, the value of post-cremation skeletal weights for bioarchaeological interpretation of funerary contexts was also investigated. This was done by examining human skeletons both prior and after cremation on two different cremation samples: one composed of recently dead cadavers submitted to cremation; and another one composed of dry skeletons recently exhumed.

The research demonstrated that, although heat-induced warping and thumbnail fracturing is much more typical of cremations on fleshed cadavers, these features are also present on the burned remains of defleshed skeletons. Therefore, the occurrence of these features is probably related to the preservation of collagen-apatite bonds which play an important role on the mechanical strength of bone. As for sexual dimorphism, the results revealed that it is not significantly affected by heat and that such differences between females and males can be useful to classify unknown individuals according to sex based on the univariate metric analysis of calcined bones. Therefore, sex determination of this kind of material needs not to rely exclusively on the examination of morphological traits which requires a multivariate approach. At last, logistic regression coefficients that are able to estimate the expected proportion of the specific skeletal regions present on funerary assemblages were developed. This was carried out in order to assist on the interpretation of the course of action adopted during the recovery of the skeletal remains from the pyre and their consequent deposition in the grave. Such method was proven to be more dependable than previous ones based on weight references from unburned skeletons.

This research demonstrated that, although heat-induced bone changes can indeed be very extensive, their analytical potential is not completely wiped out. Nonetheless, such analysis needs to be based on references that are specific to burned bone to allow for reliable insights. As a result, additional research is needed to better equip bioanthropologists with new analytical techniques more suitable for the investigation of burned human skeletal remains.

Keywords: burned bones; osteometry; cremation; heat-induced changes; funerary archaeology; skeletal weights; taphonomy.

RESUMO

A análise de ossos queimados é seriamente dificultada pelas alterações térmico-induzidas que interferem com a fiabilidade das metodologias adoptadas pelos antropólogos biológicos. Essas alterações afectam particularmente a estrutura do osso resultando em fragmentação, modificações ao nível das suas dimensões, deformação e fractura. Por essa razão, a sua análise quantitativa baseada em medições métricas e pesagens não é prática corrente porque subsistem dúvidas relacionadas com a fiabilidade desta abordagem.

Apesar de alguns trabalhos pioneiros, a investigação nesta área permaneceu esporádica e com reduzida expressão ao nível da sua aplicação por parte dos bioantropólogos. Além disso, uma parte significativa dessa investigação foi desenvolvida a partir de amostras pequenas de ossos humanos ou a partir de restos faunísticos. Outro tipo de abordagem baseou-se na extrapolação dos resultados obtidos a partir de ossos não queimados para ossos queimados. Este é um procedimento indirecto e inadequado. Esta investigação procurou fazer face a estes problemas a partir da análise de cremações contemporâneas com o objectivo de estudar três questões distintas. A primeira delas estava relacionada com a utilidade da deformação e das fracturas *thumbnail* térmico-induzidas para a determinação da condição pré-cremação de restos humanos. A segunda questão dizia respeito às implicações das alterações térmico-induzidas relativas à dimensão do osso no dimorfismo sexual e subsequente determinação do sexo em restos humanos calcinados. Finalmente, foi também abordado o valor do peso do esqueleto após a cremação para a interpretação bioarqueológica de contextos funerários. O estudo baseou-se na análise pré- e pós-cremação de duas amostras de esqueletos distintas: uma composta por cremações de cadáveres recentemente falecidos e outra composta por cremações de esqueletos previamente inumados.

Apesar da ocorrência da deformação e das fracturas *thumbnail* térmico-induzidas serem consideravelmente mais frequentes em cremações de cadáveres com tecidos moles, este evento está também presente nos restos cremados de esqueletos sem tecidos moles. Assim sendo, a sua ocorrência está provavelmente relacionada com a preservação das ligações entre o colagénio e a apatite que assumem um importante papel na força e resistência mecânicas do osso. Em relação ao dimorfismo sexual, os resultados revelaram que este não é significativamente afectado por elevadas temperaturas e que as diferenças métricas entre mulheres e homens podem ser úteis para a classificação sexual de indivíduos desconhecidos a partir da análise univariada dos seus restos ósseos calcinados. Com efeito, a determinação do sexo deste tipo de material não precisa de basear-se exclusivamente no exame multivariado de traços morfológicos. Finalmente, coeficientes de regressão logística foram desenvolvidos de forma a estimarem as proporções esperadas das regiões anatómicas do esqueleto em conjuntos funerários. Estas ferramentas permitem ajudar o bioantropólogo a reconstituir o gesto funerário relacionado com a recolha dos ossos da pira e sua subsequente deposição na sepultura. Foi demonstrada a maior fiabilidade desta técnica em relação a outras previamente adoptadas em estudos bioarqueológicos e baseadas em referências de peso desenvolvidas a partir de esqueletos não queimados.

A investigação demonstrou que, embora as alterações térmico-induzidas no osso possam ser vastas, o potencial de análise associado a este material não é completamente eliminado. No entanto, tal análise deve ter como suporte referências que sejam específicas a ossos queimados de forma a permitir inferências fiáveis. Assim sendo, é necessária investigação adicional de forma a dotar os bioantropólogos de novas técnicas de análise mais adaptadas ao estudo de restos ósseos humanos queimados.

Palavras-chave: ossos queimados; cremação; alterações térmico-induzidas; arqueologia funerária; pesos do esqueleto; tafonomia.

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1. Introduction

1.1. Area of Interest

Bioanthropologists have become quite good at reading and interpreting the human skeleton in order to retrieve important information regarding the biological profile of an individual as well as the antemortem, perimortem and postmortem circumstances pertaining to it. All this data is especially important for investigations from both the archaeological and forensic arenas for which the skills of bioanthropologists are often required. Although a considerable amount of information is often collected from the inspection of unaltered human skeletal remains, this task is usually more difficult to complete with bones affected by a heat-source. Heat typically produces extreme fragmentation of the bones accompanied by important alterations preventing the use of some of the methods adopted in their examination (Holck, 1986; McKinley, 1989; Mayne Correia and Beattie, 2002; Thompson, 2002 and 2005; Fairgrieve, 2008; Schmidt and Symes, 2008; Ubelaker, 2009). As a result, researchers have been struggling on their quest to better understand the effects of heat on bone and to find more reliable ways to undertake the bioanthropological analysis of heat-altered human remains.

The efforts of many researchers – from both bioanthropological and other intimate scientific backgrounds – has undoubtedly led to the improved knowledge of burned bones which in turn contributed for the development of new and more specific analytical approaches to this kind of material. The investigation concerning this issue will be listed and further discussed in the following sections. In a nutshell, it can be stated that important contributions have been made, only to name a few, by Baby (1954) Binford (1963) and Buikstra and Swegle (1989) regarding the differential effect of heat on fleshed and unfleshed bone; by Gejvall (1969), Piontek (1975, 1976) Malinowski (1969) and Van Vark, 1974, 1975) who discussed the implication of heat-induced dimensional change on sex determination; and by Bradtmiller ad Buikstra (1984), Shipman et al (1984) and Thompson et al (2009) who focussed on bone microscopic changes caused by heat and their implication for osteological analysis. Despite the efforts of these and several other researchers, it seems evident that more investigation is needed to further clarify the effects of heat on bone and their implications for the interpretation of the circumstances surrounding death and of the handling of the remains. Also, the implications of heat-induced changes on the assessment of the biological profile needs to be further addressed in more detail if we are ever to be able to retrieve reliable information from human skeletal burned remains. Therefore, the present investigation intends to contribute for this area of research regarding human burned bones by adopting a bioanthropological perspective associated to the analysis of heat-related taphonomy. The approach used in this investigation – based on the examination of cremated human remains in a modern crematorium – has been adopted by several other researchers and allowed for the collection of precious data (e.g.: Gejvall, 1947; Malinowski and Porawski, 1969; Van Vark, 1975; Rosing, 1977; Wahl, 1996; McKinley, 1993; Warren and Maples, 1997; Bass and Jantz, 2004). Expectantly, the present research brings new light into the topic of bone heat-induced changes and its implication for osteometric sex determination of human remains as well as for the identification of the circumstances surrounding death and funerary behaviour.

1.2. Mankind, Fire and Human Remains

In order to make fire, one only needs some flammable matter, oxygen mixed with fuel and a source of heat to start the combustive chain reaction (Figure 1.1.1). However, fire is seen by humans as something more than a simple chemical reaction. It became well mastered by mankind having an immense impact on our daily lives and on the evolution of our own genus. Such importance is demonstrated by the numerous myths that describe how humans got acquainted with fire. Those are part of the cultural heritage of several populations from all continents and often attribute a divine origin to fire. Many myths and legends describe how gods or some other supernatural beings granted fire to mankind as can be seen by the narratives regarding: the Cherokee’s Thunderers; the Chinese Chu Jung (a deified mortal); the Polinesian Mahu’ike; the Mayan Tohil; the Micronesian Olifat; the Greek Prometheus (Figure 1.1.2); the Melanesian Rokomautu; the Slavic Svarog; and also Uwolowu from the Akposso of Togo (Mercatante and Dow, 2009).

Fire brought many innovations to our ancestors. For instance, the cooking of food helped improving nutritional and energetic intake (Wrangham and Conklin-Brittain, 2003; Carmody and Wrangham, 2009; Wrangham and Carmody, 2010). It may thus have led to digestive adaptations such as smaller teeth, small hind-guts, large small intestines, a fast gut passage rate and to the reduced ability to detoxify (Wrangham and

Conklin-Brittain, 2003). This hypothesis has been disputed because reliable evidence for the intentional use of fire was of only about 250000 years (Pennisi, 2004) but support for earlier dates of at least around 790000-400000 BP have been made available in the meantime (Goren-Inbar et al, 2004; Alperson-Afil et al, 2007; Roebroeks and Villa, 2011). Another innovation provided by the controlled use of fire regards its lighting and thermal abilities which allowed mankind to occupy new habitats and spread throughout some unbearable regions of the globe which, otherwise, would be impossible to inhabit (James, 1989). Fire also maximized our skills to explore food resources whether by hunting through large-scale intentional fires whether by improving fertility of crop fields with controlled burnings (Lentz, 2000; Lewin and Foley, 2004; Miller, 2005). The advantages provided by the use of fire have been numerous. However, as soon as fire was handled by humans, the probability of the occurrence of events leading to burned skeletal remains increased. For instance, antemortem lost teeth may have been burned on hearths and burned human remains may have been the result of accidental fires. These are two examples of non-funerary contexts in which burned human remains can eventually be found on archaeological contexts.

Another very important usage for fire, which is more directly linked with the contexts in which burned human skeletal remains are found, regards funerary practices. Cremation is an old practice which was first used during Prehistory. As it seems, the most ancient burial including burned bones was found in Lake Mungo, Australia (Bowler et al, 1969). Two dates have been proposed for this burial. One radiocarbon dating indicated it to be as old as 25000 BP (Bowler et al, 1969) but a more recent luminescence dating pushed this estimation back to 40000 BP (Bowler, 2003). Either way, this is by far the most ancient known deliberate burial regarding burned human skeletal remains, although the intentional or accidental burning of the remains cannot be stated for sure. In the Americas, a cremation burial of a 3 years-old child located in Eastern Beringia was dated back to 11500 BP (Potter et al, 2011). This evidence suggests that cremation was firstly adopted almost at the same time in both the Americas and Europe. The most ancient finding concerning European human burned bones is the one from the Mesolithic site of Abri de Vionnaz in Switzerland which were dated to 9700 BP (Carreño, 2001). Further to this, cremation was a very popular practice since the Neolithic at least in Europe. Therefore, burned bones can be found on archaeological sites from several chrono-cultural contexts.

Although cremation is still used as a funerary process, the major portion of cases involving burned bones investigated by bioanthropologists are nowadays resulting from other kinds of contexts. Besides fire-related homicides and suicides, also mass-fatality incidents, accidental fires, natural disasters and post-cremation identification of remains among others, involve burned human skeletal remains. Mayne Correia (1997) and Thompson (2003) made a comprehensive review of this issue previously. Therefore, bioanthropologists have been joining the forensic teams called to investigate these cases but their analytical skills are often impaired by the extreme fragmentation and the heat-induced changes usually present in burned bones. As a result, more reliable methods specific to the analysis of burned bones have been in demand and research in this field is becoming increasingly more dynamic.

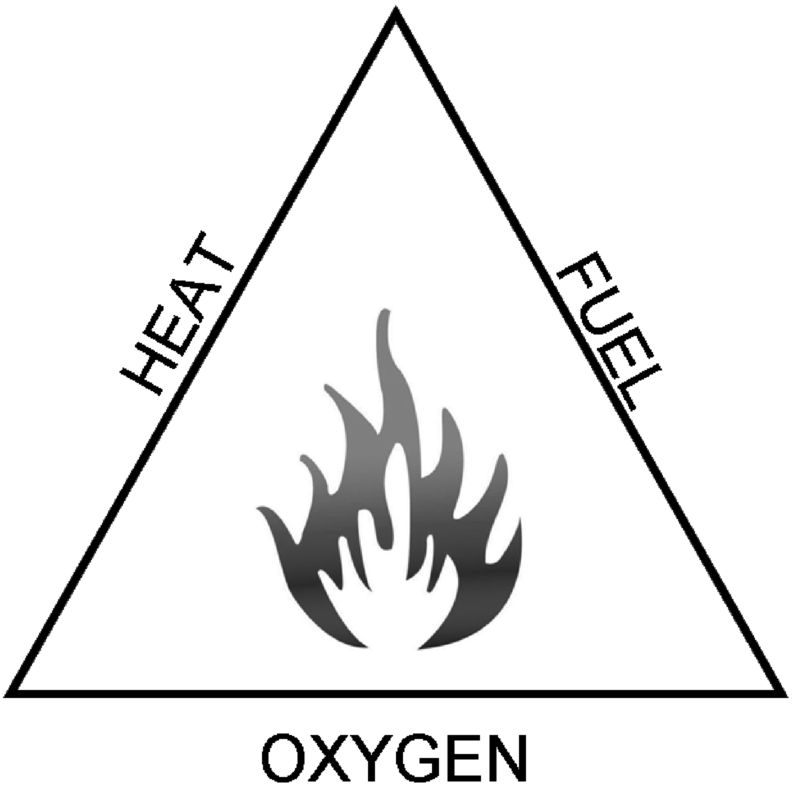

Figure 1.1.1: Diagram of the combustive chain reaction.

Figure 1.1.2: Prometheus Brings Fire to Mankind (Heinrich von Füger, 1817). Sammlungen des Fürsten von und zu Liechtenstein, Vaduz – Wien.

1.3. Research Review

The research regarding burned skeletal remains has been profiting from the interaction between the archaeological and forensic arenas. These two fields have often joined forces in order to improve our understanding of bone changes caused by heat and their implication for bioanthropological analyses (e.g.: Baby, 1954; Piontek, 1976; Rosing, 1977; Holck, 1986; Buikstra and Swegle, 1989; McKinley, 1993; Etxeberria, 1994; Thompson et al, 2009; Gonçalves et al, 2010; Gonçalves et al 2011b). Of course, this communication between the two fields is neither new nor specific to burned bones. Although the chronologies of the materials under study and their specific aims differ to some degree, both deal with the same object of study – the human skeleton. In several contexts, this often constitutes the only biological document available for analysis since it is the most resilient component of the human body. Fortunately, it allows for the retrieval of a lot of information regarding the biological and ontological profile of a given individual. In forensic research, that helps establishing the positive identification of unknown remains. Furthermore, bone analysis can also give insights about the circumstances surrounding death and the postmortem episodes affecting the remains. While adopting an interdisciplinary approach, the bioanthropologists are provided with the macro-analytical skills that allow them to read and interpret the bones in order to reconstruct someone’s life and eventually, someone’s death. However, this task is much more challenging when the skeletal remains have been altered by a heat source because this interferes with the reliability of conventional techniques which have been developed on unburned skeletons and rarely tested on burned remains (Symes et al, 2008).

The investigation of burned human bones has been addressed for at least 160 years. In 1849, a highly publicized trial took place in Boston, United States, regarding the Parkman-Webster murder case (Bemis, 1850). Fragments of bone and teeth burned in a furnace were then analysed by medical doctors and a dentist in order to determine if those were from the victim – George Parkman – and if any fracture was in fact antemortem. Therefore, this investigation was carried out in a legal context. Still on the matter of positive identification, Lepkowski and Wachholz (1903) specifically described the heat-induced changes fifty years later and was, at the time, one of the rare exceptions to this otherwise quite barren field of research. The investigation on burned bones remained sporadic and went on intermittently during the first half of the 20th century. During this extended period, anthropological analysis had a strong emphasis on anthropometric methods following the work done on several researches that aimed to correlate metric patterns with intelligence, criminal inclination and even social or racial hierarchy (Morton, 1839; Lombroso, 1876; Galton, 1886; Galton and Schuster, 1906; Jurmain et al, 2000). Apparently, this anthropometric view gave privilege to unburned skeletal remains and may have led to the sidelining of burned bones which were obviously not metrically suitable for that kind of analysis.

Nonetheless, some sporadic work was published during the first half of the 20th century, especially in Germany (Gebhardt, 1923; Böhmer, 1932; Merkel, 1932; Krumbein, 1934; Burri et al, 1935; Thieme, 1937 and 1938). Burned bones have also been investigated in France (Muller, 1945; Muller and Guidoux, 1945; Dechaume and Derobert, 1946), in Poland (Lepkowski and Wachholz, 1903; Wrzosek, 1928), in Sweden (Gejvall, 1947) and in the United States (Forbes, 1941; Krogman, 1943; Webb and Snow, 1945). The main topics addressed by these researchers were related to the effect of heat in bones and its implication for anthropological analyses. This issue was also addressed microscopically by Forbes (1941) whose results are addressed in section 1.4.2. Most of those investigations were developed under the forensic arena. However, the work of Krumbein (1934) and Webb and Snow (1945) were among the first to reportedly examine archaeological materials.

It was mainly on the second half of the 20th century that research on burned bones became more intense and experimentation started to have an essential role for the description and understanding of the effects of heat on the human skeleton. Archaeological research started to contribute more substantially to the field during the 1950s and the 1960s (Baby, 1954; Binford, 1963) and was especially interested in adopting a comparative approach to interpret ancient cremations. In order to do so, Malinowski (1969) recorded the weight of cremains of females and males from modern cremations. The recording of percentage skeletal weights to estimate the proportion of the mineral component of bone was carried out by Trotter and Peterson (1955). Additional experimental investigation came from the medico-legal arena with Günther and Schmidt (1953) documenting the effect of fire on the skull. By this time, several other works were being published, especially in the United States and the Northern and Central Europe, thus demonstrating the increasing interest regarding burned bones (e.g.:

Gejvall, 1955 and 1969; Wells, 1960; Chochol, 1961; Dokladal, 1962; Kloiber, 1963; Merbs, 1967; Lisowski, 1968; Bowler et al, 1969; Malinowski and Porawski, 1969).

The leading role of the United States and Northern and Central Europe on the investigation of burned skeletal remains was reinforced on the following decade by the influential work of several authors from these regions (Dokladal, 1970; Thieme, 1970; Binford, 1972; Buikstra and Goldstein, 1973; Strzalko and Piontek, 1974; Piontek, 1975 and 1976; Herrmann, 1976; Rosing, 1977; Dunlop, 1978; Stewart, 1979). In addition, the pioneering work of Forbes (1941) regarding the microscopic analysis of burned bone was continued by Bonucci and Graziani (1975), Harsanyi (1975) and by Herrmann (1976, 1977).

During the 1980s, the research on burned bones increased significantly and its geographical distribution became more wide-spread. Experimental research addressing both macroscopic and microscopic heat-induced changes constituted a large amount of the work produced during that decade (Thurman and Wilmore, 1981; Grupe and Herrmann, 1983; Bass, 1984; Bradtmiller and Buikstra; Shipman et al, 1984; Endris and Berrshe, 1985; Gilchrist and Mytum, 1986; Schultz, 1986; Wilson and Massey, 1987; Buikstra and Swegle, 1989; Holland, 1989; Spennemann and Colley, 1989). After some initial work done by Gejvall (1947, 1969) regarding the thickness of the skull and by Van Vark (1974, 1975) on a number of selected bones, sex determination using osteometric features was further investigated by other authors. This time, the petrous portion of the temporal bone was examined for sexual dimorphism by Schutkowski (1983) and by Schutkowski and Herrmann (1983). In addition, Holland (1989) re-addressed the impact of heat-induced shrinkage on some cranial measurements and its implication for bioanthropological analysis. Also regarding the reconstruction of the biological profile, the estimation of age-at-death on sub-adults was investigated by Wahl (1983) while the potential of assessing age histologically was addressed by Bradtmiller and Buikstra (1984). The publication of results about archaeological materials made also part of the literature enriching this field during the 1980s (e.g.: Kunter, 1980; Caselitz, 1981; Holck, 1986) which was further added by work from the forensic arena (e.g.: Eckert, 1981; Heglar, 1984). Additionally, another research innovation referred to the analysis of trace elements on burned bone for dietary reconstruction (Price and Kavanagh, 1982; Deniro et al, 1985; Runia, 1987; Herrmann, 1988).

As for the 1990s, the heat-induced changes to bone kept on being further investigated (Etxeberria, 1994; McKinley, 1994; Mayne Correia, 1997; Mays, 1998; Huxley and Kósa, 1999). Microscopic analysis became frequently addressed (Nelson, 1992; Nicholson, 1993; Holden et al, 1995a, 1995b, 1995c; Stiner et al, 1995; Taylor et al, 1995; Quatrehomme et al, 1998) Also following previous work, histological age-at-death estimation was furthermore addressed by Cuijpers and Schutkowski (1993); trace elements analyses were carried out by Grupe et al (1991), Person et al (1996) and Subira and Malgosa (1993); positive identification was discussed by Grévin et al (1998); and new investigation regarding the weight of cremains were now published for British and American populations (McKinley, 1993; Warren and Maples, 1997). As for the major innovations achieved on this decade, these were related to: research specifically dealing with the problems on the differentiation between antemortem lesions and heat-induced fractures (Mayne, 1990; Reinhard and Fink, 1994; Bohnert et al, 1997 and 1998; Herrmann and Bennett, 1999); the potential of DNA retrieval from burned bones (Duffy et al, 1991; Brown et al, 1995; Sweet and Sweet, 1995); and the potential of human albumin for the biomolecular investigation of past populations (Cattaneo et al, 1994 and 1999).

On the last decade, burned bone was investigated through a lot of perspectives continuing the research carried out in previous years. As a result, the issue regarding the identification of antemortem skeletal lesions was further addressed by several authors (Bohnert et al, 2002; de Gruchy and Rogers, 2002; Pope and Smith, 2004). Heat-induced changes were also investigated during this decade (Christensen, 2002; Brooks et al, 2006; Kalsbeek et al, 2006; Thompson and Chudek, 2007; Symes et al, 2008). Among these, macroscopic analysis addressed the heat-induced changes on colour, dimension, warping and fractures (Thompson 2002, 2004 and 2005; Walker and Miller, 2005; Walker et al 2008; Gonçalves et al, 2011b). The alterations in the crystal structure were also further investigated especially with the aim of assessing its potential to identify heating events in bone (Stiner et al, 2001; Surovell and Stiner, 2001; Rogers and Daniels, 2002; Hiller et al, 2003; Enzo et al, 2007; Hanson and Cain, 2007; Munro et al 2007; Bergslien et al, 2008; Piga et al, 2009; Thompson et al, 2009; Harbeck et al, 2011; Squires et al, 2011). In addition, skeletal weights have been again examined resorting to the analysis of modern cremations from the United States, Thailand and Portugal (Bass and Jantz, 2004; Chirachariyavej et al, 2006; Deest, 2007; Gonçalves et al, 2010; Deest et al, 2011; May, 2011). New DNA research was also carried out (Staiti et al. 2004; Williams et al, 2004; Wurmb-Schwark et al, 2004; Ye et al, 2004) along with the potential of trace elements analyses on burned bones (Brooks et al, 2006; Harbeck et al, 2011). In the latter subject, the dating of cremated bone was also addressed (Lanting et al, 2001; Olsen et al, 2008) The investigation of past populations has also provided for many publications (eg.: Bartsiokas, 2000; Duday et al, 2000; Blaizot and Georjon, 2005; Le Goff and Guillot, 2005; Richier, 2005; Ubelaker and Rife, 2007; Curtin, 2008; Wahl, 2008). Finally, the investigation of positive identification on burned skeletal remains was further addressed during this decade (Bassed, 2003; Bush et al, 2006; Blau and Briggs, 2011; Hill et al, 2011; Lain et al, 2011).

Although the investigation carried out in this particular field has become increasingly more prolific, it never achieved the level of research developed on unburned material. Despite this, the investigation regarding burned skeletal remains has been extremely important for several reasons. Besides cremation being often the only funerary ritual used for some chronological periods and geographical regions and burned bones being more resilient to post-depositional dissolution than unburned bones (Mays, 1998), the challenges involving their analysis has led to several methodological innovations. Therefore, the investigation of this kind of material drove Biological Anthropology to get more sophisticated and increasingly more reliable. Despite this, some research in the field of burned bone is still missing and therefore required for the further improvement of this reliability. For instance, the assessment of bone heat-induced change on large human samples has been seldom carried out and, apart from a few exceptions (Van Vark et al, 1996; Wahl, 1996; Gonçalves et al, 2011b; Gonçalves, in print), it has been practically non-existent in more recent work. As a result, we have had little notion of the factors involved in heat-induced change. In addition, the potential of osteometric techniques for the sex determination of burned human skeletal remains has not been addressed systematically on large samples of contemporary individuals from populations other than Swedish (Van Vark et al, 1996; Wahl, 1996). Therefore, osteometry has been recurrently left out of bioanthropological analysis of burned bone due to the uncertainties regarding its trustworthiness. Also, skeletal weight references specific to burned skeletons are lacking and weight analysis have been relying on references from unburned skeletons – such as those from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) and Silva et al (2009) – which are probably unsuitable. Consequently, bioarchaeological interpretation of bone assemblages may be based on the flawed assumption that both kinds of skeletal remains are comparable. Given all the problems stated above, additional research is needed to fill the gaps and eliminate the frailties still present in the field of burned bone. The present investigation intends to be a contribution in this regard. Expectantly, it will bring new light into these issues which have been poorly addressed in the past.

1.4. Microscopic Heat-induced Changes

In order to comprehend the specificities regarding the analysis of burned bones, one needs first to be able to know and understand what changes are induced on them by heat. Biological Anthropologists are usually very well acquainted with the bone macro-changes that can be observed at the gross level. However, these are the result of changes at the ultrastructural level that have been investigated for several decades. A review of these investigations is here addressed.

1.4.1. Heat-induced Transformation Stages

A summary of the literature regarding the stages of heat-induced transformation has been carried out by Mayne Correia (1997). Thompson (2003, 2004) reviewed it later after carrying out experimental research. Although both outlined the same four descriptive stages, these authors sometimes disagree about the intervals of temperature at which each stage is experienced by bone. These intervals overlap, so some of the events related to each stage may be taking place simultaneously.

The first stage – dehydration – refers to the breakage of the hydroxyl bonds and the loss of water leading to subsequent reduction in weight (Mayne Correia, 1997; Thompson, 2003). After scanning electron microscope analysis (SEM), dehydration was characterized by bubbles in the external lamellae and by cracking (Mayne Correia, 1997). Both authors agree that dehydration occurs approximately between 100º C and 600º C. Both the loss of weight leading to shrinkage and the formation of fractures during this stage have direct implications for bioanthropological analysis because they interfere with osteometric techniques and enhance fragmentation respectively (Thompson, 2004).

As for decomposition, this takes place at 500-800º C according to Mayne Correia (1997) and at 300-800º C in the perspective of Thompson (2003, 2004). During this stage, organic components (mucopolysaccharides, collagen, amino acids, etc.) are decomposed and changes in porosity can be observed. SEM analysis shows an increase in the diameter of both the crystals and the lacunae although bone structure is still recognised (Mayne Correia, 1997). Decomposition leads to a loss of mechanical strength which leads to further fragmentation (Thompson, 2004).

In the third stage – inversion – the carbonates are removed and magnesium is released causing additional loss of weight (Mayne Correia, 1997). Viewed at the scanning electron microscope (SEM), cracks are wider and the matrix becomes increasingly more homogenous while lacunae become less perceptible and eventually fade out. At this point, contrasting views regarding changes in the hidroxiapatite crystal structure have been put forward. Some authors argue that hidroxiapatite converts into tricalcium phosphate (Posner, 1969; Holden et al, 1995b; Stiner et al, 1995) while others did not observe such event (Shipman et al, 1984; Rogers and Daniels, 2002). The inversion stage was indicated to occur between 700º C and 1100º C by Mayne Correia (1997) and between 500º C and 1100º C by Thompson (2004). The recrystallization process also interferes with bioanthropological techniques because it causes changes in size and shape (Thompson, 2004).

Finally, the last stage refers to fusion and is typified by melting and coalescence of the crystal matrix (Thompson, 2003). An increase in crystal size can be observed while considerable dimensional reduction of bone takes place during this stage especially hampering osteometric techniques (Thompson, 2004).

1.4.2. Histological Structure

The opinions differ regarding the effect of heat on the histological structure of bone. Forbes (1941) was probably responsible for the first publication focusing specifically on the effects of increasing heat on the microstructure of bone. He detected an increase in prominence of the canaliculi in compact bone while the osteons became smaller. Then, the lamellae started presenting coarse granulates and the lacunae gradually became distorted and presenting hazy shadowy outlines until eventually disappear. Finally, the matrix turned into a flat granular homogenous surface with only a few lacunae. Cancellous bone displayed an appearance of coarse granularity in the lamellae before losing definition until completely vanishing. In mildly burned bones, lacunae and canaliculi could still be detectable. Unfortunately, Forbes (1941) was not able to establish at which times and temperatures the structural changes took place, but he stated that adult bone was subject to a Bunsen flame for intervals ranging from 25 seconds to 10 minutes.

Herrmann (1977) stated that bone structure changes significantly when heated to temperatures above 700-800º C. He mentioned a decrease in the size of osteons. Despite this, Herrmann (1977) argued that histological age estimation is still possible to achieve. Bradtmiller and Buikstra (1984) observed an increase in the diameter of osteons in 10 cm sections of femur experimentally heated at 600º C. At this temperature, the haversian systems themselves were not particularly affected by heat so these authors stated that histological age estimation through osteon counting was still achievable in bone heated up to 600º C.

On the other hand, Nelson (1992) obtained results quite similar to those from Forbes (1941) on femoral sections of dissected cadavers. He recorded a decrease in the size of osteons of about 16.7% while the canals increased 10.5%. In this case, the samples were heated to temperatures ranging between 538º C and 815º C. Although these results differ from the ones presented by Bradtmiller and Buikstra (1984), Nelson (1992) also concluded that osteon counting would not be particularly affected by heat-induced shrinkage, although he admits that the opposite could happen under different experimental conditions.

Hummel and Schutkowski (1993, In Fairgrieve, 2008) stated that histological features are still discernable in bones heated up to 700º C. This observation was corroborated by Holden et al (1995b) and this temperature was further extended to 1400º C using the SEM. The latter authors experimentally heated human femoral bone at temperatures ranging from 200º C to 1600º C. Although the lamellar structure was lost at burning levels near 800º C, the haversian canals and the lacunae were preserved up to 1400º C. In addition, Holden et al (1995b) were able to clearly distinguish between low and highly mineralised osteons in bones heated up to 1200º C by using microradiographic analysis.

Hanson and Cain (2007) experimentally burned bone from sheep on a campfire. These authors decided to use qualitative categories rather than to make a quantitative description of the heating based on temperature ranges. Therefore, it is not possible to make a direct comparison with some of the previous researches. No structural changes were observed for bones heated at low and at low/medium temperatures. In contrast, some cracks emanated from the haversian canals at medium heating level. At medium/high temperature, the histological structures were no longer seen in the areas of the bone displaying a white colour. Also, cracks extended outwards from the haversian canals. If heated at a high level, the resulting cracks were wide in the white areas of the bone. Finally, extremely high temperatures led to the loss of histological structures throughout all bone.

Cattaneo et al (1999) experimentally burned human and non-human bones at temperatures ranging from 800º C to 1200º C in order to reproduce the intensities of combustion experienced in house and car fires. Their main goal was, among others, to assess the potential of histological techniques for determining the human origin of burned bones. As a result, these authors stated that the haversian systems were clearly distinguished. This corroborates the conclusions from Holden et al (1995b) who found preserved histological structures in bones heated at very high temperatures.

The differences regarding the results from all authors are probably related with variations on the experimental design which included distinct intensities of combustion and diverse heat sources. For instance, Squires et al (2011) examined both archaeological and experimentally burned samples and proposed that differential duration of combustion is an important factor regarding the preservation of bone microstructure. Therefore, this parameter may be also responsible for the different results obtained previously. Despite these differences, the abovementioned results seem to indicate that under some conditions, the analysis of the histological structure of burned bone – focussing on age estimation or on the determination of the human origin of the remains – is prevented only at extremely high temperatures.

1.4.3. Bone Mineral Structure

The effects of heat on bone mineral structure have also been addressed previously, especially with the aim of determining genuine burning events (Shahack-Gross et al, 1997; Koon et al, 2003; Enzo et al, 2007; Piga et al, 2009; Thompson et al, 2009) and of assessing the potential in dating cremated bones (Lanting et al, 2001; Olsen et al 2008). These investigations have mainly focused on the changes of hidroxiapatite crystals and on the heat-related variations of the crystallinity index (CI), but the carbonate/phosphate ratio (C/P) and the carbonyl/carbonate ratio (C/C) have also been addressed (Thompson, 2009). The CI measures the order of the crystal structure and composition within bone (Stiner et al, 2001; Thompson et al, 2009). In this case, CI increases as crystals get larger and as crystal structure becomes increasingly more ordered (Munro et al, 2007; Thompson et al, 2009). Beyond being heat-related, this process also occurs naturally after death and is enhanced by weathering and by burning (Stiner et al, 2001; Surovell and Stiner, 2001; Piga et al, 2009; Thompson, 2009). Also, the organic content of bone (Trueman et al, 2008) and diagenetic changes in porosity (Nielsen-Marsh and Hedges, 1999) have been linked to CI values. This parameter has been measured using three different methods: X-ray diffraction (XRD); small-angle x-ray scattering (SAXS); and fourier transform infrared spectrocopy (FTIR).

Bonucci and Graziani (1975, in Nicholson, 1993) used XRD and pointed out that the first identifiable heat-induced ultrastructural changes of bone take place at 350º C and consist in the thickening of the hidroxiapatite crystals. Thickness is defined as the smallest size of the crystallite (Hiller et al, 2003). When bone is submitted to 900º C, their orderly crystalline structure is disintegrated (Bonucci and Graziani, 1975, In Hanson and Cain, 2007).

Also using XRD analysis, Shipman et al (1984) found a gradual increase in the size of hidroxiapatite crystals in sheep bones heated from room temperature to 525º C. That increase became more rapid from this point up to 645º C and the structure became more crystalline. Shipman et al (1984) proposed that the heat-related increase in crystal size is made at the expenses of the smaller crystals through coalescence. With slightly different observations, Rogers and Daniels (2002) concluded that the major changes occurred between 600º C and 800º C. Holden et al (1995b and 1995c) also stated that recrystallization began at 600º C. For Shipman et al (1984), no additional changes were detected beyond 645º C while Rogers and Daniels (2002) stated that crystal size, microstrain and lattice parameters remained almost constant only at temperatures above 800º C until carbonated calcium hidroxiapatite started to decompose at 1200º C. As for Holden et al (1995b), fusion of crystals occurred at 1000º C and was prolonged until the temperature reached 1400º C. Eventually, bone mineral melted at 1600º C. Another heat-induced change observed by Rogers and Daniels (2002) consist in the increasing formation of calcium oxide (CaO) at temperatures higher than 700º C although Holden et al (1995a) had recorded this event only at temperatures above 900º C. Roger and Daniels (2002) argue that this discrepancy may be due to the differences in the age of the donors.

Hiller et al (2003) used SAXS to investigate the heat-induced changes in crystallites in a sample of sheep bones experimentally heated at 500º C, 700º C and 900º

C. An increase in crystallite size was found for all specimens and thickness increased more than ten times at the highest temperature that was monitored. The shape also changed with heat, assuming a more homogeneously plate-like appearance in samples heated at 500º C and displaying a more variable form in those heated at 700º C. Hiller et al (2003) found no new mineral formation. The pre-existent hidroxiapatite merely developed into a more crystalline version of itself.

Experimenting on human femoral bones analysed through XRD, Piga et al (2009) found a very gradual increase in crystallite size up to 700º C. This process became more rapid after this point and was especially intense at temperatures above 800º C at least up to 1000º C. Also, the duration of the burning had an important effect on the mineral structure as crystallite size augmented in parallel to time increase.

Using sheep bone analysed with the FTIR, Thompson et al (2009) found that the measuring of the CI is not a very reliable indicator of the temperature of burning because this is not the only factor affecting it. The bone region from where the sample was taken and the FTIR method that was used influence the CI value. Surovell and Stiner (2001) had previously demonstrated that differences in sample preparation can also affect results. Nonetheless, Thompson et al (2009) concluded that the CI, as well as the C/P and C/C ratios can still help determining if bone was subject to low or high intensity burnings.

1.4.4. Surface Morphology

Shipman et al (1984) and Nicholson (1993) carried out comprehensive studies focusing on the effects of heat on the morphology of bone surface. Faunal bones were used in their experiments. The observations from these authors are quite similar although some variations were noted which can be the result of the different temperature intervals used for each experiment and of different SEM magnifications (Table 1.1.1). Shipman et al (1984) and Nicholson (1993) used amplifications from 15x to 15000x and 25x to 15000x respectively. Regrettably, neither systematically stated at which amplification specific changes were indeed observed although Nicholson (1993) did it for a few temperature ranges. Also, Shipman et al (1984) differentiates five stages while Nicholson (1993) discriminates only four distinct stages although the latter presents an intermediate period between the third and the fourth stages. In particular, some noteworthy heat-induced changes in morphology are pointed out by both authors.

These refer to: the undulating surface and observable vascular canals at temperatures lower than 200º C; the glassy appearance displayed by bones heated at approximately 300º C; the frothy appearance of bone surface in bones heated at 400-700º C; and the melting and coalescence of particles into larger structures with very variable shapes at temperatures above 800º C. Some of the differences between both statements may be the result of the different temperature intervals adopted for the analysis. For instance, Nicholson (1993) described a rougher surface with small grains at the hotter end of stage 1 (200º C) while Shipman et al (1984) described the same feature only in stage 2 (185-285º C). Nonetheless, the temperatures recorded during the analyses by both authors are not very contrasting. At the highest temperatures, Nicholson (1993) recorded a more varied surface structure than Shipman et al (1984), but this may have been the result of observation under different magnifications.

The observations made on this issue demonstrated that the analysis of the surface morphological heat-induced changes have some potential for the identification of burned bone and for the estimation of the approximate temperature at which bone was heated to. However, Nicholson (1993) states that this estimation can only have accuracies of about ± 100º C at best. Such method may be misleading because weathering and fossilization of bone mimics bone heat-induced features (Nicholson, 1993; Hanson and Cain, 2007).

1.5. Macroscopic Heat-induced Changes

As seen by the literature review carried out in section 1.3, the bioanthropological investigation has focused on several aspects of burned bones. Nonetheless, there are still many questions either in need of answers or unsatisfactorily answered. Although the level of understanding of the heat-induced changes on bone improved in the last few decades, we still are not completely aware of the effect of these changes on the reliability of the macroscopic methods that are conventionally used in Biological Anthropology.

Macroscopic heat-induced changes have been recurrently investigated in the Past. These investigations focused essentially on five distinct heat-related features. One of this refers to chromatic variations. The remaining four refer to structural bone changes and are due to warping, fracture, size and weight alterations.

Table 1.1.1: Heat-induced morphological changes on bone surface (SEM).

Shipman et al (1984)		Nicholson (1993)	
Stage 1 20 to <185º C	Undulating surface; subchondral bone with vascular canal; bone intact and continuous.	Stage 1 20º C	Surface gently undulating; vascular canals occasionally visible.
		Stage 1 200º C	Rougher surface with small grains; small pores and cracks present; vascular canals prominent.
Stage 2 185 to <285º C	Irregular surface with small granular asperities separated by tiny pores and fissures; bone intact and continuous.	-	-
Stage 3 285 to <440º C	No pores and asperities; glassy and smoother than stage 1; polygonal cracking; demarcated plates and perpendicular to bone surface.	Stage 2 300º C	Glassy layer formed by char; Surface is granular or particulate.
Stage 4 440 to < 800º C	Surface highly particulated on earlier stages rapidly followed by frothiness.	Stage 3 400º C	Surface spherical particles are frothy and less regular; polygonal cracking (LM).
		Stage 3 500º C	Subchondral bone is pitted (mag. = <1000 x) or frothy (mag. = >1000 x).
		Stage 3 600º C	Subchondral bone becomes less pitted and very frothy.
-	-	Stage 3/4 700º C	Variable surfaces: 1) frothy areas; melting; and 2) recrystallization of particles into nodular and rod-like forms
Stage 5 800 to <940º C	Particles melt and coalesce into larger structures.	Stage 4 <800 to >900º C	Pitted surface with raised areas surrounding the vascular canals (<1000 x); At higher magnifications, hidroxiapatite crystals coalesced into larger structures; donut-shaped raised areas surrounding the vascular canals; possible hexagonal plates

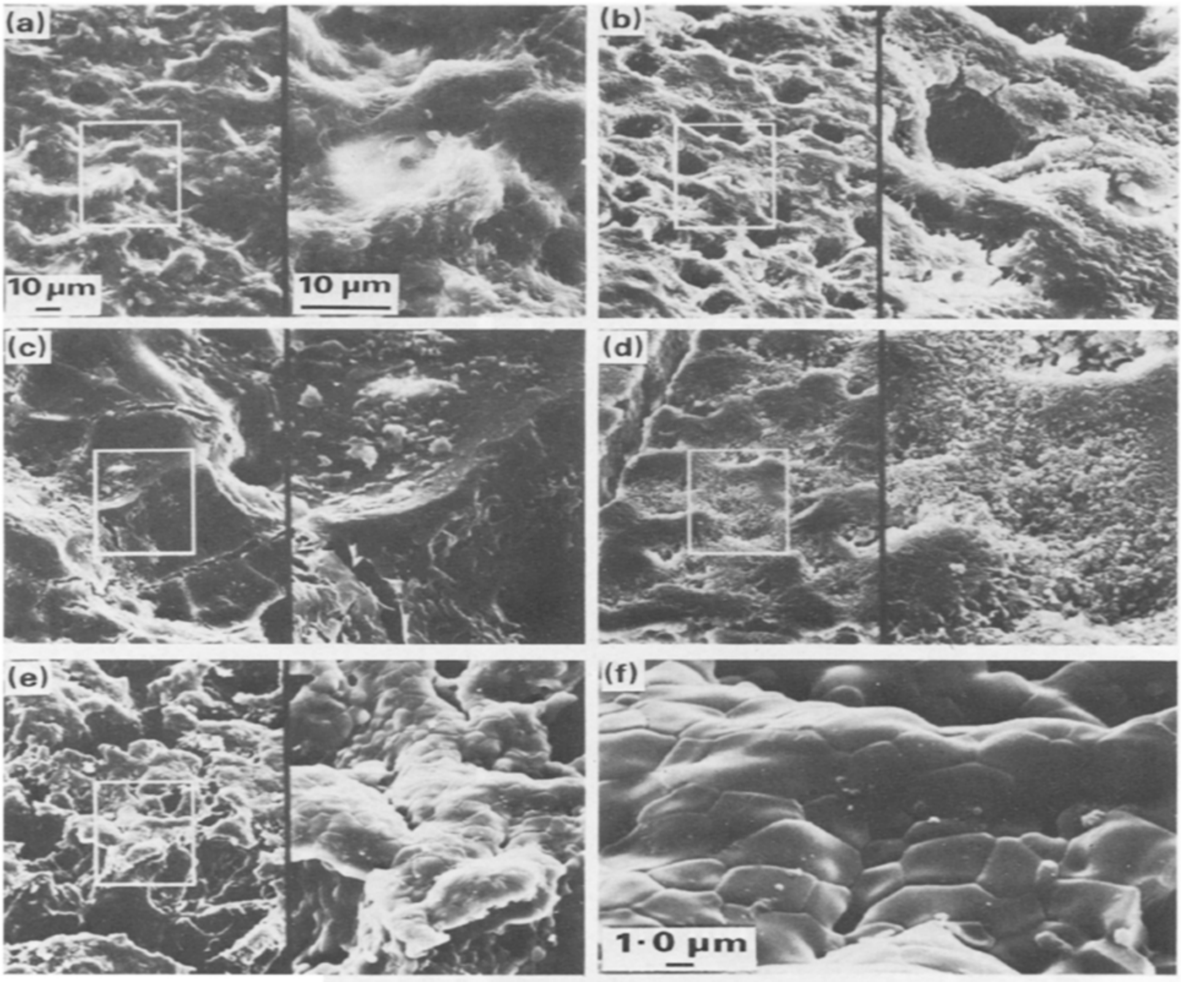

Figure 1.1.3: Heat-induced morphological changes on bone surface (SEM) as described by Shipman et al (1984). Key: a) stage 1; b) stage 2; c) stage 3; d) stage 4; e) stage 5; f) stage 5 at higher magnifications. Adapted from Shipman et al (1984).

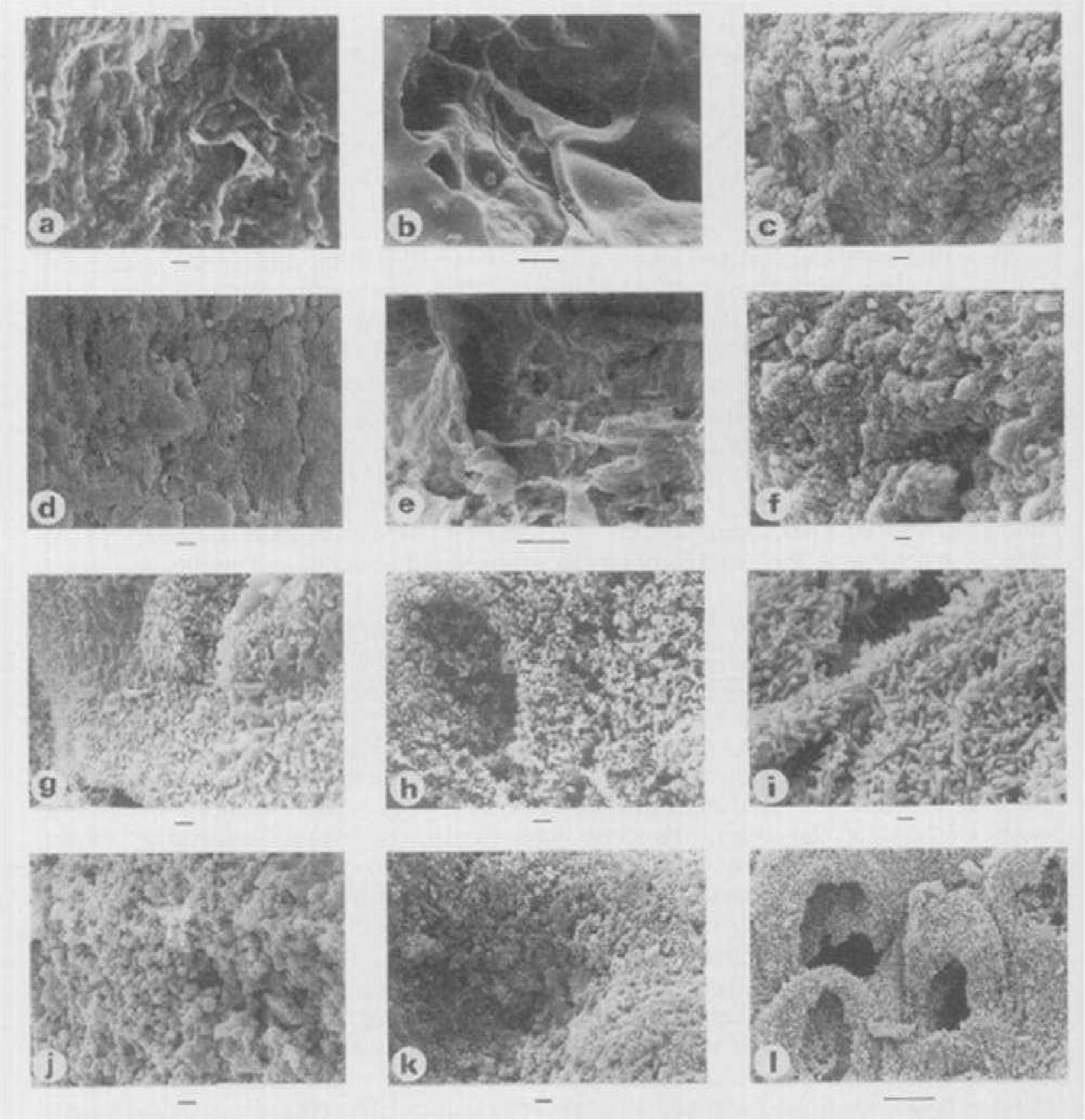

Figure 1.1.4: Heat-induced morphological changes on bone surface (SEM) as described by Nicholson (1993). Key: a) sheep phalange, unheated; b) sheep phalange, 300º C; c) sheep phalange, 400º C; d) mid-brown sheep astragalus; e) black sheep astragalus; f) mid-grey sheep astragalus; g) sheep phalange, 700º C; h) sheep phalange, 600º C; i) sheep phalange, 900º C; j) white sheep navicular-cuboid; k) light blue, light grey and white sheep phalange ; l) pigeon tibiotarsus, 900º C. Scale bar = 1 micron except (b), (e) and (l) where scale bar = 10 microns. Adapted from Nicholson (1993).

1.5.1. Colour

Colouration has been investigated by several researchers and chromatic changes were explained to be the result of heat-induced alterations in the chemical composition of bone, especially regarding its organic components (Shipman et al, 1984; Buikstra and Swegle, 1989; Mayne Correia, 1997; Thompson, 2004). This leads the bone to assume new colourations which sequentially range between brown, dark grey, black, light grey and white. Also, it was demonstrated that colour is somewhat correlated with the intensity of combustion (e.g.: Shipman et al., 1984; Etxeberria, 1994; Mays, 1998; Walker and Miller, 2005; Walker et al, 2008). However, this correlation is not straightforward because other factors, such as the oxygen intake during cremation or the combustion environment, play also a part in the chromatic variation (Walker and Miller, 2005; Walker and Miller, 2008). Also, individual variation in the ability to perceive colour and post-depositional colour changes may interfere with that assessment (Shipman et al, 1984). Nonetheless, the heat-induced bone and teeth colourations still help determining if these are pre-calcined or calcined. Colour discrimination has also been pointed out as a valuable indicator of the presence of collagen in bone (Walker and Miller, 2005; Walker et al, 2008).

1.5.2. Warping

The warping feature was proposed as an indicator of the pre-cremation condition of the remains (Baby, 1954; Binford, 1963; Etxeberria, 1994) although this statement has been disputed (Buikstra and Swegle, 1989; Spennemann and Colley, 1989; Whyte, 2001). Preliminary results of this project regarding the analysis of dry human skeletons have also confirmed the latter position (Gonçalves et al, 2011b).

As part of an investigation regarding the archaeological remains from the Hopewell people, Baby (1954) experimentally burned a whole fleshed cadaver and some dissected green bones. This author also referred to results from cremated dry bones although the origin of this material was not mentioned in the paper. Baby (1954) stated that dry bones do not exhibit warping. The same conclusion was reached by Binford (1963) who only found this event on the experimentally burned skeletal remains of a monkey cadaver. Recently macerated bones and archaeological bones with 1500 years were also experimentally burned under the same investigation and no warping was present on them. All remains were burned in a charcoal fire. Stewart (1979, In Fairgrieve, 2008) obtained similar results to those presented by Binford (1963) on defleshed and dried specimens. Thurman and Willmore (1981) experimentally burned 8 human humeri in an oak fire. From these, half still had flesh while the remaining half had been recently defleshed by caustic methods. They found warping in both cases but regrettably did not make observations on dry bones. Buikstra and Swegle (1989) presented contrasting results from those published previously. These authors found warping on archaeological human bones, fleshed human bones and recently defleshed human bones that were experimentally burned in open-air oak fires. The same observation was made by Spennemann and Colley (1989) who also found warping after the cremation of a dry archaeological human humerus. Etxeberria (1994) carried out a burning experiment in both recently human defleshed bone and human dry bone samples and found warping only on the former. As for Whyte (2001), this event was present in fleshed, recently defleshed and dry faunal bones cremated on open-air experimental pyres. Finally, Gonçalves et al (2011b) found warping in dry human bones burned at a modern crematorium fuelled on gas thus further demonstrating that this feature is not exclusively linked to the burning of fleshed bones or to recently defleshed bones.

Several explanations have been proposed for the occurrence of warping events. Binford (1963) suggested that it could be the result of the contraction of muscle fibres. Instead, Spennemann and Colley (1989) argued that the trapping of heat in the shaft hollow could lead to the bending of the bone. As for Thompson (2005), the explanation was laid on the contraction of the periosteum and to the different distribution of collagen within bone. Following the last hypothesis, Gonçalves et al (2011b) argued that the occurrence of warping events could depend on the preservation of collagen and the consequent preservation of collagen-apatite bonds within bone thus being unrelated with the presence of soft tissues.

1.5.3. Fractures

Along with warping, differences regarding the pattern of fractures have also been associated to the pre-cremation condition of the remains. A categorization of fractures can be consulted in figure 1.1.5. In this case, most authors agreed that thumbnail fractures – or transverse curved fractures – were exclusively the result of the burning of fleshed and green bones. Other fracture patterns have been linked to either fleshed/green bones or dry bones. However and unlike thumbnail fractures, none has been indisputably pointed at as discriminators of the pre-cremation condition of human remains. Krogman (discussed in Webb and Snow, 1945) linked “checking” to dry bones but Baby (1954) observed this feature in both this and fleshed bones although only superficially for the former. In addition, this author associated deep longitudinal fractures to dry bones and deep transverse fractures to fleshed/green bones. The same observation on dry bones was carried out by Binford (1963) but deep longitudinal fractures and transverse serrated and curved fractures have this time also been detected on fleshed bones from a monkey. As for Thurman and Willmore (1981), deep serrated transverse fractures and diagonal fractures were found on fleshed bones while serrated fractures near epiphyses and deep parallel-sided fractures were present on recently defleshed bones. Buikstra and Swegle (1989) pointed out deep and long longitudinal shaft fissures and deep transverse splitting as being present on fleshed and green bones. On the other hand, dry bones presented shallow and long longitudinal fissures and shallow and infrequent transverse splitting. In addition, concentric cracks in the popliteal area of the femur were found for fleshed bones but were absent on green bones. Etxeberria (1994) found both transverse and longitudinal fractures on recently defleshed long bones while dry bones were longitudinally fragmented. Longitudinal and transverse cracks were found on fleshed, green and dry bones by Whyte (2001).

Given all these statements, it becomes evident that diverse or even contrasting observations have been presented thus complicating the interpretation of the pre-cremation condition of the remains. Furthermore, many distinctions between fleshed, green and dry bones seem to rely only on differences of degree of specific kinds of fractures rather than on the presence/absence of those very same features. As a result, their description becomes quite subjective. Probably, this may have been caused more by differences regarding the intensity of combustion between each experimental cremation than by differences in the pre-cremation condition of the remains.

As previously mentioned, thumbnail fractures appear to be the only heat-induced feature that has been recurrently indicated as a discriminator of the pre-cremation condition of skeletal remains. In the experiments described above for heat-induced warping, both Baby (1954) and Binford (1963) did not find thumbnail fractures as a result of the burning of dry bones. Thurman and Willmore (1981) found them in both fleshed and recently defleshed bones but did not experiment on dry bones. As for

Buikstra and Swegle (1989), these authors also reported the absence of this feature on dry bones. However, Gonçalves et al (2011b) demonstrated that thumbnail fractures were also produced during the burning of that kind of material so its application as reliable indicator of the pre-cremation condition of human remains was jeopardized. As for justification regarding the occurrence of thumbnail fractures, no explanations have been proposed until now. However, Gonçalves et al (2011b) suggested that, like for warping, it may also be related to the preservation of collagen.

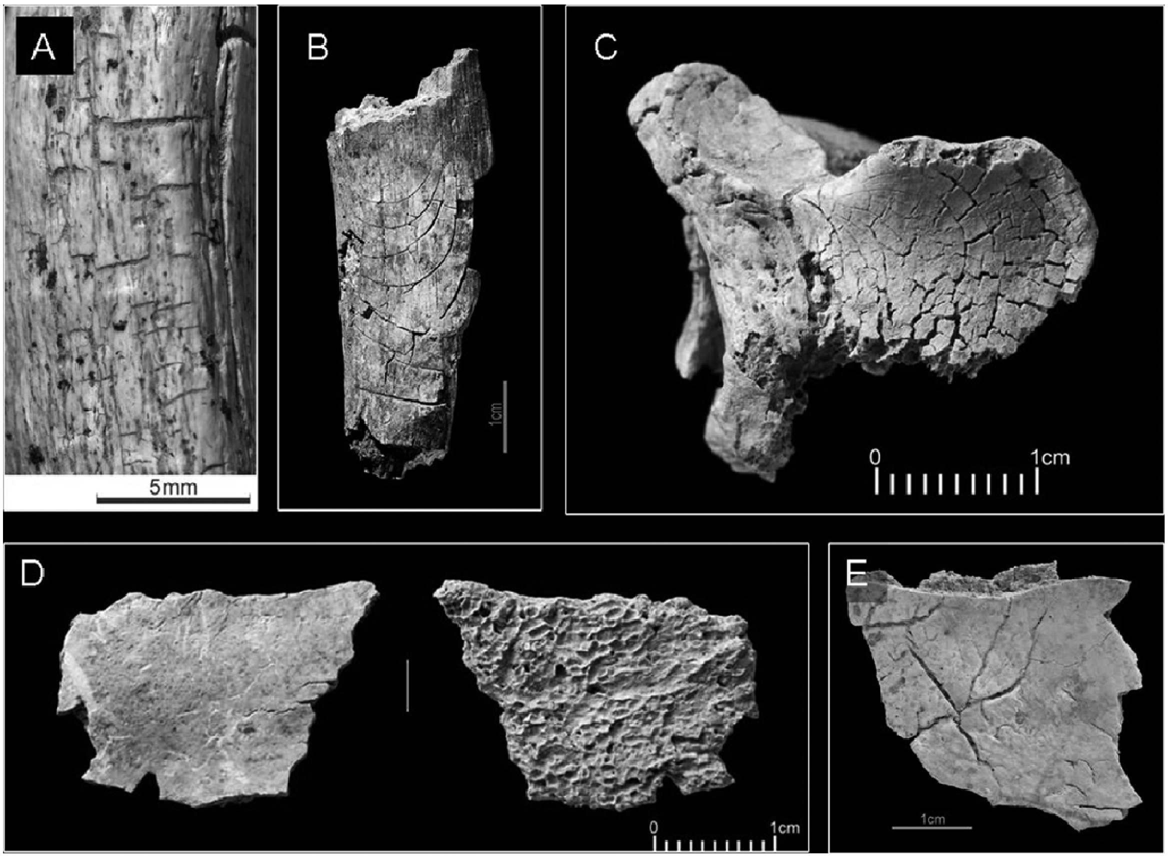

Figure 1.1.5.: Heat-induced fractures. a) transverse and longitudinal fractures in long bone; b) thumbnail or curved transverse fractures in long bone; c) patina or reticular fractures in articular surface; d) separation of cranial tables or delamination fractures; e) dendritic fractures in cranium (Photo: J. P. Ruas).

1.5.4. Dimensional Changes

It has been previously mentioned that the heat-induced transformation of bone encompasses four distinct transformation stages and that these can be observed at specific, although overlaid, intervals of temperature (Mayne Correia, 1997; Thompson, 2004). The last stage – fusion – is arguably the most relevant for osteometric analysis since heat-induced dimensional changes are more substantial during this phase.

Heat-induced dimensional change has also been the object of some experimental studies (Malinowski and Porawski, 1969; Piontek, 1975; Herrmann, 1977; Grupe and Herrmann, 1983, In Fairgrieve, 2008; Bradtmiller and Buikstra, 1984; Holland, 1989; Hummel and Schutkowski, 1989, In Fairgrieve 2008; Thompson, 2005). The degree of shrinkage obtained on these experiments has been quite varied. This variation was explained to be the result of differences in temperature of combustion (Herrmann, 1977; Shipman et al, 1984; Thompson, 2005), differences in mineral content, differences between compact and spongy bone (Herrmann, 1976, In Fairgrieve 2008) and differences in the orientation of collagen fibrils (Hummel and Schutkowski, 1989 In Fairgrieve, 2008).

Dimensional changes on burned bones have been addressed previously, especially because of its impact on the application of osteometric techniques. Malinowski and Porawski (1969) examined the measurements of several cranial and postcranial features and found a reduction in size ranging between 0.7 mm and 7 mm for the former and between 1.2 mm and 12 mm for the latter. Regrettably, the relative shrinkage was not accounted in this study. Strzalko and Piontek (1974) found heat-induced shrinkage to be of about 10.5-17.6% for the epiphyses of long bones and of about 10.2-19.3% for some cranial measurements. Herrmann (1976, In Fairgrieve 2008) stated to have found shrinkage up to 1-2% in bone segments burned to temperatures below 800º C. In contrast, bone segments burned at 1000-1200º C presented 14-18% shrinkage. Grupe and Herrmann (1983, In Fairgrieve, 2008) found a 12% size reduction for measurements on spongy bones. Shipman et al (1984) obtained a similar result on animal bone. Bones burned below 800º C recorded less than 5% of shrinkage on average while bones burned above that temperature presented a mean shrinkage of 15%. Bradtmiller and Buikstra (1984) recorded 5% overall shrinkage on human femur burned at 600º C but stated that the bone may expand slightly before shrinking. The small percent shrinkage on bones heated up to 800º C observed on these experimental researches was also confirmed by Holland (1989) who recorded 1-2.25% of reduction on sections of the occipital bone. Thompson (2005) found a wide range of dimensional changes on bones burned at different temperatures (500º; 700º; 900º), for different lengths of time (15’; 45’) and measured at different points after removal from the furnace (5’; 15’; 25’). A variation between -4.5% and 13.0% for those burned up to 500º C was recorded. An interval between -1.7 and 19.3% was found for bones burned up to 700º C. As for those burned at 900º C, the relative heat-induced dimensional changes varied between -3.9% and 37.7%. Both reduction and expansion was found to occur thus confirming the statement of Bradtmiller and Buikstra (1984). The mean value recorded by Thompson (2005) regarding eleven features, and 25’ after removal from the furnace, was of 3.2% at 500º C, 7.3% at 700º C and 13.9% at 900º C.

The potential of osteometric sex determination has been occasionally investigated in the Past. In theory, morphological sexual dimorphism is not as affected by heat-induced changes as osteometric features. On the other hand, metric analysis has one advantage over morphological analysis which is the possibility of assessing sex through a univariate approach. Morphognostic features require a multivariate examination which is very often impossible to fulfil on fragmentary cremains (Piontek, 1975; Fairgrieve, 2008). Osteometric analysis is complicated by heat-induced dimensional changes affecting bone which can be very diverse according to the variables abovementioned in this section. Overcoming this obstacle is not an easy task. Buikstra and Swegle (1989) recommended the use of a correction factor which goes from 0% to 10% depending on the degree of combustion of the organic phase. Then, such selection of the calibration factor appears to be a very subjective procedure although one may infer that calcined bones should be corrected using the largest figure because shrinkage is more substantial at this stage. We do not know how accurate such procedure is indeed.

Although at the light of our current knowledge, dimensional changes are indeed unpredictable and may lead to differential shrinkage on calcined bones, several authors stated that osteometric sexual dimorphism is still present on this kind of human remains (Gejvall, 1969; Malinowski, 1969; Piontek, 1975, 1976; Rosing, 1977; Holck, 1986; Wahl, 1996). Nonetheless, its potential for sex determination was described as being limited (Dokladal, 1962; Strzalko and Piontek, 1974; Rosing, 1977; Holck, 1986; Thompson, 2002 and 2004; Fairgrieve, 2008). Despite this, some success has been obtained regarding the sex determination of individuals from burned bones thus encouraging its further investigation. The thickness of the skull, the diameters of the humeral head and the thickness of the shafts from the femur, humerus and radius were proposed as valuable sex discriminators by Gejvall (1969) who developed is research on a modern crematorium fuelled by gas in Stockholm. The sample was composed of 50 males and 49 females and provided for metric references regarding sex determination. Van Vark (1975) and Van Vark et al (1996) investigated several sexually dimorphic cranial and post-cranial features on a sample of 136 males and 115 females also cremated in Stockholm in 1971. Several procedures were investigated in both this and a series of unburned skeletons from Amsterdam and then applied to these two and to a series of skeletons from the Bronze Age. The results for the Stockholm series – for which sex and age was known – were extremely good for the male individuals and reasonable for the female individuals. The former were correctly sex classified on 92% of the cases while the same procedure was successful in 79% on the latter. Noticeably, the results for the Stockholm burned series were slightly better than the results for the Amsterdam unburned series thus demonstrating that metric analysis was not prevented by heat-induced changes. In addition, Schutkowski (1983) and Schutkowski and Herrmann (1983) obtained reasonable results by using discriminant function analysis on the petrous bone. The research was developed on 47 isolated pars petrosae from males and another 47 from females. The correct classification ranged from 67.0% to 73.4%.

1.5.5. Skeletal Weights

Heat-induced weight loss occurs mainly during the dehydration and decomposition stages as a result of the removal of water and of the pyrolisis of the organic component (Hiller et al, 2003; Thompson, 2004). Several investigations experimentally addressed heat-induced weight loss. Grupe and Hummel (1991) recorded the pre- and post-cremation weight of three femoral samples of compact bone from modern pigs. They found an increase in weight loss according to increasing temperature which was of almost 60% on a sample burned to 1000º C. An accelerated weight reduction was recorded at 200-300º C and at 900-1000º C, although only one sample revealed the latter result. From 400º C to 900º C, the increasing weight loss was very gradual. Loss weight was also addressed by Person et al (1996) using burned cortical bone from cows. About one third of reduction occurred in samples heated up to 400º C for an hour. Only 5% additional weight loss was recorded from this to 700º C thus reproducing the results from Grupe and Hummel (1991).

Hiller et al (2003) estimated that their modern sheep samples of cortical bone lost about 31-56% of their original weight after experimental burning which included the following range of temperatures: 500º C; 700º C; and 900º C. Several samples were burned at different lengths of time (15’; 45’). In four different samples burned at 900º C, the smallest weight reduction was of 43% on a bone heated for 45 minutes while another one submitted to the same intensity of combustion experienced 52% of weight loss. Enzo et al (2007) found an association between bone weight loss and increasing temperature. The former was only of about 17% when the sample of cortical bone was heated at 900º C which is quite small when compared with the values obtained by other researchers on samples that were heated at a similar temperature (Grupe and Hummel, 1991; Hiller et al, 2003). Such difference may be explained by the fact that Enzo et al (2007) used archaeological bone so it is possible that this had already experience substantial weight loss.

Samples of cortical bone from modern white-tailed deer were also experimentally burned by Munro et al (2007) from 25º C to 900º C in 25º C increments. Once again, their results demonstrated a relationship between temperature and weight loss. This was of about 23% up to 325º C. Then, it increased quite substantially after 325-350º C. and the reduction stabilized after 450º C at which point it was of about 40%. The maximum difference between pre- and post-burning weight was of 43% at 900º C. Given the previous investigations, it seems that most of the weight reduction occurs at somewhat low intensity burns (<400º C).

The issue of skeletal weights has also been addressed using a different perspective. Rather than estimating the weight loss at the bone level, some researchers have documented skeletal weight at the population level. This has been done in order to use it as an analytical tool for the assessment of the completeness of assemblages involving burned human skeletal remains (McKinley, 1993; Warren and Maples, 1997). In theory, the weight of cremains can be compared to these reference weights and therefore make inferences about their completeness. Such documentation has already been carried out for several populations (Table 1.1.2). Some of the first studies were carried out in Europe by Malinowski and Porawski (1969) on a Polish population, by Herrmann (1976, In Duday et al 2000) on a German population and by McKinley (1993) on a British population. Then, some other studies were completed in the United States (Sonek, 1992 In Bass and Jantz, 2004; Warren and Maples, 1997; Bass and Jantz, 2004; Van Deest et al, 2011). Finally, an additional study on a Thai population was carried out by Chirachariyavej et al (2006).

The mean skeletal weight of the burned skeletons reported on all those studies presented a large variation. The European samples were apparently quite lighter than the ones from the United States and Thailand. Given that the weighing procedure was in some cases unmentioned, the variation in skeletal weights may be the result of different courses of action regarding this operation. In addition, the variation observed within and between the several studies has also been proposed to be the result of age, sex and regional differences (McKinley, 1993; Bass and Jantz, 2004; Chirachariyavej et al, 2006; May, 2011; Van Deest et al, 2011). Indeed, a negative correlation between age and weight was found by several researchers (Malinowski and Porawski, 1969; Bass and Jantz, 2004; Chirachariyavej et al, 2006; May, 2011) and females recurrently weighed less than males – a fact also demonstrated on unburned skeletons (Silva et al, 2009). As for the regional differences, Bass and Jantz (2004) and May (2011) point out that there is considerable variation in the obesity rate and the body weight of the different living populations in the United States. However, this does not seem to explain the very dissimilar results obtained on two samples from California by Sonek (1992 In Bass and Jantz, 2004) and Van Deest et al (2011). Chirachariyavej et al (2006) also indicated that body weight has a positive correlation with skeletal weight. In addition, these authors also stated that different coffins may lead to variation regarding the weight of cremains.

Table 1.1.2: Mean weights for burned skeletal remains of females and males (in grams).

Author	Females		Males	
	g	n	g	n
Malinowski and Porawski (1969)	1540	-	2004	-
Herrmann (1976, In Duday et al 2000)	1700	226	1842	167
McKinley (1993)	1616	6	2284	9
Sonek (1992 In Bass and Jantz, 2004)	1875	63	2801	76
Warren and Maples (1997)	1840	40	2893	51
Bass and Jantz (2004)	2350	155	3379	151
Chirachariyavej et al (2006)	2120	55	2680	55
Van Deest et al (2011)	2238	363	3233	365

The weight of burned skeletal remains has been used for a wide range of purposes. For example, it has been indicated as a criterion to estimate the minimum number of individuals and the sex of an individual although this approach certainly has some frailties (Duday et al, 2000; McKinley and Bond, 2001; Fairgrieve, 2008). Although sexual dimorphism is indeed present, cremains are often incomplete – especially in archaeological contexts – and may lead to erroneous estimations. The same goes for the attempt to establish the minimum number of individuals. The exception relies only with unusually large assemblages of cremains which may suggest the presence of more than one individual. Another application of skeletal weights is related to the reconstruction of the funerary behaviour and practice of Past populations. Reference weight values have been used for comparative analysis with remains from cremation burials in order to estimate the thoroughness of their retrieval and deposition in the urn or grave (Holck, 1986; Murray and Rose, 1993; McKinley, 1994; Murad, 1998; Smits, 1998; Duday et al, 2000; Richier, 2005; Gonçalves, 2007; Gonçalves et al, 2010). In addition, the proportion of the skeletal anatomical regions has been used to estimate if this presents a typical configuration in cremation burials (Duday et al, 2000; McKinley and Bond, 2001; Blaizot and Georgeon, 2005; Richier, 2005; Gonçalves, 2007; Gonçalves et al, 2010). This could thus suggest that specific bones have been selected from the pyre to be buried. In order to make the comparison, the proportion of the skeletal regions has been compared directly to weight references obtained from unburned skeletons such as those from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) and from Silva et al (2009). However, this kind of analysis does not take into account that heat-induced weight loss can be differentially experienced by each skeletal region and that the extreme fragmentation of cremains prevents the anatomical identification of all bone fragments. As a result, such comparison must necessarily be biased because burned and unburned skeletons may present different proportions. In addition, the portion of undetermined fragments is often too large to not be accounted for.

1.6. The Research Questions and Objectives

The current investigation aims to contribute for further insights on three specific issues by collecting data from modern cremations processed in a gas fuelled crematorium. The main question regards the osteometric sex determination of unknown calcined skeletal remains, but other subjects related to the skeletal weight and to the bone heat-induced changes are also addressed and are further described next to this section. Although it is not the main research question of this thesis, the latter issue is firstly addressed in order to contextualize all findings according to heat-induced bone changes. In summary, these are the main goals of this thesis:

1) Assess the potential of heat-induced warping and thumbnail fracturing on bone for the determination of the pre-cremation condition of human remains;
2) Determine the impact of heat-induced dimensional changes on skeletal sexual dimorphism and on the potential of osteometric sex determination;
3) Assess the potential of skeletal weights and skeletal proportions for bioanthropological analysis.

1.6.1. The Pre-cremation Condition of Remains

As a complement to the preliminary results of this thesis already published (Gonçalves et al, 2011b), additional results regarding the occurrence of heat-induced warping and thumbnail fracturing on bone, as well as their potential for the determination of the pre-cremation condition of the human remains are presented. These intend to tackle some of the issues that were not dealt previously. In order to do so, the sample was enlarged and both features were now examined on two different samples. One of these was composed of cadavers cremated soon after death and the other one was composed of dry skeletons that had been inhumated for several years before actually being submitted to cremation. The examination of these two samples allowed for a comparative analysis in order to detect variations between them concerning the occurrence of the two features which have recurrently – or intermittently, in the case of warping – been pointed out as discriminating criteria of the pre-cremation condition of the remains. In addition, the enlargement of the sample allowed for the carrying out of the statistical analysis which had not been completed for the publication of the preliminary results due to its small size at the time. This allowed for the investigation of a number of factors regarding its potentially significant effect on the occurrence of both events. As a result, the duration and temperature of combustion were investigated. Also, the pre-condition of the remains, the period of inhumation for the dry skeletons, the age-at death and sex were included in the analysis thus allowing for the investigation of multivariate factors. The main purpose of this specific research was then to determine the differences on the prevalence of warping and thumbnail fractures between cadavers and skeletons thus assessing its usefulness for the estimation of the pre-cremation condition of the remains.

1.6.2. Heat-induced Dimensional Changes

The previous researches regarding heat-induced dimensional changes demonstrated that, although the mean percent shrinkages obtained by the several experiments were somewhat uniform, the variation within both pre-calcined and calcined bones was quite substantial. The present topic regarding heat-induced dimensional changes encompassed three objectives. First, it aimed to document the amount of shrinkage observed in both pre-calcined and calcined bones processed in a modern crematorium. This was done by comparing pre- and post-cremation measurements on dry bones. Such documentation enriched the still quite limited amount of research carried out in this particular field. Secondly, the mean percent shrinkage for calcined bones was used as a correction factor to calibrate standardized metric references used on the sex determination of unburned skeletons. This procedure intended to assess if such a calibration improved the accuracy of osteometric sex diagnosis and if this could therefore be reliably applied to calcined bones. Thirdly, the potential of colour assessment in order to roughly determine the amount of shrinkage was investigated. In order to do this, the blackish charred bones were separated from the whitish calcined bones and the mean percent shrinkages of each were then calculated to assess if the former had shrink lesser than the latter. A successful discrimination between less size-affected bones and more size-affected bones could eventually be helpful to determine what kind of shrinkage correction factors – if such procedure is proven to be reliable – should be used on a specific burned bone. Therefore, the investigation on heat-induced dimensional changes was closely linked to the investigation regarding the osteometric sex determination.

1.6.3. Osteometric Sexual Dimorphism

Different parts of the skeleton may be subject to different intensities of combustion. Therefore, dimensional change may be contrasting between specific bones from the left and right sides of the body. In addition, variation from one skeleton to another may also be present. This complicates to a great extent any osteometric analysis. Nonetheless, this research tried to assess if such a procedure was still useful regarding sex determination. The investigation was carried out in a modern gas-fuelled crematorium which does not completely recreate the combustion conditions present on ancient cremations or modern accidental or incidental deaths associated with fire events. However, the sequence of heat-induced transformation of bone was maintained for this sample since it is dependent of temperature (as explained in section 1.4.1). Based on this sequence, the calcined bones examined in this investigation forcibly experienced dimensional changes since most of them were burned at temperatures higher than 800º C. As a result, mean relative shrinkage must have been of about 12-18% based on a review of previous researches (Strzalko and Piontek, 1974; Herrmann, 1977; Grupe and Herrmann, 1983, In Fairgrieve, 2008; Shipman et al, 1984; Thompson, 2005).

The analysis of osteometric sex determination on burned bones included three objectives. The first research subject approached by this investigation was to document the preservation of all measurable features that were here taken into account. In addition, the investigation of eventual factors significantly related with preservation was carried out. Therefore, the effect of specific biological traits – age and sex – and of the intensity of combustion on preservation was examined. This investigation was done in order to determine the potential for the use of osteometric techniques on this kind of material. The present research also assessed if sexual dimorphism was indeed retained by calcined bones despite possible differential shrinkage. This was carried out on two different samples. The first one was composed of bones from individuals cremated right after death and the second was composed of dry bones from previously inhumated skeletons. Finally, another aim of the investigation was to find out if classification according to sex on completely cremated skeletal remains could be achieved on a Portuguese population based on population-specific metric references developed from calcined bones. If proven to be reliable, such a procedure would contribute considerably for the bioanthropological analysis of skeletal burned remains.

Three different osteometric strategies were adopted. First, the blind sex determination of individuals – for which the sex was known – has been attempted by using a sex discriminating cut-off point. Secondly, the same operation was carried out by using logistic regression coefficients. Finally, as abovementioned, sex classification was carried out by calibrating the standardized metric references developed on the collections of identified unburned skeletons from the University of Coimbra. This calibration was done according to two specific shrinkage correction factors recommended by both this investigation and by Buikstra and Swegle (1989).

Although osteometric traits should maintain only a supporting role in relation to morphological traits for the estimation of sex, the former may well be often the only diagnostic features available for analysis when dealing with burned remains. Although the preservation of measurable features is the Achilles' heel regarding cremains, the multiplicity of available techniques developed for sex determination enhances the opportunities for establishing this key parameter of the biological profile. Therefore, this investigation intends to be a contribution to this particular field.

1.6.4. Skeletal Weights

Skeletal weights were also investigated in the current project. Following the studies mentioned in section 1.5.5, values for the Portuguese population were now obtained. This was done for two main reasons. First, it allowed for the comparison with other weight references for burned skeletons. The aim was to compile Portuguese population-specific weight references and to determine if substantial variation was present between this and the already published references from other geographical regions. Once more, the analysis was carried out in two different samples: cadavers and skeletons. The variation in skeletal weight was investigated accordingly to the pre-cremation condition of the remains, age-at-death, sex, duration and temperature of the combustion. This was done to determine if any of the factors had a significant effect on the weight of the cremains. Expectantly, the new references intend to be useful for the analysis of both archaeological and forensic contexts. Although weight analyses can be problematic – especially in disturbed contexts including only incomplete sets of human remains – they can still be of some use, particularly when supported by other kinds of data such as the estimated minimum number of individuals. It can be suggestive of the presence of more than one individual in a given assemblage and of the consequent commingling of remains (Duday et al, 2000). In addition, the variation between the expected and observed representation of skeletal regions can point towards the incompletion and scattering of the remains over more than one location. This procedure has been followed previously by some researchers as seen in section 1.5.5.

Secondly and to contribute for the analyses regarding the skeletal representation, a comparison with weight references for unburned skeletons (Silva et al, 2009) was carried out with the aim of determining to what extent the heat-induced weight loss and the incomplete anatomical identification of bone fragments interfere with the natural proportions of each skeletal region. This is important because such interference may lead to the inadequacy of the weight references developed on unburned skeletons – such as the ones from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) or Silva et al (2009) – when used as comparison for assemblages of burned skeletal remains. As a result, the documentation of references for skeletal proportions that are more suited for the analysis of burned bones was also carried out. This kind of analysis has previously been used to recreate the mode of retrieval of the remains from the pyre and their mode of deposition in the place of burial (see section 1.5.5). The adoption of references specific to assemblages of burned bones in single burials could lead to more reliable results regarding the interpretation of funerary practice from archaeological remains. We believe that the use of the current weight references developed on unburned skeletons lead to the flawed overestimation of burials displaying atypical skeletal proportions. This is probably the result of incomplete and differential anatomical identification of bone fragments which tends to be more easily achieved for the cranium and the trunk than for the limbs (Duday et al, 2000; McKinley and Bond, 2001; Duday et al, 2009). Therefore, the potential for the adoption of references specific to burned skeletal remains was investigated.

1.7. Thesis Structure

This thesis was built based on the typical scientific format: introduction > material and methods > results > discussion > conclusion. Therefore, its structural arrangement and comprehension are quite straightforward. The introductory text presented in the previous pages attempted to familiarize the reader with the specificities regarding the bioanthropological analysis of burned bone. Chapter 2 focuses on the material that was examined in this study and the methods that were used for its fulfilment. That chapter describes the equipment used for the cremation of the remains and the burning process itself. Then, the samples are presented in detail. Finally, the methods followed to attain every research aim are also explained.

The objectives of this study were outlined in section 1.6. Each of these was dealt independently from the others as autonomous topics. As a result, all of these have separate and specific sections regarding their results (Chapter 3) and respective discussion (Chapter 4). Although the research of heat-induced dimensional changes is closely linked to the topic regarding sexual dimorphism, it was dealt separately so that the documentation of this event and the investigation of the factors related to it could be addressed on their own. Also, this allowed making less burdensome the structure of the thesis which would have otherwise become more complex and more difficult to apprehend. Nonetheless, some of the results obtained for the dimensional changes analysis were afterwards adopted for the investigation of osteometric sex determination.

At last, the conclusion (Chapter 5) makes an overview of the findings resulting from this research and their importance for biological anthropology and bioarchaeology.

2. Material and Methods

2.1. The Crematorium

2.1.1. The Cremator

Permission was granted by the municipal authorities of Porto for the collection of quantitative data at the local crematorium (Fig. 2.1.1.). The cemetery of Prado do Repouso uses a Diamond Mark III cremator from J. G. Shelton (United Kingdom). Plans of this equipment can be consulted in figures 2.1.2 and 2.1.3. This kind of cremator runs on gas. It has been coated in brick and is composed of three different platforms (or hearths) thus forming three rather distinct functional chambers. The admission of the human remains is carried out through the loading gate onto the top chamber at the beginning of the cremation. The gate opens vertically and is located at the anterior end of the cremator. The platform on the top chamber has been built in brick and displays several openings running through it and acting as a mesh in order to allow for the disarticulated bones to fall onto the platform of the lower intermediate chamber. Two other smaller gates are located at the posterior end of the cremator. These gates slide horizontally and have small circular heat-resisting spyglasses that allow for visual inspection during the cremation. After this is concluded, a metal rake is introduced through these gates in order to shove the remains onto the recollection interface situated in the ground chamber.

The platform of the intermediate chamber has also been built in brick but has no openings. It gathers most of the remains falling from the top chamber during cremation. However, both the top and intermediate platforms do not run completely across the length of the chambers thus presenting a gap at their posterior end. This causes some remains – especially those from the feet – to fall onto the ground floor.

The Diamond Mark III cremator has two main burners placed at the vault of the top chamber. This position allows directing the flame downwards at the axial skeleton which is more resilient to fire than the limbs. These burners thus act over the top platform on which the body is placed at the beginning of the operation. A third burner – the entry burner – is present at the posterior end of the ground chamber of the cremator.

This can be used for pre-heating the oven and also at the end of the cremation to further burn the wood residues from the coffin. The three burners are also able to inject air into the chambers. The extraction of the remains is carried out through the retrieval chamber at the lower posterior end of the cremator after gathering them into a tray.

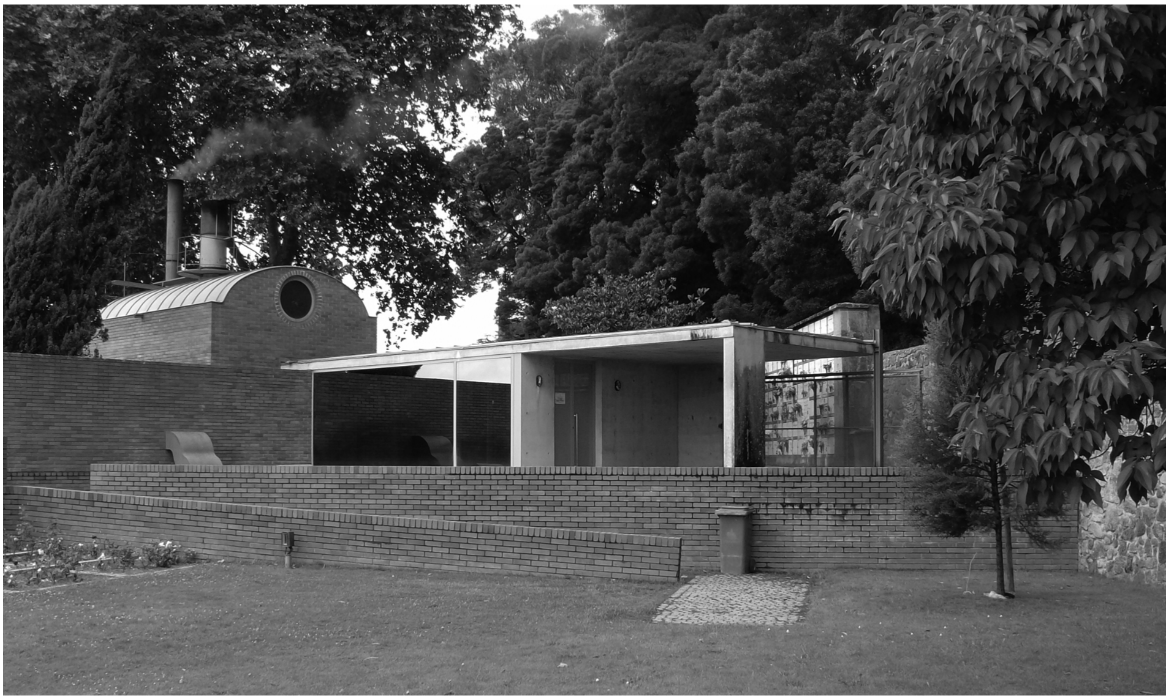

Figure 2.1.1.: The crematorium of Prado do Repouso (Porto, Portugal).

2.1.2. The Cremation

The cremation was constantly monitored by the technicians who adjusted the combustion protocol according to the requirements of each cadaver or skeletal remains being processed. This adjustment consisted on the selective use of the three burners and on the regulation of gas and oxygen intake during the operation with the aim of attaining a balance between combustion efficiency and smoking emission. Ideally, the combustion gases should be as less opaque as possible. In order to do that, the cremator should be pre-heated when the cremation takes place.

After loading of the remains into the top chamber of the cremator, the wooden coffin was entirely consumed by fire after 15-30 minutes. In the meantime, the body was reasonably protected from it. The time spent on this process varied considerably according to several factors such as type of wood, size of the coffin, temperature of combustion and oxygen intake.

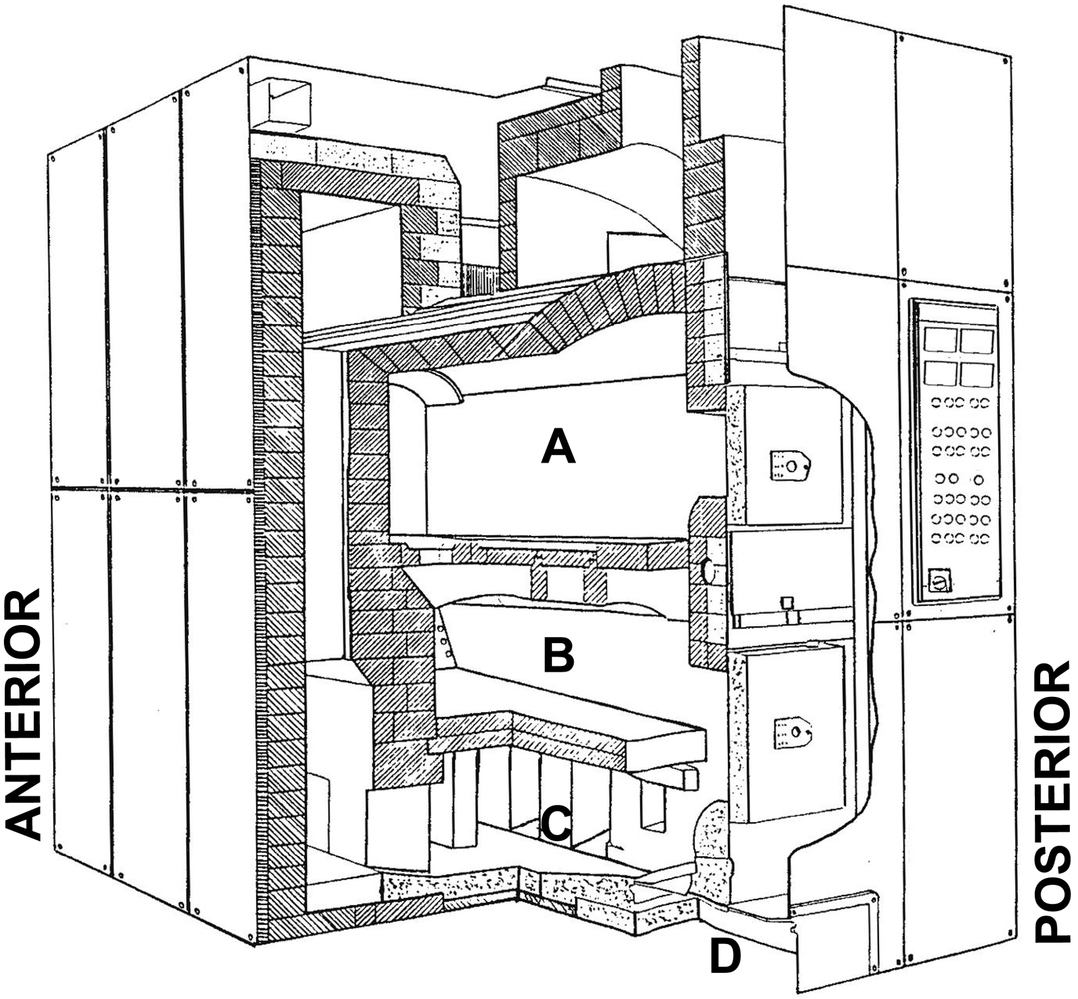

Figure 2.1.2.: 3D section of the Diamond Mark III cremator (J. G. Shelton). Key: a) top chamber; b) intermediate chamber; c) ground chamber; d) retrieval chamber. The scheme was kindly provided by *Necropolis, Lda.*

The time spent on the pyrolisis of the soft tissues was also widely variable and ranged from 30 minutes to much longer periods. Usually, it took about 60 minutes but it could take up to 120 minutes or more to completely remove the soft tissues, especially on the first cremation of the day because the cremator was still fairly cooled. Along with some of the factors abovementioned, also the idiosyncrasies of each individual most probably affected the amount of time spent on each cremation. Among these, sex and age were apparently important factors because men tend to be more robust than women.

As a result, men usually took longer to cremate than women and the same happened for youngsters when compared to the elderly. However, other factors must have had an effect on the duration of the cremation procedure. For instance, the thickness and anatomical distribution of insulative skin, body mass and muscle also influence considerably the length and temperature of the cremation (Wells, 1960; Warren and Maples, 1997; Pope and Smith, 2004).

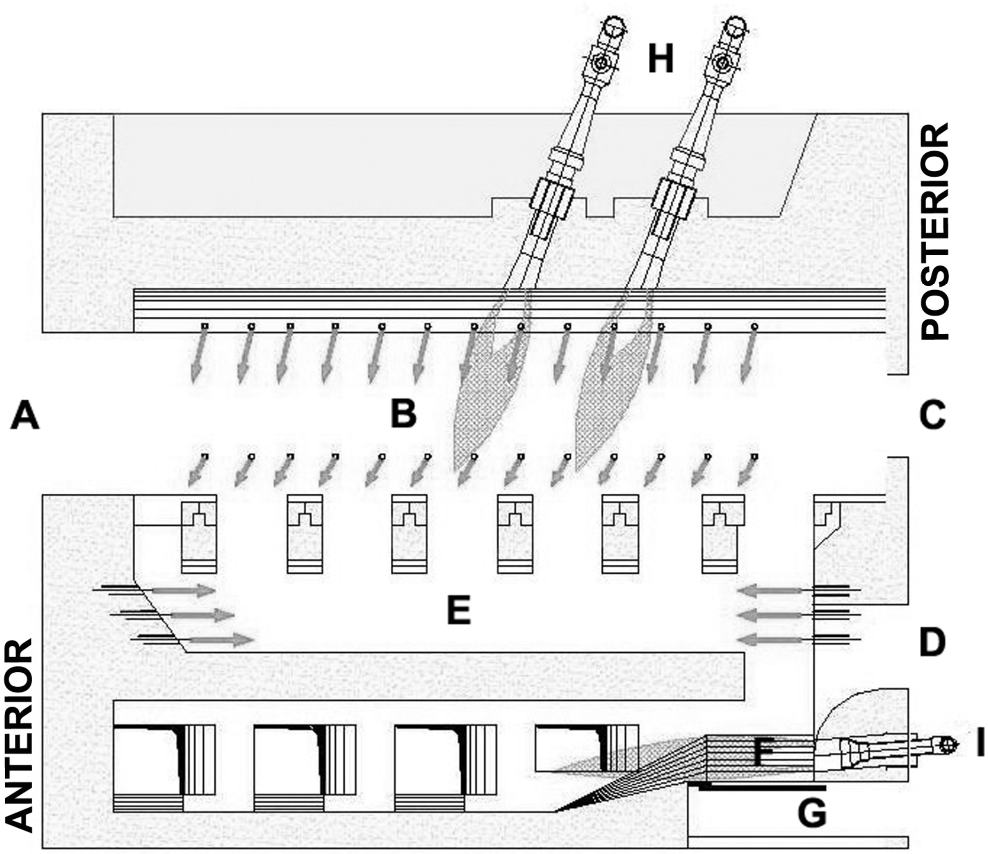

Figure 2.1.3.: Cross-section of the Diamond Mark III cremator (J. G. Shelton). Key: a) anterior loading gate; b) top chamber; c) posterior-superior gate; d) postero-inferior gate; e) intermediate chamber; f) recollection interface between the ground chamber and the retrieval chamber; g) retrieval chamber; h) main burners; i) secondary burner. The scheme was kindly provided by *Necropolis, Lda*.

With the ongoing cremation, soft tissues gradually disappeared and the skeleton started to be directly exposed to heat. At this point, significant changes affect bones that are essentially caused by the loss of water, organic components and carbonates along with the debatable conversion of the hydroxyapatite crystal structure into beta-tricalcium phosphate and the melting and coalescence of the crystal structure (Mayne Correia, 1997; Thompson, 2004; Thompson, 2005). As a result, bones become more brittle and begin to fragment, fracture, warp, shrink and change in colour

Some of the disarticulated bones and the combustion residues fell onto the platform of the intermediate chamber through the openings of the upper platform. This caused further fragmentation of the bones. After cremation was completed, the burners were switched off and the cremator was allowed to cool down. When temperature got to about 600-700º C, the cremains still remaining on the upper platform were manually shoved to the intermediate platform. This was carried out through the anterior loading gate and the postero-superior gate. Then, the remains were further shoved to the recollection interface located at the posterior end of the third and lower platform by using the posterior-inferior gate. Here, the air ventilation allowed the cremains to cool down. At the same time, this caused the screening of some of the charcoals which were boosted away from the human remains. The cremains were then dragged into the recipient placed on the retrieval chamber and finally taken out from the cremator. It was at this point that the bone analysis was carried out. Afterwards, the second part of the cremation procedure finally took place. The bone fragments were grinded by using a mechanical cremulator powered by electricity. This led to the ash-like appearance of the human cremations.

2.2. The Sample

The research was carried out on a sample of 534 adult cremated individuals. This sample was composed of two distinct kinds of human remains. The first one included the remains from individuals cremated soon after death which were classified as cadavers. The second sample included the remains from individuals who have been primarily inhumated for some years and subsequently exhumed and cremated. Cremation was thus used as a secondary practice. These remains were classified as skeletons.

The samples of cadavers and skeletons were not representative of a natural population and therefore did not mirror the sex ratio, age distribution and the ancestry of the population living in Portugal. Several factors were responsible for this scenario. As stated before, differential preservation affected the skeletal remains of females and males. In addition, only adult individuals were chosen for the samples in order to avoid bias regarding sex determination. Therefore, no sub-adults were included. Also, only Portuguese individuals were included on the sample to guarantee that all of them shared the same ancestry. However, this was not a straightforward procedure because some individuals could present mixed ancestries. Although in some cases the admixture was somewhat clear, in other cases only with the help of relatives it could be pinpointed. Sometimes, not even the relatives were aware or completely sure of the deceased's own ancestry. Finally, the sample was not the result of systematic sampling because not all cremated skeletal remains were available for analysis.

As stated previously, several topics were addressed by this research. This led to the compilation of different sub-samples according to the differential preservation of diagnostic features. The specific description of these sub-samples will be further described on the following sections that address each topic of research. For now, only the overall samples are thus described.

2.2.1. The Cadavers

The sample of cadavers included 401 individuals. Males made up the larger part of the sample with a total of 233 (58.1%) individuals. On the other hand, 168 (41.9%) female individuals provided data for the present research. Additional individuals – especially females – have been monitored but no data has been collected from their remains because of poor heat-related preservation. More males ended up being analysed because females burned skeletal remains exhibited poorer fragmentation thus allowing for fewer data collection. Although the sample of cadavers was over-represented by males, this was more the result of preservation related issues than the result of the natural demographic death profile.

The individuals were aged between 27 and 105 years-old at the time of death (Table 2.2.1). The mean age was of 71.4 years-old thus indicating that most of the deceased was elderly (Fig. 2.2.1). About 90% of the sample of cadavers was composed of individuals over 50 years-old so there was little representation of younger individuals. In fact, only one individual was less than 30 years-old at the time of death. When broken down by age cohorts, the interval of 80-89 years-old presented the largest frequency on the female sample. As for the males, the interval of 70-79 years-old presented the largest number of individuals.

Table 2.2.1: Age and sex composition of the samples of cadavers and skeletons.

	Cadavers			Skeletons		
Age Cohort	Females	Males	Total	Females	Males	Total
20-29	0	1	1	0	3	3
30-39	1	9	11	2	2	4
40-49	13	16	29	2	1	3
50-59	17	33	50	2	6	8
60-69	20	50	70	4	5	9
70-79	32	58	90	20	10	30
80-89	69	52	121	11	3	14
90-99	15	13	28	8	4	12
>100	1	0	1	0	0	0
Unknown	0	1	1	18	32	50
Total	168	233	401	67	66	133

The duration of the cremation of cadavers ranged between 50 and 210 minutes (mean = 93.8) while the maximum temperature varied from 750º C to 1050º C (mean = 925.8). The details regarding the intensity of combustion are presented in table 2.2.2 according to sex and to age. The sample of 241 individuals was divided into three age cohorts. The remaining 160 individuals were not included in this accounting because their cremation procedure was somewhat more intricate and thus complicated its codification in terms of the duration of the combustion. In some cases, the cremation was completed with the cremator being turned off for the later stage of the operation. The second cremation of the day coincided with lunch break so the cremator was switched off during this period of about 60-90 minutes. This contributed for further cremation although also accompanied by the gradual cooling down of the remains. The temperature gradually decreased but the cremator was still heated to temperatures of about 600º C when the remains were retrieved despite of that rather extended time span. In other cases, the same course of action was adopted although this turn the cremator was switched off for longer periods of time. This coincided with the last cremation of the day. If the remains were to be delivered only on the following day, these were left in the cremator overnight. As a result, the combustion was not fuelled but was still taking place during the night due to the high temperature present in the chambers. Eventually, the temperature decreased until it reached about 200º C by the morning. Given the specificities of these two combustion protocols, they were not used to calculate the average durations and maximum temperatures of combustion that are given in table 2.2.2 It is also important to notice that the latter refers to the maximum temperature reached on each cremation and that this was recorded using 25º C increments. For instance, a maximum temperature of 910º C was rounded to 900º C and a maximum temperature of 917º C was rounded to 925º C. .

Table 2.2.2: Descriptive statistics for the intensity of combustion regarding the cremation of cadavers according to sex and age cohort.

Age Cohort	Females					Males				
		Duration		Temperature			Duration		Temperature	
	n	Mean	SD	Mean	SD	n	Mean	SD	Mean	SD
0-59	21	99.3	19.8	885.7	67.8	41	98.9	23.0	931.7	72.7
60-79	29	92.8	24.4	914.7	62.9	61	95.7	27.8	934.8	68.1
≥ 80	54	86.0	21.4	921.8	57.9	35	94.0	21.6	942.1	51.7

2.2.2. The Skeletons

The sample of skeletonized individuals was considerably less numerous than its cadaver’s counterpart. It included 133 individuals and presented a more balanced sex ratio. The sample was composed of 67 females (50.4%) and 66 males (49.6%) with ages ranging from 23 to 99 years-old. The mean age was of 71.4 years-old and the 70-79 years-old age cohort presented the largest frequencies for both females and males (Figure 2.2.1). Because the skeletons were already disarticulated and removed from soft tissues, the cremations took less time and attained lower temperatures thus fragmentation was not as severe as in the case of the cadavers. The most part of these skeletons were not claimed by their relatives and the municipality proceeded with the cremation of the remains in order to free some burial slots at the cemetery. Unfortunately, some of the cemeterial records were incomplete so the age-at-death was not disclosed for many of these individuals. In some cases, this parameter was successfully obtained on the Instituto dos Registos e Notariado (Civil Records Office).

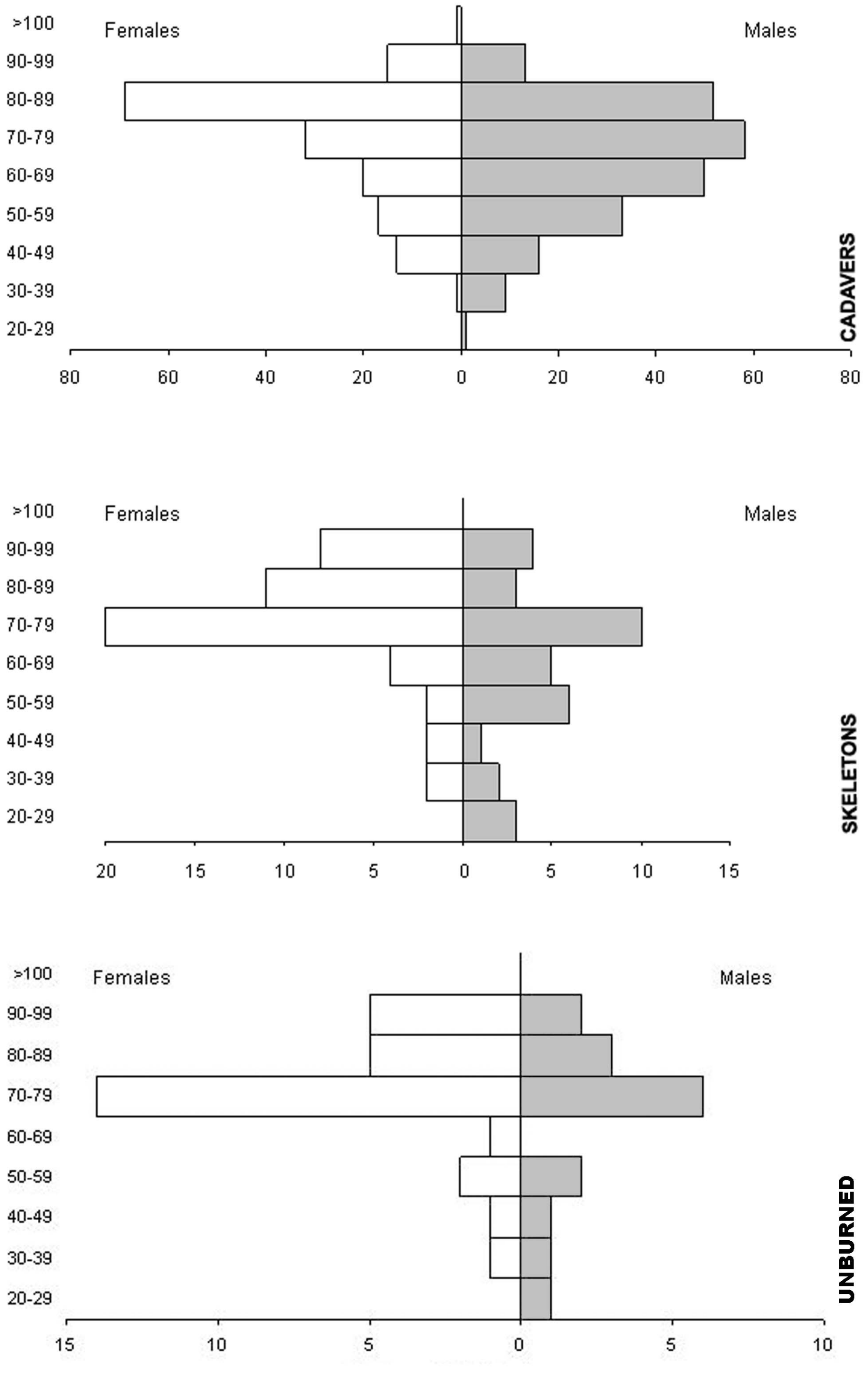

Figure 2.2.1: Age-pyramids for the sample of burned cadavers, burned skeletons and unburned skeletons.

The duration of the cremations of the skeletons ranged between 15 and 120 minutes (mean = 28.4). The maximum temperature varied between 450º C ad 950º C (mean = 742.3). This calculation was obtained on a sample of 105 skeletons. The remaining 28 skeletons were not included for the same reasons pointed out on the case of the cadavers – the cremator had been switched off for part of the cremations. The details regarding the intensity of combustion according to each sex are presented in table 2.2.3.

Table 2.2.3: Descriptive statistics for the intensity of combustion regarding the cremation of skeletons.

Females					Males				
	Duration		Temperature			Duration		Temperature	
n	Mean	SD	Mean	SD	n	Mean	SD	Mean	SD
52	28.4	9.8	742.3	145.6	53	30.0	17.0	728.5	147.4

2.2.3. The Unburned Skeletons

A sample of 82 skeletons inhumated at Prado do Repouso was also osteometrically analysed. These were un-reclaimed by their living relatives and were therefore ordained for cremation. The sample was composed of 41 females (50.0%) and 41 males (50.0%) with ages ranging from 27 to 99 years-old. The mean age was of 73.3 years-old (n = 45) and the 70-79 years-old age cohort presented the largest frequencies for both females and males (Figure 2.2.1). As for the sample of skeletons, the cemeterial records were incomplete so age-at-death was not known for many of these individuals. Again, age-at-death in some cases was obtained on the Instituto dos Registos e Notariado (Civil Records Office).

2.3. The Methodology

2.3.1. Heat-induced Warping and Thumbnail Fractures

Two samples were used for the analyses. The first one was composed of 96 cadavers from adults with ages ranging from 35 to 97 years-old (mean =71.4; sd = 14.7). It included 41 females and 55 males cremated soon after death. The duration of the cremations ranged between 60 and 145 minutes (mean = 98.7 minutes; sd = 25.7) for 58 of the cadavers. The remaining 38 cadavers were left to burn and cool overnight therefore being removed from the cremator only on the subsequent morning. The maximum temperature attained by the cremation varied between 750º and 1050º C (mean = 944.0º; sd = 60.7). All cadavers entered the cremator fully dressed and enclosed in wooden coffins.

The second sample was composed of 88 skeletons from adults. The age was known for only 56 of these and ranged from 23 to 99 years-old (mean = 69.7; sd = 17.3). The sample was composed of 41 males and 47 females previously inhumated for at least five years before being eventually exhumed and cremated. The mean inhumation period was of 15.2 years (sd = 14.1; min. = 5; max. = 72). As far as macroscopic inspection can detect, apparently soft tissues had been completely removed from all bones. The cremation of 79 skeletons lasted between 15 and 105 minutes (mean = 34.8 minutes; sd = 20.7) while the remaining 9 skeletons were burned and left to cool overnight. The mean maximum temperature was of 750.0º C (sd = 141.5). The laying of the skeletal remains on the cremator was diversified. Some were contained by plywood boxes, others were merely wrapped in a shroud and the remaining ones were placed directly on the cremator on top of a plywood board.

As stated in section 2.1.2., the cremation protocol varied widely in function of the requirements of each assemblage of human remains. The number of active burners and the oxygen intake was set or rectified by the technicians during the cremation according to its progress. This was dependent of numerous circumstances related to the biological profile of the deceased, the pre-cremation condition of the remains, the pre-cremation heating status of the cremator or the type of container used for the confinement of the remains. The cremation process was not entirely followed by the author because during this time, the analysis of the remains from the previous cremation was often taking place. Therefore, only the approximate maximum temperature was recorded for each cremation. Both this and the removal of the cremains from the cremator were carried out exclusively by the technicians. After the cremation and before cremulation, the remains were visually inspected for heat-induced warping and thumbnail fractures. For the first of these features, bones were checked for unusual bending of the diaphysis and of their heat-fractured ends (Figure 2.3.1.). The second feature was searched for on the diaphysis of long bones (Figure 2.3.1). The overall data recording form of each cremated individual included age, sex, duration of combustion, maximum temperature of combustion, bone and the bone region where the heat-induced feature was detected. In some cases, the specific colour(s) of the bone was recorded. For skeletons, the time span between death and cremation was also documented.

The statistical analysis was somewhat different for each of the heat-induced features. Multivariate associational statistics were not used for the investigation of the warping events due to the small amount of bones displaying this feature thus requiring a much larger sample to allow for reliable inferences. Alternatively, non-parametric Mann-Whitney tests were carried out in order to check for differences between the group of skeletons presenting warping and the group of skeletons not presenting it. The investigated factors were age, time span from death to cremation and maximum temperature of combustion. Sex and duration of combustion were not analysed due to small sample sizes.

As for thumbnail fractures, logistic regression analyses were carried out. The required sample size was calculated using the following formula based on the work of Peduzzi et al (1996). In the equation, k is the number of covariates and p is the smallest of the proportions regarding the positive and negative cases in the sample (Equation 2.3.1.).

$$N = 10 * k / p$$

Equation 2.3.1: Calculation of the required sample size for logistic regression analysis.

Two different models were investigated with the purpose of assessing if these were significantly associated to whether or not thumbnail fractures occurred during cremation. The first one regarded age, sex and time span from death to cremation and aimed to check if biological parameters had a significant effect on the frequency of thumbnail fractures. Time span was added to this model as a way to approximately account for post-depositional degradation of collagen. The second model referred to the intensity of combustion and therefore included duration and maximum temperature of combustion. Although logistic regression was used, the main goal was not to find predictive models but rather to assess if the interaction of several factors had any significant effect on the frequency of thumbnail fractures. All statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS), version 14.0.

Figure 2.3.1: Heat-induced warping and thumbnail fracture. Left – warped tibia from the Iron Age site of Altera (Portugal); right – thumbnail fractures on a long bone from the Roman Age site of Encosta de Sant'Ana (Portugal). Photos: J. P. Ruas.

2.3.2. Heat-induced Dimensional Changes

Visual inspection of the bone heat-induced colours was carried out with the aim of separating the calcined bones from the pre-calcined bones. Those presenting the typical colours of calcined bone – white, light grey and light blue – on roughly more than 90% of their surface were classified as calcined. Any bone presenting a colour other than the typical calcined shades on about more than 10% of the surface was included in the pre-calcined category. This procedure was taken to assess if differential percent shrinkages between pre-calcined and calcined bones could be detected.

A sample of 54 calcined skeletons was analysed in order to document the effect of heat on the dimensions of bones. This was composed of 34 females with ages ranging from 30 to 99 years-old and 20 males with ages between 27 and 95 years-old. As for the pre-calcined bones, a sample of 15 skeletons was analysed. It included 12 females with ages varying from 45 to 92 years-old and 3 males with ages between 72 and 76 years-old.

The skeletons were subject to measurements in mm prior to the cremation and re-measured after it. The measurements were carried out three times with a digital standard calliper and the median value was recorded. All standard measurements included in the analysis are described in tables 2.3.1 and 2.3.2. In addition, those are also illustrated in figures 2.3.2 to 2.3.6. The description of the measurements of the humerus and femur was adapted from the guidelines of Martin and Saller (1957). The description of the measurements of the talus and calcaneus was adapted from Silva (1995). The description of the measurements of the smaller tarsals was adapted from Harris (2009). Some of the measurements were included on the analytical protocol only at a later stage and therefore present smaller samples. These were the humeral articular width, the talus trochlear length, the length and the width of the load arm of the calcaneus and all the measurements from the cuboid, the navicular and the cuneiforms. The late inclusion of these standard measurements was due to several reasons. Prior to the field research, the set of measurements was intentionally small because the time available for analysis was short. However, when the interaction with the cremation operators became more fluid, an increase in time was gained thus allowing for the analysis of extra features. In addition, other features with good preservation rates were identified during the first year of research thus being added to the analytical protocol.

This was the case of the humeral articular width and the additional standard measurements from the talus and calcaneus. As for the small tarsals, the research of Harris (2009) was very useful by demonstrating that statistically significant sexual dimorphism was present in them on unburned skeletons. As a result, and given that many of those bones are well preserved after cremation, they were also added to the research. Regrettably, the late inclusion of these features led to smaller samples than the ones obtained for the original measurements from the humerus, femur, talus and calcaneus.

Bones presenting poor preservation or pathological lesions – especially osteoarthritis – were discarded from the analysis. The humeral articular width was included in table 2.3.1 although it was not monitored for heat-induced shrinkage. However, this feature was used on other analyses that will be reported in later sections. The selection of the standard measurements followed two main criteria. First of all, small features from spongy bones were chosen because these tend to be better preserved than other features composed of compact bone such as the length of the diaphysis. On the other hand, features for which the sex determination accuracy has been demonstrated to be higher than 80% were selected. This was done for the humerus and the femur (Wasterlain and Cunha, 2000), for the talus and the calcaneus (Silva, 1995) and for the small tarsals (Harris, 2009).

The intra-observer variation regarding the measurement of the osteometric features was determined by calculating the technical error of measurement. This was done on a sample of 20 bones for most standard measurements investigated in this research. The humeral articular width and the height of both the intermediate and the lateral cuneiforms were not examined due to their small sample sizes.

The rate of shrinkage was calculated by quantifying the relative difference between the dimension of the cremated bones and their dimension before cremation. Sexual differences regarding shrinkage were then assessed by using both parametric and non-parametric independent samples testing. The selection of the tests depended on whether or not the assumptions of the parametric analysis were met. The effect of the intensity of combustion on shrinkage was investigated using the duration and the maximum temperature of combustion as variables. Multiple linear regression analysis was carried out to investigate the combined effect of both these variables. The prediction value of the model was tested on an independent sample of 39 bones. The predicted values were compared to the observed values and its eventual correlation was assessed by using a t- test for paired samples. One-way ANOVA tests were used to further understand the effect of both combustion related variables on bone dimensional change. The statistical analyses were carried out by using the Statistical Package for the Social Sciences (SPSS), version 14.0.

Figure 2.3.2 – Standard measurements of the left humerus. Proximal is up.

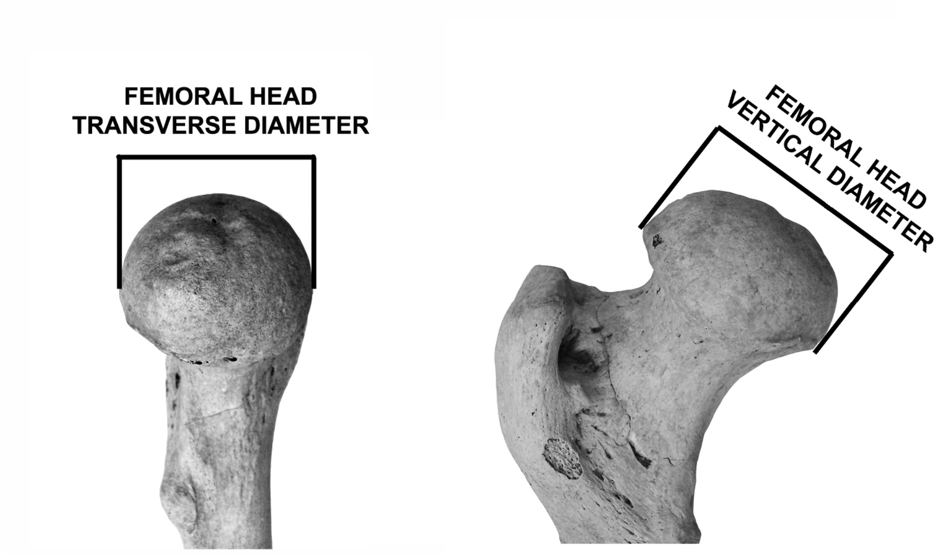

Figure 2.3.3 – Standard measurements of the left femur. Proximal is up.

Table 2.3.1: Standard measurements of the humerus, femur, the calcaneus and the talus.

Bone	Standard Measurement	Acronyms	Description
Humerus	Head Transverse Diameter	HHTD	Projected line from the most anterior point to the most posterior point of the humeral head.
	Head Vertical Diameter	HHVD	Projected line from the most proximal point to the most distal point of the humeral head.
	Epicondylar Breadth	HEB	Distance of the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle
	Articular Width	HAW	Mesio-lateral width of the distal articular surface composed of the capitulum and trochlea.
Femur	Head Transverse Diameter	FHTD	Projected line from the most anterior point to the most posterior point of the femoral head.
	Head Vertical Diameter	FHVD	Projected line from the most proximal point to the most distal point of the femoral head.
Talus Description from Silva (1995)	Maximum Length	TML	From the *M. flexor hallucis longus* groove to the most anterior point on the head measured parallel to the sagittal axis of the trochlea.
	Trochlear Length	TTL	Maximum length of the trochlear articular surface on the midline measured parallel to the sagittal axis of the trochlea.
Calcaneus Description from Silva (1995)	Maximum Length	CML	Projected line from the most posterior point of the tuberosity of the calcaneus to the most anterior/superior point of the cuboidal facet.
	Load Arm Length	CLAL	Projected line from the most posterior point of the posterior articular surface for the talus to the most anterior/superior point of the cuboidal facet.
	Load Arm Width	CLAW	Projected line perpendicular to long axis from the most lateral point of the posterior articular surface to the most medial point of the *sustentaculum tali*.

Table 2.3.2: Standard measurements of the small tarsals.

Bone	Standard Measurement	Acronyms	Description
Cuboid	Length	CL	Projected line from the proximal articular surface to the distal articular surface.
	Breadth	CB	Projected line from the medial facet articulating with the lateral cuneiform to the lateral surface.
	Height	CH	Projected line from the cuboid tuberosity on the plantar surface to the dorsal surface.
Navicular	Length	NL	Distance from the projected line between the most proximal points at the medial and the lateral edges of the proximal articular facet to the most distal point of the distal surface.
	Breadth	NB	Projected line from the tubercle to the most lateral point.
Medial Cuneiform	Length	MCL	With the distal surface resting on one arm of the calliper: distance to the most proximal point.
	Breadth	MCB	Projected line from the most medial point to the most lateral point on plantar view.
	Height	MCH	Whit the plantar surface resting on one arm of the calliper: distance to the most superior point.
Intermediate Cuneiform	Length	ICL	With the proximal surface resting on one arm of the calliper: distance to the most distal point.
	Breadth	ICB	Projected line from the most medial point to the most lateral point on dorsal view.
	Height	ICH	With the dorsal surface resting on one arm of the calliper: distance to the most inferior point.
Lateral Cuneiform	Length	LCL	With the distal surface resting on one arm of the calliper: distance to the most proximal point.
	Breadth	LCB	Projected line from the most medial point to the most lateral point on dorsal view.
	Height	LCH	With the dorsal surface resting on one arm of the calliper: distance to the most inferior point.

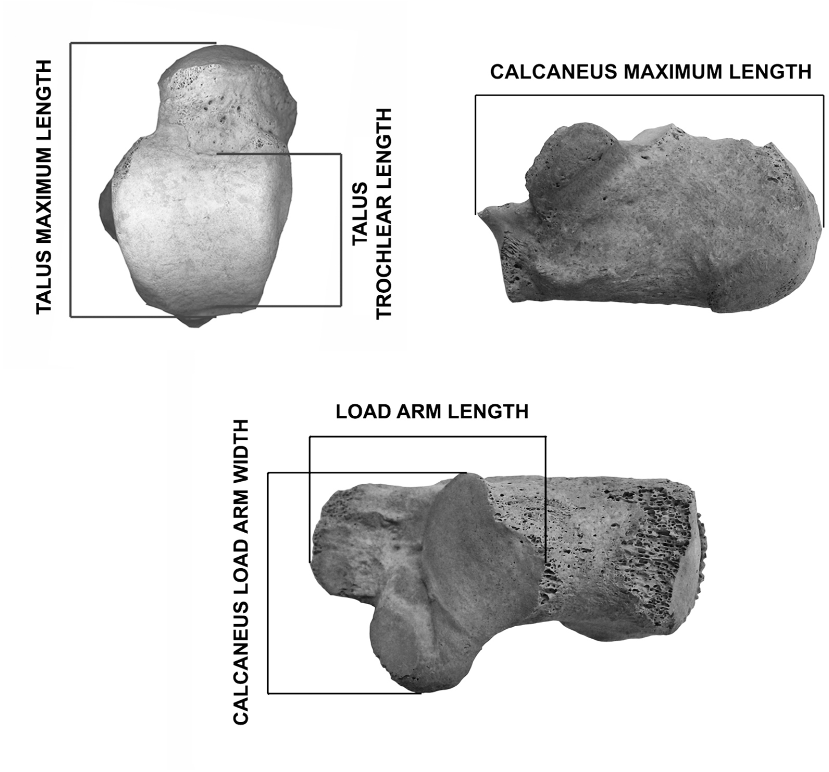

Figure 2.3.4 – Standard Measurements of talus and calcaneus. Left talus: distal is up. Right calcaneus: distal is left.

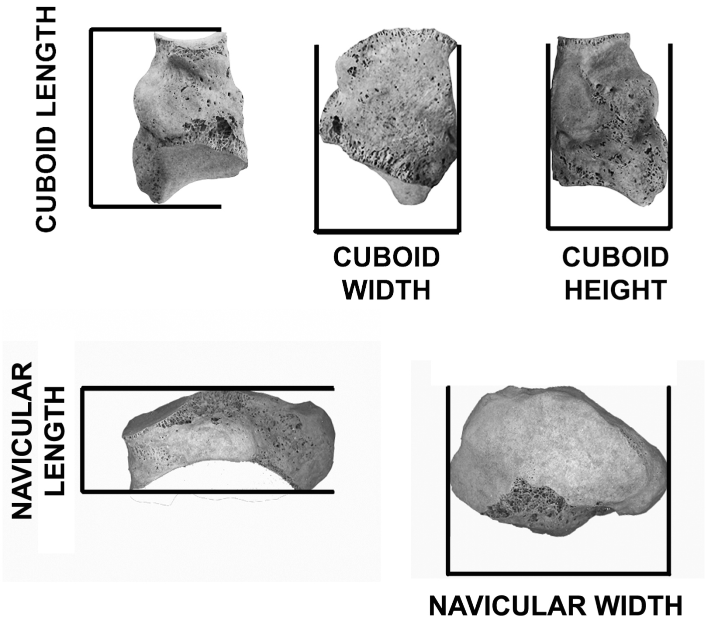

Figure 2.3.5 – Standard measurements of the cuboid and navicular. Top row: Left cuboid. Distal is up. Bottom row: Right navicular. Distal is up/Distal view.

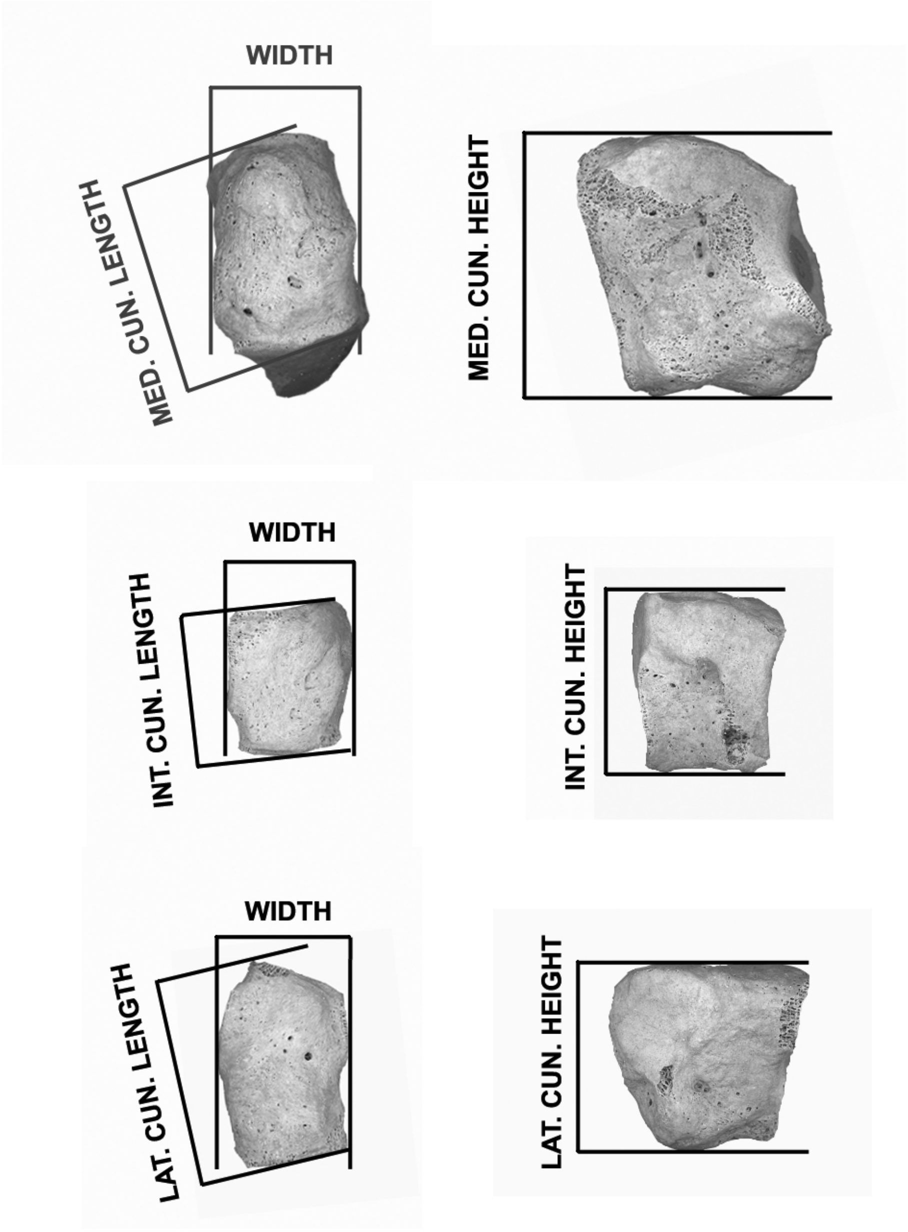

Figure 2.3.6 – Standard measurements of the cuneiforms. Top row: Left medial cuneiform. Distal is up. Intermediate row: left intermediate cuneiform. Distal is up. Bottom row: Right lateral cuneiform. Distal is up.

2.3.3. Osteometric Sexual Dimorphism

2.3.3.1. Post-cremation Preservation of Diagnostic Features

The remains of cadavers and skeletons were analysed in order to assess the post-cremation preservation of the standard measurements investigated on this research. Along with the features enumerated and described in section 2.3.2 regarding the heat-induced dimensional changes, also the internal auditory canal of the petrous bone was investigated. All cases were coded as “preserved” if the feature was intact and therefore allowed for measurement. The reverse condition was coded as “unpreserved”. This was carried out to determine the potential for the adoption of osteometric methods on calcined human skeletal remains.

The operation was completed on a sample of cadavers and on a sample of skeletons. The first one was composed of 118 individuals with ages ranging from 34 to 97 years-old (mean = 71.3; sd = 15.1). Females were represented by 52 individuals while the remaining 66 were males. As for the skeletons, the sample was composed of 50 females and 44 males. The overall sample of 94 individuals presented ages varying from 23 to 92 years-old (mean = 70.8; sd = 18.3).

The remains were thoroughly scrutinized after cremation looking for specific osteometric features of the humerus, the femur, the tarsals and the petrous bone. Examples of preserved features are presented in figures 2.3.7 and 2.3.8. For some of the overnight cremations, the remains were cooled enough by the morning to allow for the opening of the loading gate and for the specific handpicking of the humeri and the femurs which were then visually inspected and measured if well preserved. The bones were then returned to the cremator and subject to the usual recovery of the remains using the metal rake. As a result, the observations made on the humeri and the femurs burned on overnight cremations were not included in the analysis regarding the preservation of osteometric features so that the results would not become biased.

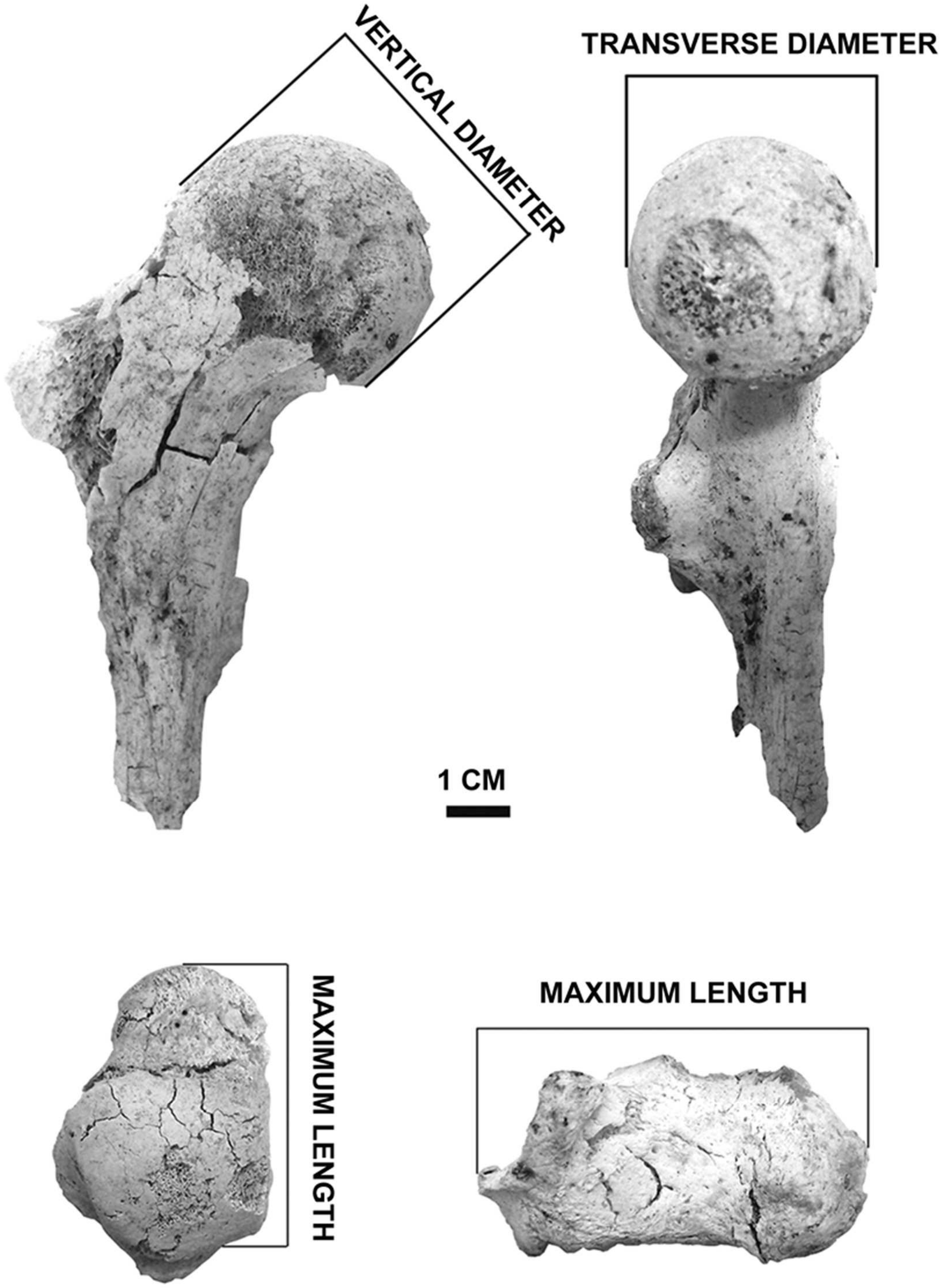

Figure 2.3.7: Preserved features on calcined femur, talus and calcaneus.

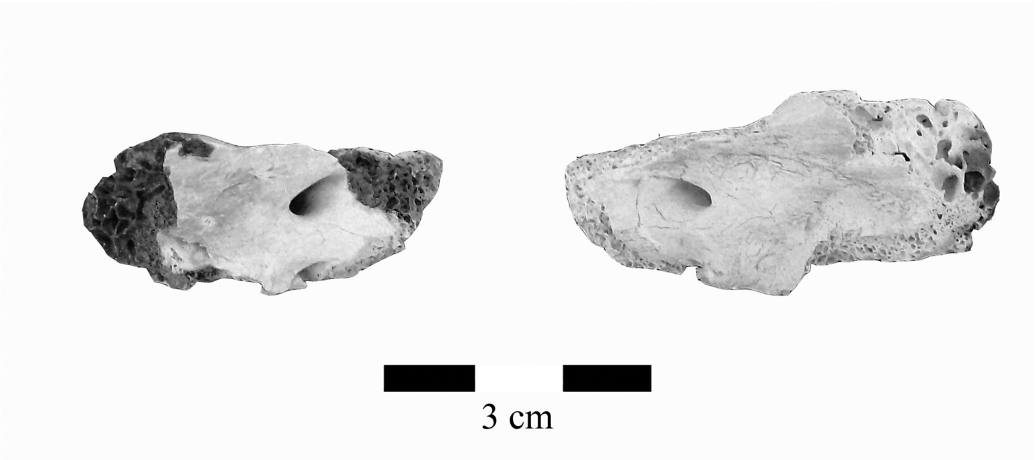

Figure 2.3.8: Preserved features on two calcined petrous bones.

The relative frequency of preserved elements was calculated for each feature on its own and for each bone by including all of their inherent standard measurements. Therefore, the latter referred to the preservation of any of the monitored features on a specific bone. The statistical analysis of the data aimed to assess the effect of several variables on the preservation of these features. Age, sex, duration and maximum temperature of combustion were thus investigated. In theory, these variables would hardly account for all the variation found on the preservation of the standard measurements though. One major additional factor was related to the fragmentation caused by the recovery of the remains from the cremator. As mentioned previously, this was done by using a metal rake to remove the remains from the platforms and to gather them at the posterior end of the cremator. This procedure thus contributed for the further fragmentation of the bones. However, it was not accounted as a variable because no objective way was found for the measuring of the destruction caused by this operation. Therefore, although the effect of the other abovementioned variables was indeed statistically analysed, these forcibly explain only part of the variation found on the preservation of the osteometric features. Results regarding this issue must thus be dealt with caution.

The statistical analysis adopted a multivariate approach whenever the sample size allowed it. Rather than looking for predictor models, logistic regression analysis was used to investigate the functional relationships between the independent variables – age, sex, duration and maximum temperature of combustion – and the dichotomous dependent variable (preserved; unpreserved). Given that a major factor – the post-cremation recovery of the remains – was not included in the list of variables, the search for logistic models able to predict the preservation of specific features was considered to be a somewhat futile exploit. Nonetheless, logistic regression was still adopted to assess if each one of the monitored variables on its own and if the interaction of the variables had a significant effect on the preservation of the features. Only the coefficients of significant logistic models were presented on the results section.

Regrettably, the sample size and the ratio of preserved/unpreserved features did not allowed for the inclusion of the four variables on the same logistic model. Therefore, some of these were sometimes investigated separately and the models included only the amount of variables supported by the sample size. The calculation of the minimum required sample size was carried out for each bone using the formula – equation 2.3.1 – based on the work of Peduzzi et al (1996).

The further exploration of the significant relationships indicated by the logistic regression analysis was carried out by using univariate statistics. The tests that were selected for the univariate statistical analysis depended on the level of measurement of the dependent variables. Ratio scaled dependent variables were investigated by using the parametric t-test for independent samples or the non-parametric Mann-Whitney test depending on whether or not the assumptions were met. This was the case for the age variable and for the maximum temperature of combustion. Pearson chi-square tests were used for the assessment of the effect of sex and of duration of combustion on the state of preservation of the osteometric features.

A comparison of the results for the cadavers and for the skeletons was done in order to investigate if the variance in preservation could be attributed to differences regarding the demographic composition of the samples and to differences regarding the intensity of combustion.

2.3.3.2. Sexual Dimorphism

Sexual differences regarding the size of calcined bones were investigated with the purpose of determining if heat-induced shrinkage eliminated the sexual dimorphism intrinsic to the human skeleton. Two samples were analysed. The first one was composed of 370 cadavers. It included 154 females with ages ranging from 39 to 105 years-old (mean = 75.0 years-old; sd = 14.5) and 216 males with ages varying from 27 to 99 years-old (mean = 68.4; sd = 14.8). All cremations lasted for more than 60 minutes and one of them took 250 minutes, not accounting with the individuals cremated overnight. The maximum temperature of combustion ranged between 750º C and 1050º C. Maximum temperature was less than 800º C for only 2.4% (n = 9) of the cremations.

The second sample was composed of 103 skeletons. This included 51 females aged between 30 and 99 years-old (n = 41; mean = 74.1; sd = 15.1) but the age-at-death was unknown for 10 of them. The sample also incorporated 52 males with ages ranging from 27 to 95 years-old (n = 25; mean = 65.9; sd = 18.2) although age-at-death was unknown for 27 of them. All the cremations took more than 15 minutes. Several of them took more than 60 minutes but this had less to do with skeletal resilience to heat and more to do with functional aspects related to the daily timetable of the technicians. Some skeletons had been left on the cremator during lunch time so the duration of the combustion was much longer than the time required for the calcination of the remains. The maximum temperature achieved during the cremations varied between 450º C and 950º C.

The time period for the cooling of the bones was diverse. Sometimes, these were measured right after their recovery from the cremator. Other times, the bones were already completely cooled down when measured. The bones and the osteometric features examined for this analysis were enumerated and described in section 2.3.2. The measurements were limited to the bones displaying the typical white, light blue and light grey colours produced by calcination. Other colours – usually black or dark grey – could be present on less than 10% of the bone surface though. The measurements were performed three times and the median value was recorded in millimetres. Those were carried out with a digital standard calliper. The specifications regarding the demographic profile – age and sex – and the combustion protocol were recorded. However, age was not known for all skeletons.

The assessment of the lateral angle was carried out on casts regarding the internal auditory canal (IAC) because this feature could not be measured directly on the bone. A light bodied dental casting material – Coltène President® – was used for this procedure following Norén et al (2005). The bone surface was cleaned and coated with Vaseline before the application of the silicone on the IAC in order to make its removal after setting easier. For the measurement of the lateral angle (Figure 2.3.9), the cast was bisected according to the major axis of this feature. The angle regarding the intersection of the posterior external surface of the petrous bone and the adjacent edge of the IAC

(Graw et al, 2003; Graw et al, 2005; Norén et al, 2005; Gonçalves et al, 2011a) was then taken on the sectioned surface by using the measuring tools of the Adobe Photoshop CS2® software (Gonçalves et al, 2011a). The measurements were performed three times and the median value was recorded in degrees.

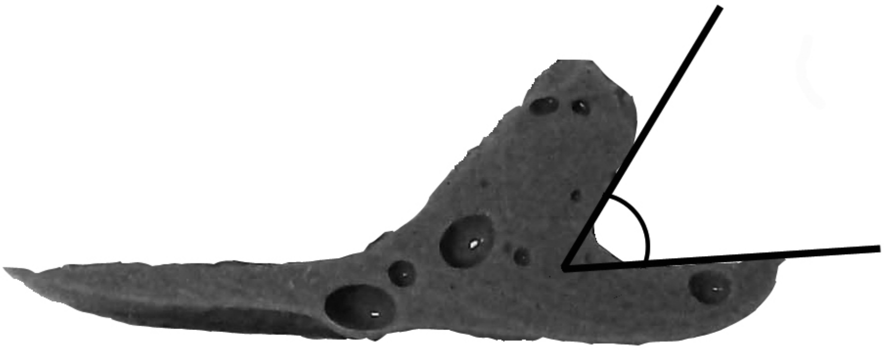

Figure 2.3.9: Schematics for the measurement of the lateral angle of the internal auditory canal.

The assessment of sexual dimorphism was preceded by some analytical procedures. Given that two types of samples – cadavers and skeletons – have been assembled for the current research, the prospect of combining them into a single pooled sample was investigated. As a result, the bone dimensions of cadavers and skeletons were compared to assess if the mean differences between them were statistically significant. This was carried out by using both parametric and non-parametric tests for independent samples – t-test and Mann-Whitney test. Another procedure regarded the decision on whether or not the bones from the right and left sides should be analysed separately or if the results of one side could be reliably extrapolated to the other side. In order to do that, bones from both sides were investigated to assess if these were significantly correlated to each other and therefore dispense the analysis of both sides.

The sexual differences were investigated by using the parametric t-test and the non-parametric Mann-Whitney test depending on whether or not the assumptions of the former had been met.

2.3.3.3. Sex Determination

The classification of individuals according to sex was attempted on test-samples by using three different procedures. The first of these was carried out by using cut-off points to discriminate individuals from two test-samples: one composed of cadavers and another one composed of skeletons. As a result, individuals presenting scores above the cut-off point were classified as males while the individuals presenting scores under the cut-off point were classified as females. Two different cut-off points were used for the non-cranial features. One consisted on the standard references recommended by Silva (1995) and by Wasterlain and Cunha (2000) for the talus and calcaneus and for the humerus and the femur respectively. These standards were developed on the Portuguese collection of identified skeletons from the University of Coimbra and are commonly used on Portuguese skeletal remains thus explaining its adoption for the present research. These references were designated as "Coimbra Standards". The goal of this procedure was to document the accuracy of standards specifically developed from samples of unburned skeletons on the sex classification from burned skeletal remains. The Coimbra Standards were developed on the skeletons of individuals who lived during the later half of the 19th century and the first third of the 20th century and Padez (2003, 2007) found a positive secular trend for the Portuguese population during the latter. Therefore, the Coimbra Standards were tested in order to assess if this process may have led those standards to be somewhat adjusted to present day cremated skeletal remains. As for the IAC, the cut-off point was taken from previous researches (Graw et al, 2003; Norén et al, 2005).

The second kind of cut-off points were calculated during this investigation according to the sexual dimorphism analyses carried out by this research. The sex pooled mean values of each standard measurement were thus used as cut-off points specifically developed from calcined skeletal remains. This course of action allowed for the comparison with the Coimbra Standards and therefore to document if the use of the new references improved the rate of correct classification. Because the samples had the same amount of females and males, the calculation of the mean value of the sex pooled sample followed the procedure used by other authors (Black, 1978; DiBennardo and Taylor, 1979; Silva, 1995; Wasterlain and Cunha, 2000). As a result, the midpoint between the male and female means was used as a cut-off point.

The test-sample of cadavers was composed of the remains from individuals other than those composing the sample used for the sexual dimorphism analysis. This was done so that the cut-off points made available by the latter would not be tested on the same sample from which they were developed on. This could have produced some biased results. The amount of individuals composing the test-samples varied depending of the osteometric feature (Table 2.3.3). For most standard measurements, females were in lesser amounts than males so the latter composed the larger part of the test-samples. These had relatively few females because it was decided to favour the sample regarding the sexual dimorphism analysis so that this would be based on larger groups. This meant that most test-samples were composed of only 10 females although the number of males was usually quite large.

The test-sample of skeletons was the same one used for the sexual dimorphism analysis. No biased results were produced because the cut-off points used for the sex determination were the ones developed from the sample of cadavers. Regrettably, the test-sample of skeletons was very small for many of the standard measurements so these results were merely indicative and could not be reliably used for any comparison with the results from the test-sample of cadavers. Nonetheless, the sex classification results were presented as a small documentation of the accuracy of the cut-off points.

Table 2.3.3: Composition of the test-samples for the sex classification according to discriminating cut-off points.

Sample	Sex	HHTD	HHVD	HEB	HAW	FHTD	FHVD	TML	TTL	CML	CLAL
Cadavers	Females	10	10	11	-	10	10	10	-	10	-
	Males	35	57	8	-	46	59	32	-	13	-
Skeletons	Females	5	14	4	3	9	10	29	7	13	3
	Males	9	14	12	2	9	10	28	10	21	8

The second attempt to classify the test-samples according to sex was carried out by using logistic regression analyses for the humerus, the femur, the talus and the calcaneus. This was done by testing the prediction power of each standard measurement and by doing the same with two-predictor logistic models referring to specific bones. Larger models were not tested due to the small size of the samples. It was only in rare cases that two or more standard measurements were successfully preserved on the same bone, so most regression analyses were performed on relatively small samples. No logistic models based on features from different bones of the skeleton were tested also because of small sample sizes.

The accuracy of the regression coefficients was tested in three different ways. First, the same sample from which the coefficients were calculated was classified. With the aim of avoiding bias that could result from this procedure, an independent test-sample was then also classified according to sex. This was much smaller though (Table 2.3.4). The third test-sample was composed of skeletons and had the same composition of the one presented in table 2.3.3.

Table 2.3.4: Composition of the test-samples for the sex classification according to the logistic regression coefficients.

Sample	Sex	HHTD	HHVD	HEB	HAW	FHTD	FHVD	TML	TTL	CML	CLAL
Cadavers (same sample)	Females	33	62	25	18	42	55	30	26	47	21
	Males	33	62	25	19	42	55	30	39	47	29
Cadavers (independent sample)	Females	10	10	8	-	10	10	10	-	10	-
	Males	10	10	11	-	10	10	10	-	10	-

A third attempt to determine the sex of the individuals composing the test-sample was carried out. This was done by using two different references regarding the calibration of the cut-off points developed from unburned skeletons to fit into the specificities of burned skeletons. Firstly, the mean percent shrinkage value obtained from the analysis regarding the heat-induced dimensional changes of larger bones – humerus, femur, talus and calcaneus – was used as a correction factor of the Coimbra Standards. The rate of shrinkage was thus used to calibrate the standardized cut-off point of each specific osteometric feature. The percent shrinkages of specific standard measurements were not used for this procedure due to the small sample sizes which were usually under 15 cases. The overall mean calculated from 150 features was considered to be a safer bet and therefore adopted. Secondly, the calibration method was based on the correction factor of 10% recommended by Buikstra and Swegle (1989).

As mentioned above, Padez found a positive secular trend affecting the stature of the Portuguese population since the beginning of the 20th century (2003, 2007). Therefore, secular trend may be interfering with the reliability of the Coimbra standards when applied to contemporary populations. For this reason, we decided to examine a Contemporary Sample and thus investigate if the calibration of the cut-off points drawn from it would be more adequately used than the Coimbra Standards on the sex determination of the calcined sample. Several measurements taken on a sample of unburned and un-reclaimed contemporary skeletons from Prado do Repouso (see section 2.2.3) were thus recorded and the sex pooled mean was used as reference for the calibration.

The two calibration methods were performed twice according to the Coimbra Standards and to the references from the Contemporary Sample. The calibrated cut-off points were subsequently tested on the overall sample of cadavers that was used for the assessment of the sexual dimorphism on calcined bones and on the sample of skeletons previously described on table 2.3.3. The composition of the sample of cadavers is presented in table 2.3.5. The documentation of the accuracy regarding sex classification allowed for the comparison between the two strategies. The main goal was to identify the most appropriate correction factor and the most appropriate reference values from the Coimbra Standards and the Contemporary Sample.

All statistical analyses of the several studies performed in section 2.3.3 were carried out using the Statistical Package for the Social Sciences (SPSS), version 14.0.

Table 2.3.5: Composition of the test-sample of cadavers for the sex classification according to the calibration methods.

Sample	Sex	HHTD	HHVD	HEB	HAW	FHTD	FHVD	TML	TTL	CML	CLAL
Cadavers	Females	33	62	25	18	42	55	30	26	47	21
	Males	33	62	25	19	42	55	30	39	47	29

2.3.4. Skeletal Weights

2.3.4.1. The Anatomical Identification

The weight of bone fragments was recorded according to each specific bone. As a result, the proportion of determined bones was used as an indicator for the anatomical identification of each skeletal component. This was carried out in order to assess if anatomical identification of bone fragments was related to the demographic profile and to the intensity of combustion. As a result, the variance regarding the rate of anatomically identified bone fragments (RAI) was investigated according to several factors – age, sex, duration of combustion and maximum temperature of combustion. The RAI consists on the adding of the weights from all identified bones thus representing the full determined bones weight and its relative proportion in relation to the overall weight – including both determined and undetermined bones – provided for the rate of anatomically identified bone fragments. The 2 mm fraction was not used for this calculation.

The analysis was carried out on two different samples. The sample of cadavers included 116 individuals. This was composed of 51 females with a mean age of 74.5 years-old (sd = 15.1; min.: 41; max.: 97) and of 65 males with an average age of 68.6 years-old (sd = 14.8; min.: 34; max.: 93). The second sample was composed of 88 skeletons which included 49 females with ages ranging from 46 to 99 years-old and 39 males with ages varying from 23 to 92 years-old. However, age-at-death was known for only 24 females and 21 males.

After the cremation, skeletal remains were left to cool for a while. This could take from 60 minutes to several hours in the case of the overnight cremations. Afterwards, the cremains were usually analysed during 50-90 minutes. The remains were sieved using a 2 mm mesh in order to separate larger bone fragments from bone chips which were dismissed as ash and therefore weighed separately. The remaining portion was inspected for metal objects which were removed by using a magnet. Other objects such as plastic buttons, portions of brick or charcoals were also taken out of the assemblage. The cremains were then analysed and anatomically attributed to a specific bone whenever possible. The unidentified bone fragments were included in a category of undetermined bones. When all the remains had been inspected, each bone was weighed by using a digital scale that allowed for the weighing up to one decimal case (max.: 2000 g; error: 0.1 g).

Rather than looking for predictor models, multiple regression analysis was used to investigate the functional relationships between the independent variables and RAI. Given that the extraction of the cremains from the cremator was not accounted as a variable, the prediction of RAI would have therefore been a somewhat useless procedure in this case. The calculation of the minimum required samples was carried out by using the statistics calculator's application available at: www.danielsoper.com. The further investigation of any predictor variables significantly correlated to RAI was carried out by using basic inferential statistics with the aim of assessing what sort of differences were present between groups. These were the t-test, the Mann-Whitney test and the one-way ANOVA test. The latter was followed by Games-Howell post-hoc tests. In addition, differences between the samples of cadavers and skeletons were investigated by using both these kinds of tests and the Pearson chi-square test.

2.3.4.2. The Weight of Cremains

The overall weight of skeletal remains was recorded in order to investigate for differences regarding the demographic profile. In addition, the effect of the intensity of combustion on the weight of the remains was also investigated. The samples and the procedures used for this analysis were the same described in section 2.3.4.1. This time though, both the overall weight excluding the 2 mm fraction and the overall weight including the 2 mm fraction were used for the statistical analyses.

Once again, multiple regression analysis was used to investigate the functional relationships between the independent variables – age, sex, duration and maximum temperature of combustion – and the dependent variable which in this case was the overall skeletal weight. The detection of prediction models was thus not the aim of this procedure. The statistical analysis included the same tests mentioned in the previous section for the further investigation of the significant correlations between variables. In addition, t-tests for independent samples were used for the assessment of the nature of the differences regarding the cadavers and the skeletons.

2.3.4.3. The Skeletal Representation

The absolute weight and the relative proportion of each bone regarding the overall weight of the skeleton were recorded in order to investigate sexual differences. The samples were composed of individuals for whom all categories were anatomically identified. However, the sternum and the patellae were not included in the analysis because these bones were absent on a large amount of remains and would therefore narrow the sample. As for the hyoid, this bone was added to the cranium category. As a result, the sample of cadavers was composed of 29 females with ages varying from 43 to 93 years-old (mean = 70.5; sd = 16.1) and of 55 males aged from 34 to 90 years-old (mean = 67.1; sd = 14.7). Therefore, 84 cadavers were examined. On the other hand, the sample of skeletons was composed of 31 females ranging from 30 to 92 years-old and 30 males with ages between 27 to 92 years-old. The procedure regarding the analysis of the cremains was already described in section 2.3.4.1.

Following the bone representation analysis, the same was done for the proportion of each skeletal region. These are basically greater anatomical regions that include the cranium, the trunk, the upper limbs and the lower limbs. Bone elements that were not included in the skeletal analysis by bone categories were now considered this time. Therefore, the cranium included the skull, the mandible and the hyoid. The trunk included the vertebrae, the ribs and the sternum. The upper limbs included the scapulae, the clavicles, the humeri, the radii, the ulnae and the bones from the hand (including carpals). The lower limbs included the os coxae, the femora, the patellae, the tibiae, the fibulae and the bones from the foot (including tarsals).

The effects of age, sex and the rate of anatomical identification on the representation of each skeletal region was investigated using Pearson bivariate tests regarding selected pairs of variables and multiple regression analysis regarding all variables. Further analysis was carried out in order to better understand the results from the multiple regression. That included the calculation of t-tests for independent samples, one-way ANOVA and Kruskall-Wallis tests. Tukey HSD and Mann-Whitney statistics were carried out as post-hoc tests.

The results for the representation of the skeletal regions were statistically compared with those obtained by Silva et al (2009) on a sample of unburned skeletons by calculating single-sample t-tests. Because their results were not presented according to each skeletal region, their data was adapted by adding the values of each bone category into those four categories. As a result, the relative mean weight obtained for the cranial region was of 19.54%. The trunk region presented 16.57%. The upper and lower limbs presented 17.28% and 45.94% each. The pooled standard deviation was also calculated so that the effect size of each single-sample t-test could be estimated. This was afterwards interpreted by following the recommendations of Cohen (1988).

The differences between the samples of cadavers and skeletons regarding the representation of each skeletal region were statistically assessed. A two-way ANOVA could not be used to investigate the differences according to sex and to the pre-cremation condition of the remains because the assumptions of normal distribution and homogeneity of variances were not met. SPSS does not offer a non-parametric alternative to two-way ANOVA. Because the re-codification of the scale dependent variables (the representation of the cranium, trunk, upper limbs and lower limbs) into a dichotomous variable in order to use the log-linear statistic would weaken the differences inherent to them, basic inferential statistics were chosen instead of complex inferential tests. This meant that the relationship between sex and each skeletal region and between pre-cremation condition of the remains and each skeletal region was carried out one at a time without investigating the interaction between the two factor variables.

2.3.4.4. Estimating the Proportion of Skeletal Regions

Linear regression statistics were carried out in order to investigate if the weight proportion of each skeletal region could be predicted from the RAI. Besides the data for the burned cadavers and skeletons, the data provided by Lowrance and Latimer (1957, In Krogman and Işcan, 1986) and by Silva et al (2009) were also included so that the relative weight of the remains from skeletons that have been completely identified according to anatomical region could contribute to the equation. The formula for the calculation of the expected proportion is presented in Equation 2.3.2.

Expected Percentage = Constant + (RAI * RAI coefficient for each skeletal region)

Equation 2.3.2: Calculation of the expected proportion of the skeletal regions on burned remains.

Besides the data obtained from the unburned samples, the linear regression coefficients were also based on a sample of 129 cremations. These included 54 females aged between 43 and 93 years-old and 76 males aged between 27 and 92 years-old.

The testing of the coefficients from this method was carried out on an independent test-sample composed of 20 contemporary individuals cremated at the modern crematorium. The sample included 10 cadavers (5 females; 5 males) and 10 skeletons (5 females; 5 males). Although the smallest bone fragments may sometimes not be recovered from the cremator, we postulated that normal representation of each skeletal region was present in all cremains. Therefore, any variance when compared with the standardized references was considered to be other than the result of incomplete recovery of the remains.

The difference between the mean predicted values and the mean observed values was assessed by using a Wilcoxon signed ranks test. In addition, Pearson correlation was calculated in order to investigate the association between both variables.

For the interpretation of the proportions obtained on each case, a comparison was carried out with the predicted value. As a result, all observed values inside the respective interval – with a range of ±1 standard deviation (±1SD) – were interpreted as being normally represented. In contrast, the outliers were interpreted as having a tendency to over-representation or under-representation depending of the case. In addition, intervals with a range of ±2 standard deviations (±2SD) were also created. Given this interval, the outliers were then interpreted as being strongly over-represented or under-represented depending of the case. The skeletal unburned references from Lowrance and Latimer (1957, In Krogman and Ișcan, 1986) and subsequently adapted by Richier (2005) were also used to analyse the test-sample in order to make a comparison with the results obtained on the present investigation. As such, the lower and upper bounds of the intervals used for the interpretation were 50% apart from the mean proportion of each skeletal region. These large intervals were used so that a conservative approach would be adopted while using this method which is not calibrated for burned skeletal remains. Therefore, the cranial interval ranged from 10% to 30%. The trunk interval ranged from 8.5% to 25.5%. The upper limbs interval ranged from 9% to 27% and the lower limbs ranged from 32.5% to 67.5%. All proportions inside these intervals were therefore interpreted as being normally represented.

The regression coefficients and the skeletal unburned references were also tested on a sample of archaeological cremation burials. From Portugal, these included one primary burial and three urned burials from the Roman necropolis of Encosta de Sant'Ana in Lisbon (Gonçalves et al, 2010) – bustum, Urns 3, 4 and 5. Two urned burials from the Iron Age necropolis of Cerro Furado – NCF1 and NCF2 – in Beja were also included (Gonçalves, 2007). One urned burial (MT12) from the Iron Age necropolis of Altera in Mora was added to the sample (Gonçalves, 2007). Finally, two Roman urned burials from the Praça da Figueira in Lisbon were also included – PF00 and PF01 (Gonçalves, 2007). From France, the sample included four in situ burials – 7, 80, 136 and 479 – from the Roman necropolis of Sainte-Barbe in Marseille (Richier, 2005) and another four urned burials from Sainte-Croix-en-Plane (Colmar), a necropolis from the Bronze Age and the Ancient Hallstatt (Blaizot and Georjon, 2005) - S-O/1, S-O/2, 36 and 64/1. Although the correction of the interpretative results from both methods on the archaeological sample could obviously not be assessed, it still allowed documenting the variability regarding their use.

All statistical analyses were carried out with the Statistical Package for the Social Sciences (SPSS 14.0).

3. Results

3.1. Heat-Induced Bone Thumbnail Fractures and Warping

The frequency of bone warping and thumbnail fractures was assessed for the sample of burned cadavers and burned skeletons. The results are presented in figure 3.1.1. Although the features were present on both samples, its frequency was much larger on cadavers. For these, only one female aged – 64 – presented no warping while three females – with ages of 44, 71 and 81 years-old – and one male aged 63 presented no thumbnail fractures. These five individuals were cremated at temperatures higher than 850° C for 80-140 minutes. For the sample of skeletons, thumbnail fractures were more often present than warping (Figure 3.1.2). The details for the skeletons presenting these features are given in tables 3.1.1 and 3.1.2.

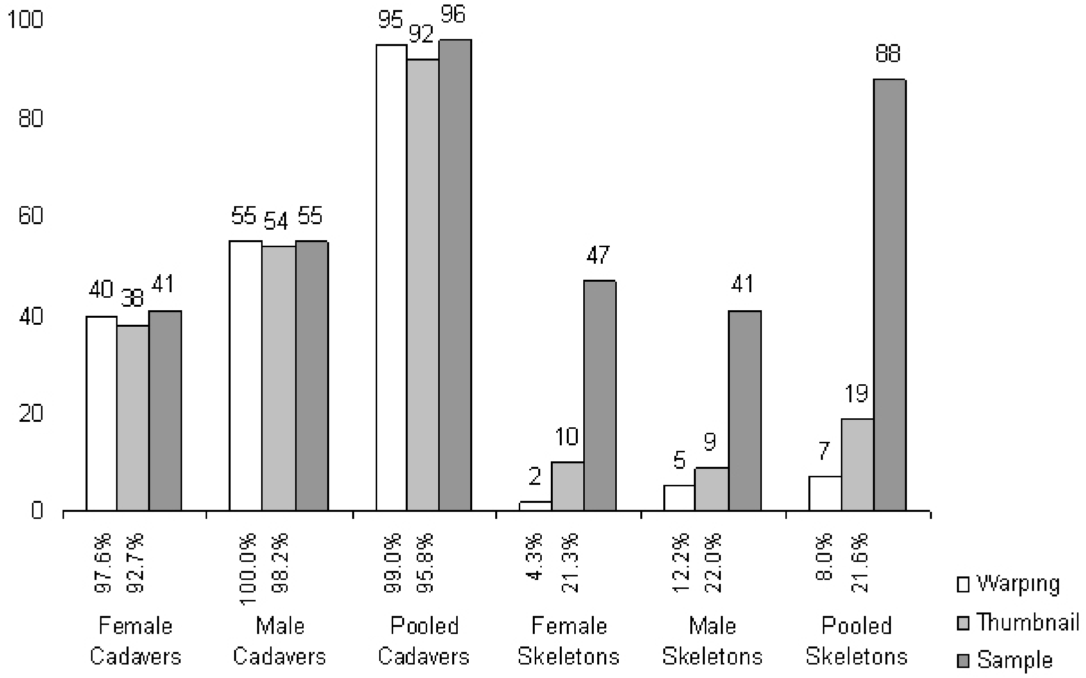

Figure 3.1.1. Absolute and relative frequencies of heat-induced warping and thumbnail fractures on the sample of cadavers and skeletons.

Almost all cadavers displayed heat-induced warping and thumbnail fractures, so these variables had too little variance to allow for statistical analyses. Therefore, this was carried out only for the sample of skeletons. However, the statistical investigation of the warping events could not rely on the analysis of logistic regression models due to the small sample size which was not compatible with the ratio of present/absent cases (8/80). This would stipulate a minimum required sample of 220 cases for two factor variables. The sample did not meet the requirement so each factor was investigated on its own.

Table 3.1.1: Details of the skeletons displaying heat-induced warping.

No.	Sex	Age	Duration	º C	Bone	Region	Colour	Time Span
35	M	23	15	450	Long bone	Diaphysis	Not recorded	7 years
38	M	-	20	450	Long bone	Diaphysis	Not recorded	45 years
148	M	-	30	890	Radius	Diaphysis	Almost all white	7 years
323	M	-	45	600	Tibia	Diaphysis	Pale white; white	19 years
339	F	92	80	525	Tibia	Diaphysis	Not recorded	7 years
490	F	78	40	600	Long bone	Diaphysis	Not recorded	7 years

The differences according to sex and to duration of combustion were not statistically addressed with a Pearson chi-square test, once more because of the small amount of cases presenting warping. The remaining factors were investigated using Mann-Whitney non-parametric tests. No significant differences were found between the group of skeletons with warping events and the group of skeletons absent of warping events according to age and to time span from death to cremation (Table 3.1.3). In contrast, a statistically significant difference at the .05 level was detected according to maximum temperature of combustion. The magnitude of the difference was medium to large according to Cohen (1988).

In order to investigate if any of the variables monitored for this analysis was a significant factor regarding the presence of thumbnail fractures, logistic regression analyses were then carried out. Because of the small sample size, a single model could not reliably test all variables monitored for each cremation. Therefore, both duration and maximum temperature of combustion were used to form one logistic model while a second model was composed of sex, age and time span since death. The first model was used to investigate the effect of the intensity of combustion on the occurrence of heat-induced warping and thumbnail fractures. The second model was used to investigate if this event was significantly linked to biological and taphonomic parameters.

Table 3.1.2: Details of the skeletons displaying heat-induced thumbnail fractures.

No.	Sex	Age	Duration	° C	Bone	Region	Colour	Time Span
34	F	83	40	730	Long bone	Not recorded	Not recorded	7 years
35	M	23	15	450	Long bone	Diaphysis	Not recorded	7 years
38	M	-	20	450	Long bone	Diaphysis	Not recorded	45 years
257	M	65	15	600	Long bone	Not recorded	Black endocortex White exocortex	7 years
267	F	54	30	720	Long bone	Diaphysis	Black endocortex White exocortex	7 years
337	F	83	75	750	Long bone	Diaphysis	Not recorded	7 years
339	F	92	80	525	Humerus	Diaphysis	Not recorded	7 years
346	M	82	70	900	Long bone	Diaphysis	Black endocortex White exocortex	7 years
348	M	69	Overnight	925	Long bone	Diaphysis	Not recorded	7 years
349	F	72	30	500	Long bone	Diaphysis	Not recorded	46 years
350	M	70	30	625	Long bone	Diaphysis	Not recorded	50 years
360	M	90	25	550	Femur	Diaphysis	Black endocortex White exocortex	11 years
361	F	78	25	550	Long bone	Diaphysis	Not recorded	20 years
384	F	85	20	800	Long bone	Diaphysis	Not recorded	7 years
490	F	78	40	600	Long bone	Diaphysis	Not recorded	7 years
507	F	78	Overnight	800	Femur	Diaphysis	Not recorded	7 years
512	M	-	75	800	Long bone	Diaphysis	Not recorded	5 years
525	M	55	30	750	Long bone	Diaphysis	Not recorded	7 years

For the assessment of the effect of intensity of combustion on thumbnail fracturing, a minimum sample size of 90 cases was required given the ratio of present/absent thumbnail cases. The logistic regression was carried out although only 85 cases were available for statistical analysis so results must be dealt with some caution. The duration of combustion was divided into three groups (0-25’; 26-110’; overnight) and maximum temperature was used as a ratio scaled variable (mean = 763.9; sd = 139.8). When considered on its own, only maximum temperature was indicated as a significant factor at the .05 level (Table 3.1.4). The omnibus test found that the model was significant although only temperature remained the only significant factor (χ^2 = 7.13; df = 2; p = .028). However, the model only explained for 12% of the variation in whether thumbnail fractures were present or not. As for the second model, sex was used as a dichotomous variable while age and time span from death to cremation were used as ratio scaled variables. When these variables were considered out of the model, none was found to be significant (Table 3.1.5). The model was not significant either (χ^2 = 2.14; df = 3; p = .544).

Table 3.1.3: Descriptive statistics and Mann-Whitney test results regarding the median differences between the groups with and without warping events according to age, time span since death and maximum temperature of combustion.

		n	Mean	S.D.	Median	Range	MW	Sig.	Effect Size
Age	Present	5	65.2	26.4	74.0	69.0	118.0	.785	-
	Absent	51	70.2	16.5	75.0	72.0			
Time Span	Present	6	15.3	15.3	7.0	38.0	239.5	.912	-
	Absent	82	15.2	14.1	9.0	67.0			
Temperature	Present	6	587.5	167.2	562.5	450.0	95.0	.013	-.27
	Absent	80	762.2	132.7	800.0	450.0			

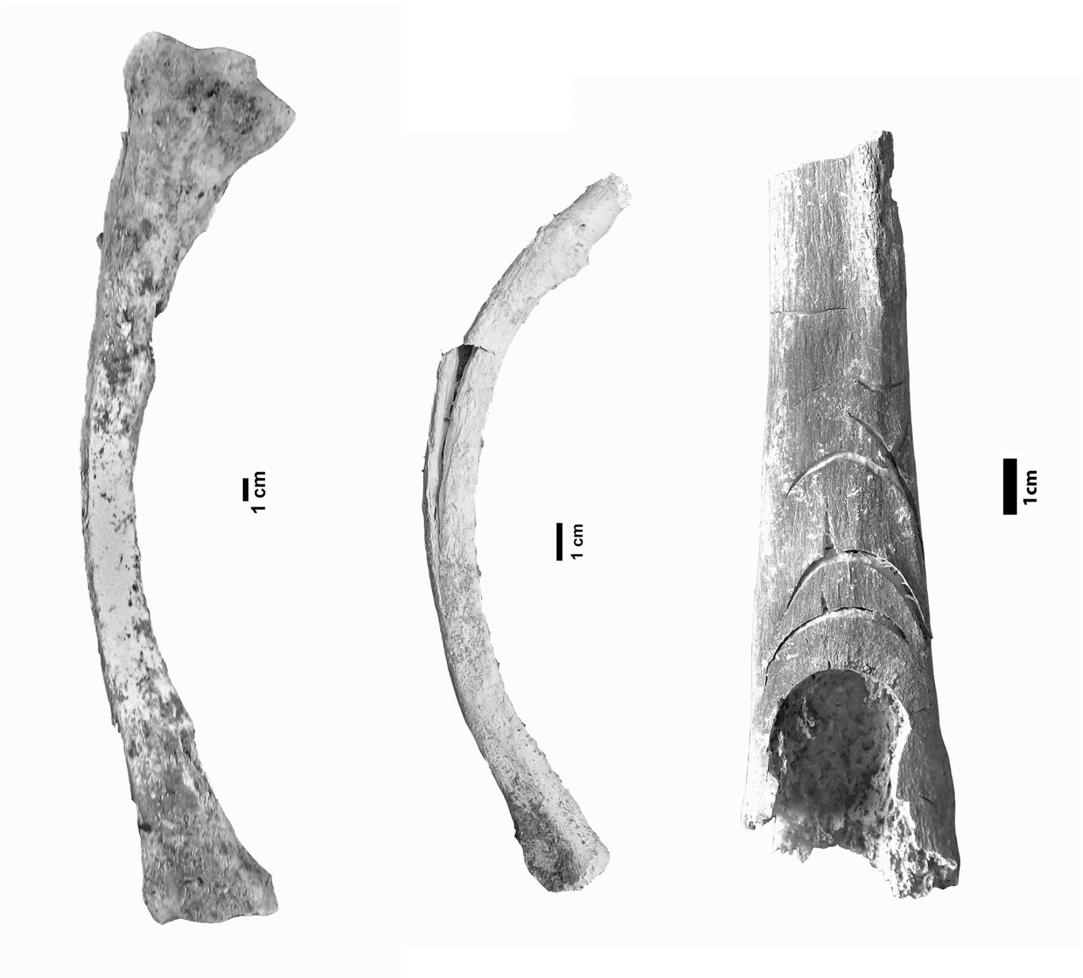

Figure 3.1.2. Heat-induced features found on skeletal remains. Left: bone warping present on the tibia of individual 323. Central: bone warping present on the radius of individual 148. Right: thumbnail fractures present on the long bone of individual 38.

Table 3.1.4: Results for the logistic regression analysis regarding the effect of the intensity of combustion on the occurrence of thumbnail fractures.

	Out-of-Model			Model			
	Score	df	Sig	β	SE	Odds Ratio	Sig.
Duration	1.237	1	.267	.489	.413	1.63	.236
Temperature	5.395	1	.020	-.004	.002	1.00	.023
Constant	-	-	-	1.736	1.379	5.68	.208

n = 85

Given the significant effect found for the maximum temperature of combustion with the logistic regression analysis, statistical testing was carried out in order to investigate the mean maximum temperature differences between the skeletons presenting thumbnail fractures (mean = 684.2; sd = 151.2) and the skeletons presenting no such features (mean = 768.7; sd = 134.0). A statistically significant difference was indeed found for the thumbnail feature (t = 2.357; df = 84; p = .021; d = .59) with a small to medium effect size according to Cohen (1988). This means that the skeletons presenting thumbnail features were cremated at significantly lower temperatures than skeletons free of these features.

Table 3.1.5: Results for the logistic regression analysis regarding the effect of sex, age and time span since death on the occurrence of thumbnail fractures.

	Out-of-Model			Model			
	Score	df	Sig.	β	SE	Odds Ratio	Sig.
Sex	.125	1	.724	.404	.608	1.50	.506
Age	1.554	1	.212	.027	.020	1.03	.180
Time Span	.001	1	.976	.004	.020	1.00	.859
Constant	-	-	-	-2.857	1.613	.06	.076

n = 56

3.2. Heat-induced Dimensional Changes

3.2.1. Measurement Error

A sample of 20 individuals was assembled in order to calculate the intra-observer variation for some of the standard measurements. Results for the absolute technical error of measurement (TEM), the relative error of measurement (%TEM) and the coefficient of reliability (R) are presented in table 3.2.1.

The %TEM was less than 3% for most standard measurement thus demonstrating good repeatability. However, a quite large intra-observer %TEM was obtained for the lateral cuneiform breadth thus revealing some repeatability problems. Nonetheless, the R was close to 1.0 for all standard measurements indicating that only a small portion of the measurement variance present in the sample was the result of measurement error.

Table 3.2.1: Absolute technical error of measurement (TEM), relative technical error of measurement (%TEM) and coefficient of reliability for selected standard measurements.

Std. Measurements	TEM (mm)	%TEM	R	Std. Measurements	TEM (mm)	%TEM	R
HHTD	0.16	1.14	0.999	CL	0.15	2.54	0.996
HHVD	0.23	1.76	0.996	CW	0.26	2.64	0.993
HEB	0.14	0.94	0.999	CH	0.16	4.51	0.993
FHTD	0.12	0.78	0.999	MCL	0.10	2.09	0.998
FHVD	0.17	0.84	0.999	MCW	0.10	3.78	0.996
TML	0.13	0.91	0.999	MCH	0.11	1.74	0.998
TTL	0.24	2.01	0.995	ICL	0.15	5.31	0.992
CML	0.14	0.45	0.999	ICW	0.07	2.56	0.998
CLAL	0.21	1.16	0.998	LCL	0.10	4.43	0.996
CLAW	0.23	1.39	0.997	LCW	0.08	8.06	0.994

3.2.2. Relative Dimensional Changes

The results for the heat-induced bone dimensional changes are presented in figure 3.2.1. The percentage of bone reduction ranged from 9.7% to 19.2%, with the femoral head vertical diameter showing the smallest degree of shrinkage and the cuboid breadth presenting the largest degree of shrinkage. These results were obtained on calcined bones from both the right and the left sides so the samples referred to the amount of bones and not to the amount of individuals analysed. In addition, the sample included bones from both females and males.

Larger bones – humerus, femur, talus and calcaneus – presented a mean percent shrinkage of 11.97% (n = 150) while the small tarsals shrunk 16.19% (n = 218) on average. A substantial difference between bones of opposite sides from the same individual was sporadically detected (Figure 3.2.2).

The results regarding the heat-induced dimensional changes of pre-calcined bones are presented in figure 3.2.3. The rate of shrinkage presented for each bone included the standard measurements which were earlier analysed for the calcined bones. However, these were all combined to estimate the percent shrinkage of each bone, that is, the humerus, the femur and all the tarsals. The mean rate of shrinkage was much smaller for pre-calcined bones than for calcined bones. In addition, an increase on the dimensions of two bones was observed. That was the case for the head vertical diameter of a charred humerus and the load arm width of a charred calcaneus from two females. The former increased 0.14% and the latter increased 0.70% in size.

The results indicated that a visual inspection of the colour palette displayed by bones was able to differentiate between less and more heat-induced shrunk bones. However, the highest rate found for pre-calcined bones was of 11.7% on an intermediate cuneiform which was well inside the range of variation found for calcined bones. Therefore, the colour inspection was not entirely reliable.

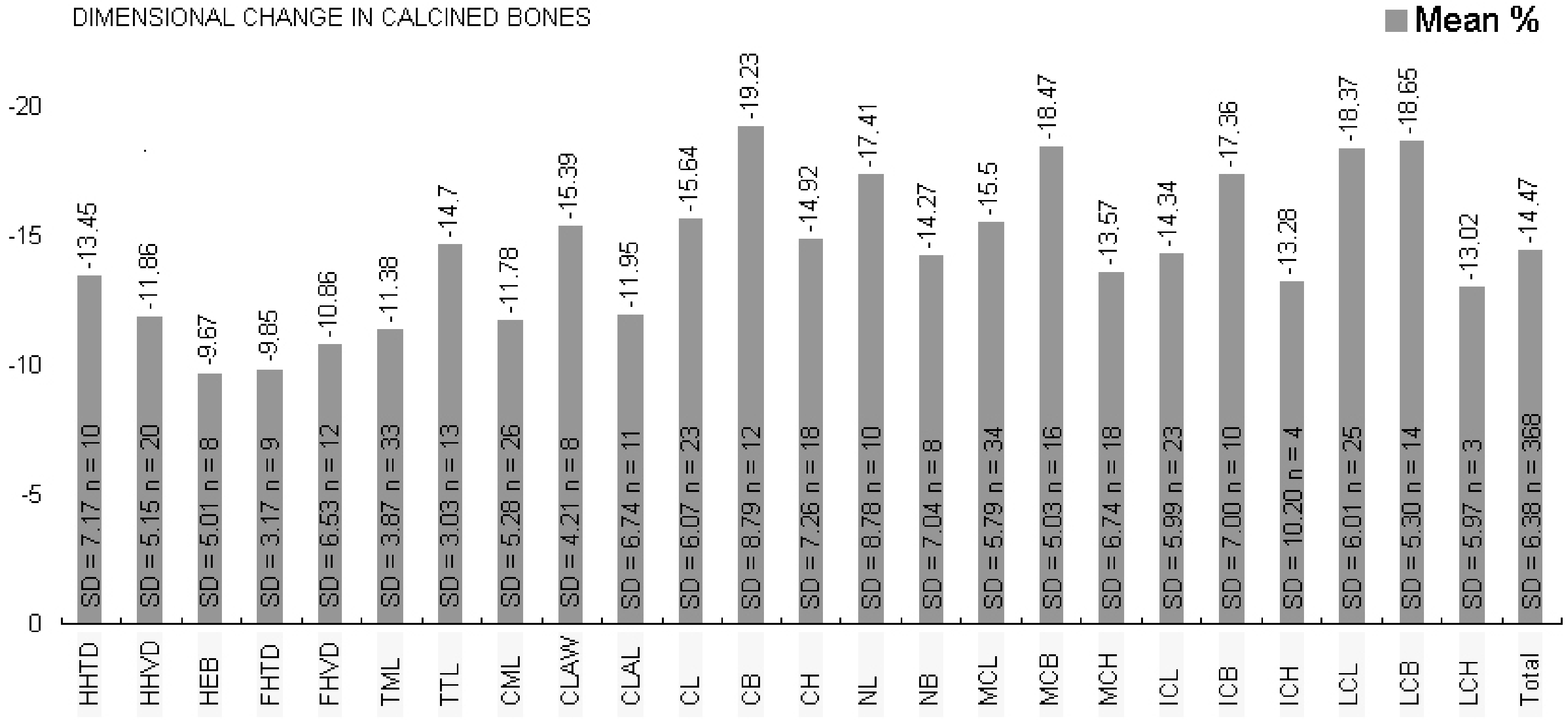

Figure 3.2.1: Descriptive statistics for the percentage of dimensional change experienced by the calcined bones. SD = standard deviation.

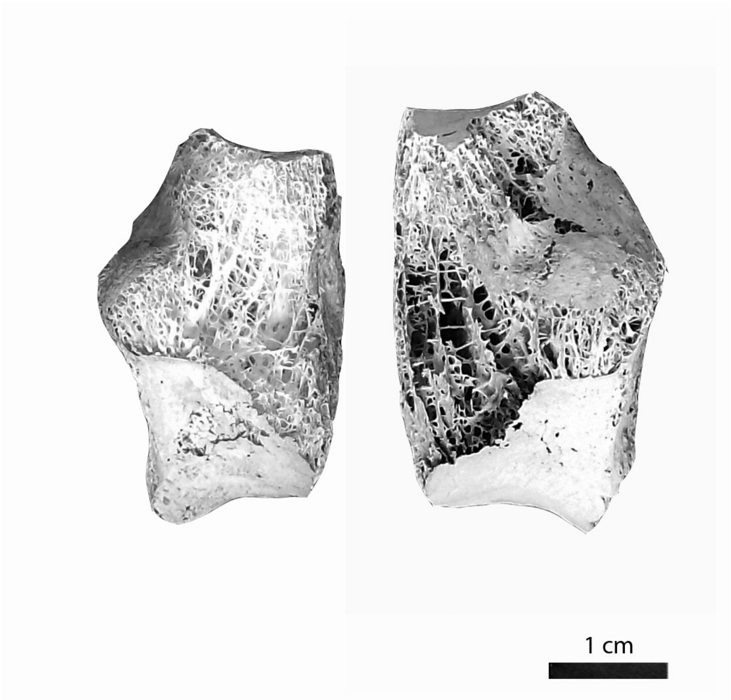

Figure 3.2.2: Differential shrinkage on the right and left cuboids from individual 331.

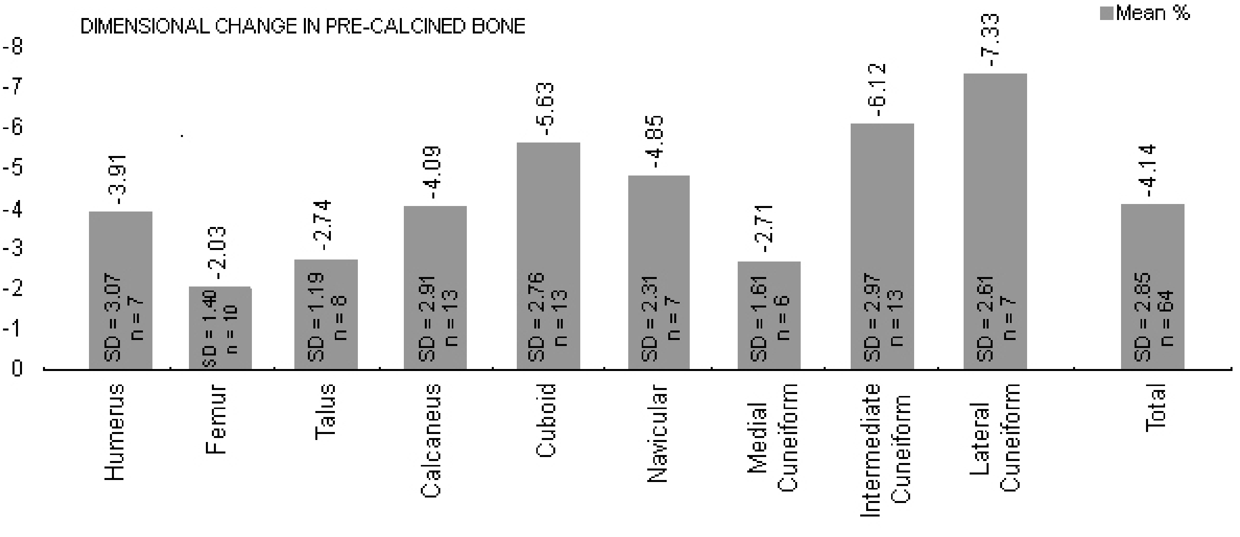

Figure 3.2.3: Descriptive statistics for the rate of dimensional change experienced by the pre-calcined bones.

3.2.3. Influent Factors

For the larger samples of calcined bones, it was possible to investigate if females and males presented differences regarding the rate of shrinkage. The descriptive statistics are given in table 3.2.2. No significant differences were found for any of the features.

Table 3.2.2: Descriptive and inferential statistics for the sexual differences regarding heat-induced dimensional change.

Standard Measurement	Sample	n	Mean (%)	S.D	Median	Range	Value	Sig.
HHVD	Female	10	-12.49	5.12	-	-	.536 [a]	.598
	Male	10	-11.22	5.38	-	-		
TML	Female	21	-11.76	4.08	-	-	.750 [a]	.459
	Male	12	-10.71	3.55	-	-		
CML	Female	11	-14.03	4.46	14.77	14.50	49.0 [b]	.087
	Male	15	-10.14	5.37	9.25	16.83		
CL	Female	11	-14.48	6.09	15.46	17.12	52.0 [b]	.413
	Male	12	-16.71	6.11	18.19	18.09		
MCL	Female	20	-15.71	5.19	17.06	22.48	134.0 [b]	.849
	Male	14	-15.20	6.75	16.73	20.18		
ICL	Female	12	-16.23	4.41	-	-	1.637 [a]	.116
	Male	11	-12.28	6.98	-	-		
LCL	Female	15	-19.14	5.50	18.98	21.16	.785 [a]	.440
	Male	10	-17.20	6.85	20.08	22.41		

[a] T-test; [b] Mann-Whitney test.

As for the intensity of combustion, a multiple regression was carried out in order to investigate its effect on the rate of shrinkage. A sample of 432 bones was examined including both calcined and pre-calcined elements. The duration of combustion was used as an ordinal scaled variable with four increasing time intervals (0-40’; 41-80’; 81-120; overnight). Maximum temperature was used as a ratio scaled variable. The pre-test correlations demonstrated that both duration of combustion [r (432) = .097; p = .022] and maximum temperature of combustion [r (432) = .459; p = .000) were significantly correlated to the rate of shrinkage, although the former was only so at the .05 level. The model was significant [F (2, 429) = 57.5; p = .000] and accounted for 21% of the variation on the rate of shrinkage (Table 3.2.3). However, only maximum temperature of combustion contributed with a significant prediction power to the equation. When tested on an independent sample of 39 bones, the predicted shrinkage rate (mean = 13.12; sd = 3.05) and the observed rate (mean = 10.39; sd = 6.80) were significantly different according to the t-test for two related samples (t = -2.59; df = 38; p = .013; d = -.55). Therefore, the regression equation was not able to reliably predict the shrinkage rate from the intensity of combustion.

In order to better understand the isolated effect of the duration of combustion on shrinkage, further testing was carried out using a one-way ANOVA. It found a significant difference between the four levels (Table 3.2.4). The post-hoc Games-Howell tests indicated that bones burned for 0-40’ had a significantly smaller mean rate of shrinkage than bones burned for 41-80’ and 81-120’ but the former was not significantly different from bones burned and left to cool down overnight. These were only statistically different form bones burned for 81-120’. As for bones burned for 41-80’ and 81-120’, the rate of shrinkage was not significantly different between them.

Maximum temperature of combustion was divided into three different groups and a one-way ANOVA was carried out to investigate its isolated effect on shrinkage (Table 3.2.5). The results showed that the rate of shrinkage increased with temperature and the differences between temperature intervals were statistically significant.

Table 3.2.3: Summary of the linear regression analysis for duration and maximum temperature of combustion predicting the rate of heat-induced shrinkage.

	B	SE B	Beta	t	Sig.
Duration of Combustion	.133	.271	.021	.490	.624
Maximum Temperature of Combustion	.022	.02	.456	10.48	.000
Constant	-3.800	1.549		-2.45	.015

Table 3.2.4: Descriptive and inferential statistics regarding the rate of heat-induced dimensional change according to four levels of duration of combustion.

Time (Maximum Temperature)	n	Mean	SD	Min.	Max.	F	df	Sig.	Eta	Games-Howell	Sig.
1 - 0-40’ (674.6º C)	215	-10.89	6.73	+.70	-29.61	10.15	3 428	.000	.26	1 vs 2 1 vs 3	.000 .000
2 - 41-80’ (771.9º C)	109	-14.55	7.25	-.91	-31.05					1 vs 4 2 vs 3	.792 .522
3 - 81-120’ (727.5º C)	30	-16.11	4.95	-8.43	-32.30					2 vs 4	.052
4 - Overnight (730.5º C)	78	-11.77	7.30	-1.01	-24.75					3 vs 4	.004

Table 3.2.5: Descriptive and inferential statistics regarding the rate of heat-induced dimensional change according to three levels of maximum temperature of combustion.

Temperature	n	Mean	SD	Min.	Max.	F	Sig.	Games-Howell	Sig.
1. 500-649º C	157	-8.35	5.68	-0.20	-26.02	71.56	.000	1 vs 2	.000
2. 650-799º C	91	-13.08	7.03	+0.70	-31.05			1 vs 3	.000
3. 800-950º C	145	-16.70	5.85	-3.15	-32.30			2 vs 3	.000

3.3. Osteometric Sexual Dimorphism

3.3.1 The Preservation of Diagnostic Features

3.3.1.1. The Humerus

3.3.1.1.1. The Cadavers

The results for the post-cremation state of preservation of the humeral standard measurements on the sample of cadavers are presented in figure 3.3.1. The head vertical diameter was the most often found with preservation suitable for measurement. The epicondylar breadth was more susceptible to fragmentation and thus less often available for osteometric examination.

An investigation into the relationship between state of preservation and a number of factors was carried out. The list of independent variables included age, sex, duration of combustion and temperature of combustion.

The "humerus total" category was used as an outcome dichotomous variable (unpreserved; preserved). However, the humeral articular width was excluded from the analysis so that the sample would be enlarged from 21 to 78 cases. Unpreserved features were represented by 35 bones while 43 bones presented preserved features. The sample included 36 females and 42 males. As for the independent variables, age was used as a ratio scaled variable (mean = 69.7 years-old; sd = 16.4). The age of females ranged from 43 to 97 years-old while the age of males ranged from 34 to 93 years-old. Sex was used as a dichotomous categorical variable (F; M). Maximum temperature of combustion was also used as a ratio scaled variable. The average temperature of combustion was of 935.9º C (sd = 57.6; max. = 1050; min. = 800). The average duration of combustion was of 101.7 minutes (sd = 30.7; max. = 180; min. = 60). This variable was turned into a dichotomous variable (0 to 100'; 101 to 200').

Only three variables were included in the logistic model – sex; duration of combustion; and temperature of combustion – in order to allow for a reliable analysis. The minimum required size of the sample was of 67 cases. Age was therefore investigated on its own. When each of the three variables of the model was considered on its own, sex ($\chi^2 = 1.52$; df = 1; p = .218), duration of combustion ($\chi^2 = .511$; df = 1; p = .475) and temperature of combustion ($\chi^2 = .13$; df = 1; p = .715) were not significantly correlated to the state of preservation. When all independent variables were considered together, the model was also not significant ($\chi^2 = 2.03$; df = 3; n = 78; p = .567).

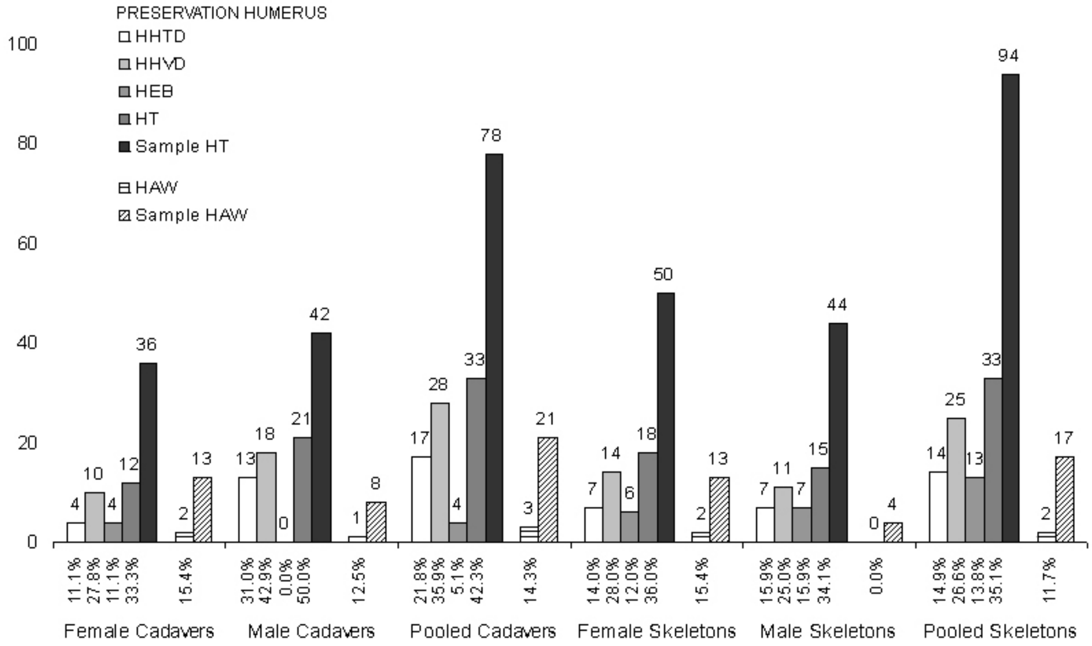

Figure 3.3.1.: Absolute and relative frequencies of preserved humeral standard measurements after cremation. Key: humeral head transverse diameter (HHTD); humeral head vertical diameter (HHVD); humeral epicondylar breadth (HEB); amount of bones with at least one preserved standard measurement considering HHTD, HHVD and HEB = humerus total (HT); amount of bones observed for the HT analysis (Sample HT); humeral articular width (HAW); amount of bones observed for the HAW analysis (Sample HAW).

The mean age difference between bones with preserved and unpreserved features was assessed by calculating an independent samples t-test. The group with preserved features was younger (n = 35; mean = 65.0; sd = 17.1) than the group with unpreserved features (n = 43; mean = 73.6; sd = 15.0) and the difference was statistically significant at the .05 level (t = 2.37; df = 76; p = .021; d = .54). The magnitude of the difference was medium to large (Cohen, 1988).

3.3.1.1.2. The Skeletons

The preservation of the humeral standard measurements regarding the sample of skeletons is summarized in figure 3.3.1. As seen for the sample of cadavers, the head vertical diameter was the most often preserved standard measurement for the sample of skeletons. The “humerus total” category did not include the articular width because this would turn the sample a lot smaller and less representative.

The sample included 48 females and 43 males. The mean maximum temperature of combustion was of 751.8º C (sd = 140.2; max. = 950; min. = 450). Average duration of combustion was of 110.4 minutes (sd = 264.8; max. = 1020; min. = 15) and this variable was computed into a categorical variable with three levels (0 to 25’; 26 to 110’; overnight).

Sex, duration and temperature of combustion (unpreserved n = 58; preserved n = 33), were chosen to fit a three-variable model which required a sample composed of at least 83 cases. The effect of age (unpreserved n = 30; preserved n = 17) on the preservation of humeral features was assessed by running a non-parametric independent-samples test. When on its own, duration of combustion was a significant predictor of humeral preservation (χ^2 = 6.59; df = 1; p = .010). Sex (χ^2 = .32; df = 1; p = .859) and maximum temperature of combustion (χ^2 = .13; df = 1; p = .723) were not significant factors affecting preservation. When both independent variables were combined, the model did not significantly predict whether or not a humeral measurement would be preserved after cremation as well (χ^2 = 6.88; df = 3; n = 91; p = .076).

The further examination of the significant effect of duration of combustion was carried out by calculating a Pearson chi-square. Results demonstrated that humeral features were more often preserved than expected for the skeletons burned for 26-110’ (Table 3.3.1). The opposite was found for the skeletons burned for 0-25’ and this difference was statistically significant with a medium to large effect size (Cohen, 1988).

Mann-Whitney statistic found no significant difference (U = 181.0; p = .101) between preserved features (n = 17; median = 78.0; range = 51) and unpreserved features (n = 30; median = 73.5; range = 72) regarding the age of the individuals. As for sex, a Pearson chi-square test was carried out with the aim of investigating its effect on humeral preservation. No significant difference was found (Table 3.3.2).

Table 3.3.1: Chi-square analysis of the prevalence of preserved and unpreserved humeral features according to the duration of combustion. Expected prevalence is presented in brackets.

	n	0 to 25’	26 to 110’	Overnight	χ^2	p	Phi
Preserved	36	6 (14)	25 (17)	5 (4.5)	13.58	.001	.39
Unpreserved	55	32 (24)	21 (29)	2 (2.5)			
Total	91	38	46	7			

Table 3.3.2: Chi-square analysis of the prevalence of preserved and unpreserved humeral features according to sex. Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Females	50	32 (32)	18 (18)	.001	.971
Males	44	16 (16)	28 (28)		
Total	94	60	34		

3.3.1.1.3. The Pooled Sample

The preservation of humeral features was not significantly different between cadavers and skeletons (Table 3.3.3). However, the results regarding the intensity of combustion were quite different. For this analysis, both cadavers and skeletons burned overnight were excluded from the sample. A Pearson chi-square found a statistically significant difference between cadavers and skeletons regarding the duration of combustion (Table 3.3.4). Skeletons were more often burned for shorter periods of time. The effect size was large, according to Cohen (1988). In addition, maximum temperature of combustion was also significantly different at the .01 level (t = 11.0; df = 160; p = .000; d = -1.86) between cadavers (n = 78; mean = 935.9; sd = 57.6) and skeletons (n = 84; mean = 748.0; sd = 144.3). The effect size was large (Cohen, 1988).

Results indicated that, although cadavers and skeletons had been subject to different intensities of combustion, humeral preservation was not significantly different between them.

Table 3.3.3: Chi-square analysis of the prevalence of preserved and unpreserved humeral features according to the pre-cremation condition of the remains. Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Cadavers	78	43 (47)	35 (31)	1.46	.226
Skeletons	87	56 (52)	31 (35)		
Total	165	99	66		

Table 3.3.4: Chi-square analysis of the prevalence of combustion time periods on cadavers and skeletons. Expected prevalence is presented in brackets.

	n	0-100’	101-200’	χ^2	p	Phi
Cadavers	78	40 (59)	38 (19)	49.98	.000	-.55
Skeletons	84	83 (64)	1 (20)			
Totals	162	123	39			

3.3.1.2. The Femur

3.3.1.2.1. The Cadavers

The preservation of the femoral standard measurements on the sample of cadavers is summarized in figure 3.3.2. The head vertical diameter was most often preserved than the head transverse diameter.

Given that the sample was composed of 77 femoral bones, it only sustained a logistic model with three independent variables. The effect of age on femoral preservation was therefore assessed without interacting with the other independent variables. The “femur total” category was used for the statistical analysis. The group of unpreserved features was composed of 48 bones and the group of preserved features included 29 bones. The sample was the same as the one described for the humerus on the sample of cadavers.

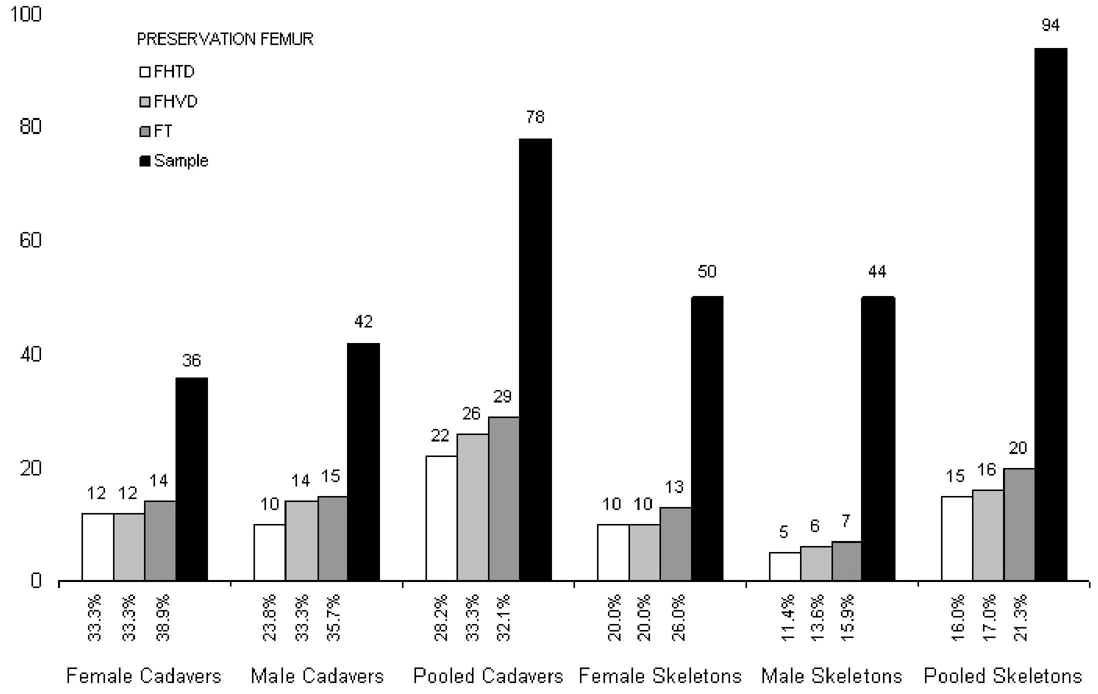

Figure 3.3.2: Absolute and relative frequencies of preserved humeral standard measurements after cremation. Key: femoral head transverse diameter (FHTD); femoral head vertical diameter (FHVD); amount of bones with at least one preserved standard measurement considering FHTD and FHVD = femur total (HT); amount of bones observed for the FT analysis (Sample FT).

When considered on its own, sex (χ^2 = .01; df = 1; p = .943), duration of combustion (χ^2 = .57; df = 1; p = .452) and maximum temperature of combustion (χ^2 = 1.22; df = 1; p = .269) were not significant factors. The logistic model was also not significant (χ^2 = 2.95; df = 3; n = 78; p = .399). Age was not significantly different (U = 535.0; p = .057) between the group of bones with preserved features (n = 30; median = 65.0; range = 59) and the group of bones with unpreserved features (n = 48; median = 72.8; range = 58).

3.3.1.2.2. The Skeletons

The preservation of femoral standard measurements on the sample of skeletons is summarized in figure 3.3.2. Preservation was similar for both features but was considerably worse than the results obtained for the sample of cadavers. The measurable features were better preserved on the female sample.

The identification of significant predictors regarding the preservation of standard measurements was attempted by carrying out a logistic regression analysis using "femur total" as the outcome variable. The sample used for this analysis was the same as the one described for the humerus. However, in this case only 20 bones presented preserved features while 71 bones presented unpreserved features. Given this ratio, the femoral sample only allowed for the outlining of a logistic model with two independent variables (Peduzzi et al, 1996). Duration and maximum temperature of combustion were chosen so that the effect of the intensity of combustion on femoral preservation could be properly assessed. No two-variable logistic regression was carried out for age and sex because the sample requirements were not fulfilled. Therefore, these variables were analysed with basic inferential statistics.

When on its own, duration of combustion (χ^2 = .11; df = 1; p = .738) was not significant while temperature of combustion (χ^2 = 4.17; df = 1; p = .041) was a significant predictor of humeral preservation at the .05 level. When both independent variables were combined, the model did not significantly predict whether or not femoral features would be preserved after cremation (χ^2 = 4.43; df = 3; n = 91; p = .109).

The further analysis regarding the mean maximum temperature of the group with preserved femoral features (mean = 695.5; sd = 147.3) and the group with unpreserved femoral features (mean = 767.6; sd = 135.0) demonstrated a slightly significant difference at the .05 level (t = 2.068; df = 89; p = .042; d = .51). The effect size was medium (Cohen, 1988).

The mean age was not significantly different (U = 113.0; p = .061) between the group with preserved features (n = 10; median = 78.5; range = 45) and the group with unpreserved features (n = 37; U = 73.0; range = 69)

3.3.1.2.3. The Pooled Sample

A statistically insignificant difference between cadavers and skeletons was found regarding the state of preservation of the femoral features (χ^2 = 3.43; df = 1; p = .064). Because the sample of the femur was the same used for the humerus, it has already been demonstrated that duration of combustion and maximum temperature of combustion were significantly different between the two groups according to the pre-cremation condition of the remains (see section 3.3.1.1.3). Therefore, although cadavers and skeletons experienced different intensities of combustion, femoral preservation was not significantly different between them.

3.3.1.3. The Talus

3.3.1.3.1. The Cadavers

The preservation regarding the talar standard measurements on the sample of cadavers is presented in figure 3.3.3. Results indicated that the trochlear length was better preserved than the maximum length.

The sample used for inferential analysis included 80 bones with unpreserved features and 38 bones with preserved features. It was composed of 52 females and 66 males. Sex was used as a dichotomous variable (F; M). Age was used as a ratio scaled variable (mean = 71.2 years-old; sd = 15.1). The age of females ranged from 43 to 97 years-old while the age of males ranged from 34 to 93 years-old. The average duration of combustion was of 413.0 minutes (sd = 437.2; max. = 1020; min. = 60). Duration of combustion was turned into a categorical variable with three levels (0 to 100’; 101 to 200’; overnight). Maximum temperature of combustion was treated as a ratio scaled variable and the mean value was of 940.3º C (sd = 61.2; max. = 1050; min. = 750).

Sex, duration of combustion and maximum temperature of combustion formed the logistic model to investigate its effect on talar preservation. Age was not included because the sample size and the preservation ratio could not reliably sustain a fourth independent variable (Peduzzi et al, 1996). The outcome variable was the "talus maximum length" because the sample was larger than the one from the "talus total" category. This was done because the talus trochlear length included the analytical protocol only at a later stage of the research so it presented a much smaller sample. The effect of age on preservation was assessed by calculating an independent-samples t-test.

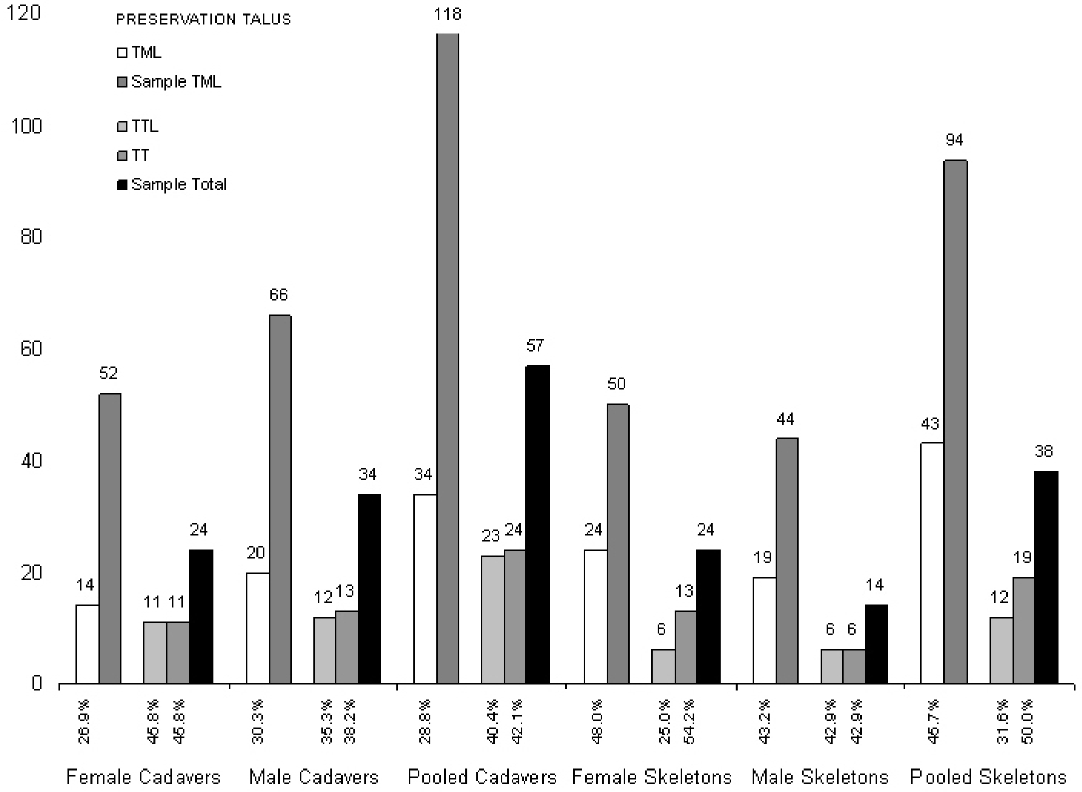

Figure 3.3.3: Absolute and relative frequencies of preserved talar standard measurements after cremation. Key: talar maximum length (TML); amount of bones observed for the TML analysis (Sample TML); talar trochlear length (TTL); amount of bones with at least one preserved standard measurement considering TML and TTL = talar total (TT); amount of bones observed for the TT analysis (Sample Total).

Duration of combustion was identified as having a significant effect on preservation at the .01 level when considered on its own (χ^2 = 9.68; df = 1; p = .002). In contrast, sex (χ^2 = .25; df = 1; p = .619) and temperature of combustion (χ^2 = 2.40; df = 1; p = .121) were not indicated as significant factors. When all independent variables were considered together, the model was significant at the .01 level in predicting whether or not a humeral measurement would be preserved after cremation (χ^2 = 12.46; df = 3; n = 118; p = .006). The variance in whether or not a measurement was preserved that could be predicted from the linear combination of the three independent variables was of 14.0% as indicated by the Nagelkerke R^2. However, duration of combustion remained the only significant predictor of the equation (Table 3.3.5).

Table 3.3.5: Logistic regression regarding the state of preservation of the talar standard measurements (cadavers).

Variable	β	SE	Odds Ratio	Sig.
Sex	-.235	.418	.79	.573
Duration of combustion	.808	.269	2.24	.003
Temperature of Combustion	-.005	.003	1.00	.147
Constant	3.067	3.149	21.48	.330

In order to further describe the significant effect of duration of combustion on the preservation of talar measurements, a Pearson chi-square analysis was carried out (Table 3.3.6). This demonstrated that bones burned overnight were more likely than expected to preserve some of their standard measurements when compared to bones burned for 0-100’ or for 101-200’. This difference was statistically significant and the effect size for this association was small to medium (Cohen, 1988).

Mean age was not significantly different (t = .327; df = 116; p = .744) between the bones with preserved features (n = 38; mean = 70.5; sd = 13.3) and the bones with unpreserved features (n = 80; mean 71.5; sd = 15.9).

Table 3.3.6: Chi-square analysis of the prevalence of preserved and unpreserved talar features according to the duration of combustion (cadavers). Expected prevalence is presented in brackets.

	n	0 to 100’	101 to 200’	overnight	χ^2	p	Phi
Preserved	38	7 (13)	11 (12)	20 (13)	9.95	.007	.29
Unpreserved	80	33 (27)	27 (26)	20 (27)			
Totals	118	40	38	40			

3.3.1.3.2. The Skeletons

The summary for the preservation of the talar measurable features on the sample of skeletons is displayed in figure 3.3.3. The maximum length was more often preserved than the trochlear length and the preservation of at least one of these features was observed for half of the sample.

The sample regarding the maximum length was used for the inferential analysis. Therefore, the sample was the same previously described for the sample of skeletons (see section 3.3.1.1.2). Sample size and preservation ratio required the logistic regression analysis to be performed with three independent variables – sex, duration of combustion and maximum temperature of combustion – based on the recommendations of Peduzzi et al (1996). This model was composed of 48 bones with preserved features and 43 bones with unpreserved features. Age was investigated by calculating an independent-samples test.

When considered on its own, sex (χ^2 = .95; df = 1; p = .329), duration of combustion (χ^2 = 3.34; df = 1; p = .068) and maximum temperature of combustion (χ^2 = .051; df = 1; p = .821) had no significant effect on talar preservation. The model did not significantly predict whether or not a femoral feature would be preserved after cremation as well (χ^2 = 4.77; df = 3; n = 91; p = .189).

Mean age differences between the bones with preserved features (n = 25; median = 78.0; range = 72) and the bones with unpreserved features (n = 22; median = 73.0; range = 69) were not statistically significant (U = 216.5; p = .212).

3.3.1.3.3. The Pooled Sample

Pearson chi-square statistic was carried out with the aim of investigating the differences in talar preservation according to the pre-cremation condition of the remains. A statistically significant difference was found (Table 3.3.7). Preservation of the maximum length was better than expected for skeletons and worse than expected for cadavers. The effect size was small to medium according to Cohen (1988).

Table 3.3.7: Chi-square analysis of the prevalence of preserved and unpreserved talar features according to the pre-cremation condition of the remains (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p	Phi
Cadavers	118	84 (75)	34 (43)	6.49	.011	.175
Skeletons	94	51 (60)	43 (34)			
Totals	212	135	77			

A Pearson chi-square statistic demonstrated that cadavers were significantly more often burned for 101-200' and burned overnight than skeletons (Table 3.3.8). Also, a significant difference regarding temperature of combustion (t = 13.08; df = 207; p = .000; d = -1.87) was found at the .01 level between cadavers (n = 118; mean = 940.3; sd = 61.2) and skeletons (n = 91; mean = 751.8; sd = 140.2).

Results suggested that significant differences in preservation could be related to also significant differences regarding the intensity of combustion between cadavers and skeletons.

Table 3.3.8: Chi-square analysis of the prevalence of cadavers and skeletons according to the duration of combustion for the talar preservation (pooled sample). Expected prevalence is presented in brackets.

	n	0 to 100’	101 to 200’	overnight	χ^2	p	Phi
Cadavers	118	40 (69)	38 (22)	40 (27)	71.0	.000	.58
Skeletons	91	83 (54)	1 (17)	7 (21)			
Total	209	123	39	47			

3.3.1.4. The Calcaneus

3.3.1.4.1. The Cadavers

The post-cremation preservation of the calcaneal standard measurement on the sample of cadavers is presented in figure 3.3.4. The maximum length was the better preserved feature and the load arm width was the worse. Measurements were possible for only about 1/5 of the cases.

The power of age, sex, duration of combustion and maximum temperature of combustion as significant predictors regarding the preservation of calcaneal standard measurements was once more assessed based on the results for the maximum length. This was done instead of using the “calcaneus total” category to maximize the sample already described for the other bones. The sample included 91 bones with preserved features and 27 bones with unpreserved features. The description of the sample was previously carried out for the analysis of the talus.

The size of the sample and the ratio regarding the preservation of calcaneal features only allowed for the inclusion of two variables in the logistic model (Peduzzi et al, 1996). Therefore, it was decided to test two variables at-a-time. First, the demographic profile was analysed by using age and sex as variables. Then, the intensity of combustion was also investigated. This model aimed to investigate the effect of both duration and maximum temperature of combustion on the preservation of the standard measurements from the calcaneus. When considered on its own, age (χ^2 = 1.44; df = 1; p = .231) and sex (χ^2 = .236; df = 1; p = .627) had no significant effect on preservation.

When both independent variables were considered together, the model was also not significant ($\chi^2 = 1.53$; df = 2; n = 118; p = .465).

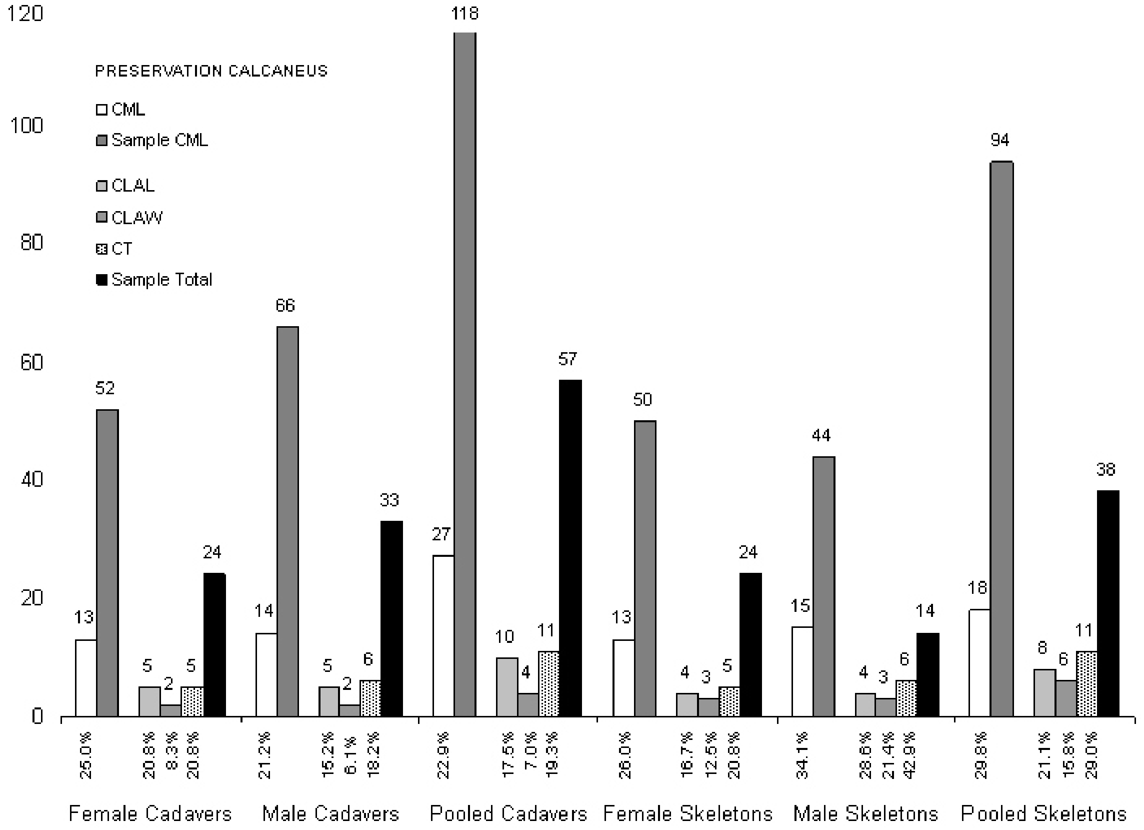

Figure 3.3.4: Absolute and relative frequencies of preserved calcaneal standard measurements after cremation. Key: calcaneal maximum length (CML); amount of bones observed for the CML analysis (Sample CML); calcaneal load arm length (CLAL); calcaneal load arm width (CLAW); amount of bones with at least one preserved standard measurement considering CML, CLAL and CLAW = calcaneus total (CT); amount of bones observed for the CT analysis (Sample Total).

When considered on its own, duration of combustion was a significant factor at the .01 level ($\chi^2 = 10.20$; df = 1; p = .001). In contrast, maximum temperature of combustion did not significantly affect preservation of the calcaneal maximum length ($\chi^2 = .180$; df = 1; p = .671). When both independent variables were considered together, the model was significant at the .01 level (χ^2 = 10.88; df = 2; n = 118; p = .004). Results are presented in table 3.3.9.

The further investigation of the effect of duration of combustion on the preservation of calcaneal features demonstrated a significant difference between the three groups (Table 3.3.10). Bones burned overnight were more often preserved than expected and the opposite was found for the remaining time periods. The effect size was small to medium according to Cohen (1988).

Table 3.3.9: Logistic regression regarding the state of preservation of calcaneal standard measurements (cadavers).

Variable	β	SE	Odds Ratio	Sig.
Duration of combustion	.924	.302	2.52	.002
Temperature of Combustion	.002	.004	1.00	.634
Constant	-3.958	3.521	.019	.261

Table 3.3.10: Chi-square analysis of the prevalence of preserved and unpreserved calcaneal features according to duration of combustion (cadavers). Expected prevalence is presented in brackets.

	n	0 to 100’	101 to 200’	overnight	χ^2	p	Phi
Preserved	27	5 (9)	5 (9)	17 (9)	13.20	.001	.34
Unpreserved	91	35 (31)	33 (29)	23 (31)			
Total	118	40	38	40			

3.3.1.4.2. The Skeletons

Results regarding the calcaneal standard measurements indicated that the maximum length was the most often preserved feature on the sample of skeletons (Figure 3.3.4).

The maximum length was used for the logistic regression analysis in order to identify significant factors associated to the state of preservation. The sample was the same one used for the talus, but was composed of 28 bones with preserved features and 63 bones with unpreserved features. The size of the sample and the preservation ratio allowed for a logistic model with two independent variables – duration and maximum temperature of combustion (Peduzzi et al, 1996). The effect of age and sex were assessed with basic inferential statistics.

Duration of combustion (χ^2 = .83; df = 1; p = .363) and maximum temperature of combustion (χ^2 = 2.40; df = 1; p = .121) were not significant factors affecting preservation when considered on its own. The model was not a significant predictor as well (χ^2 = 3.47; df = 2; n = 91; p = .177).

The mean ages between the group of bones with preserved features (n = 17; median = 78.0; range = 51.0) and the group of bones with unpreserved features (n = 30; median = 73.5; range = 72.0) were not significantly different (U = 181.0; p = .101). In addition, no statistically significant difference was found between sexes regarding calcaneal preservation (Table 3.3.11).

Table 3.3.11: Chi-square analysis of the prevalence of preserved and unpreserved calcaneal features according to sex (skeletons). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Females	50	37 (35)	13 (15)	.73	.392
Males	44	29 (31)	15 (13)		
Total	94	52	42		

3.3.1.4.3. The Pooled Sample

Beside the significant difference regarding the duration and temperature of combustion between cadavers and skeletons which was already demonstrated on the pooled analysis for the talus (see section 3.3.1.3.3), no significant difference regarding the preservation of the calcaneal maximum length was found (Table 3.3.12). Results demonstrated that, although skeletons and cadavers were subject to different intensities of combustion, no significant difference in calcaneal preservation was found.

Table 3.3.12: Chi-square analysis of the prevalence of preserved and unpreserved calcaneal features according to the pre-cremation condition of the remains (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Cadavers	118	27 (31)	91 (87)	1.30	.254
Skeletons	94	28 (24)	66 (70)		
Total	212	55	157		

3.3.1.5. The Cuboid

3.3.1.5.1. The Cadavers

Figure 3.3.5 displays the results for the preservation of the cuboid standard measurements on the sample of cadavers. The length of the cuboid was the most often preserved feature. No inferential statistics was carried out for the cuboid preservation due to the small size of the sample composed of 8 bones with preserved features and 49 bones with unpreserved features.

3.3.1.5.2. The Skeletons

The results for the preservation of standard measurements of the cuboid on the sample of skeletons are presented in figure 3.3.5. As previously seen for the sample of cadavers, the length of the cuboid was the most often preserved feature. Preservation of at least one measurable feature was found for half of the sample (n = 21). The sample was composed of 25 females and 17 males. Average duration of combustion was of

163.9 minutes (sd = 328.5; max. = 1020; min. = 15) but this variable was turned into an ordinal scale variable with three levels (0-25’; 26 to 110’; overnight). The average maximum temperature of combustion was of 693.4º C (sd = 123.3; max. = 925; min. = 500) for the “cuboid total” category.

A logistic model with two variables was supported by the sample according to the recommendations of Peduzzi et al (1996). Therefore, duration and maximum temperature of combustion were included in the model. The same procedure was not followed for age and sex because the sample size did not met the minimum requirements, so those were analysed separately.

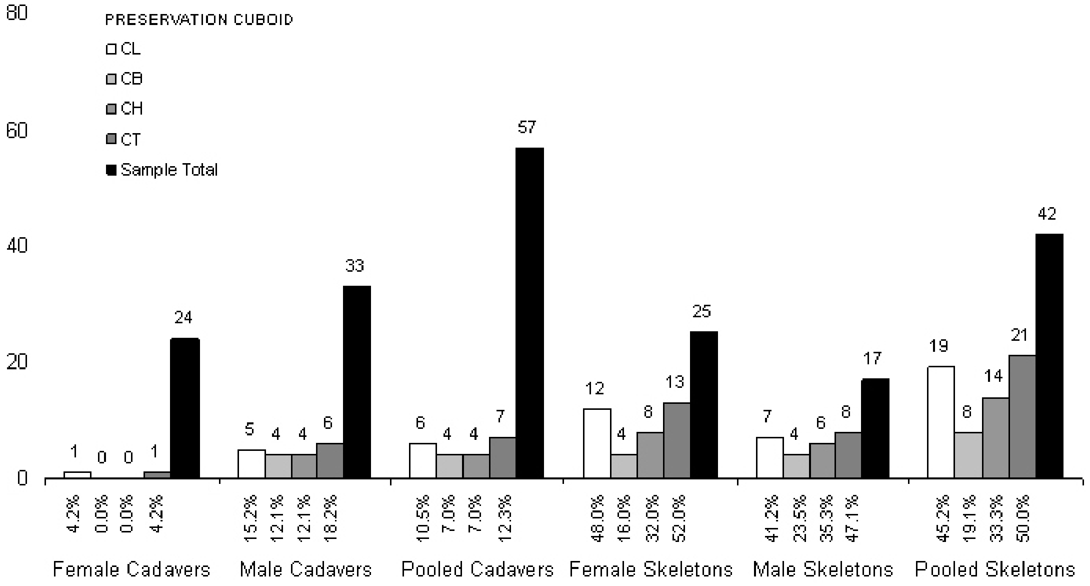

Figure 3.3.5: Absolute and relative frequencies of preserved cuboid standard measurements after cremation. Key: cuboid length (CL); cuboid breadth (CB); cuboid height (CH); amount of bones with at least one preserved standard measurement considering CL, CB and CH = cuboid total (CT); amount of bones observed for the CT analysis (Sample Total).

Duration of combustion (χ^2 = .06; df = 1; p = .814) and maximum temperature of combustion (χ^2 = .14; df = 1; p = .711) were not significant factors affecting preservation when considered on its own. The model was not a significant predictor as well (χ^2 = .30; df = 2; n = 40; p = .860).

The mean age difference between the group of preserved bones (n = 13; median = 78.0; range = 62.0) and group of unpreserved bones (n = 12; median = 71.5; range = 39.0) was not statistically significant. In addition, Pearson chi-squared statistics also demonstrated no significant difference regarding sex (Table 3.3.13).

Table 3.3.13: Chi-square analysis of the prevalence of preserved and unpreserved cuboid features according to sex. Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Females	25	12 (13)	13 (13)	.099	.753
Males	17	9 (9)	8 (9)		
Total	42	21	21		

3.3.1.5.3. The Pooled Sample

Chi-square statistics demonstrated a significant difference between cadavers and skeletons regarding the preservation of cuboid features (Table 3.3.14). These preserved less often than expected for the cadavers and more often than expected for the skeletons. This difference was medium to large (Cohen, 1988).

Table 3.3.14: Chi-square analysis of prevalence of preserved and unpreserved cuboid features according to the pre-cremation condition of the remains (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p	Phi
Cadavers	57	50 (41)	7 (16)	16.96	.000	.414
Skeletons	42	21 (30)	21 (12)			
Totals	99	71	28			

A Pearson chi-square statistic was carried out to investigate the prevalence of the duration of combustion according to the pre-cremation condition of the remains (Table 3.3.15). A statistically significant difference was found and the effect size was large according to Cohen (1988). Cadavers were less often burned for 0-100’ than expected and the opposite was found for the remaining levels of time. The opposite scenario was found for the skeletons. Also, cadavers (mean = 930.3º C; sd = 67.9) were burned at higher temperatures than skeletons (mean = 693.4º C; sd = 123.3) and this difference was statistically significant at the .01 level (t = 12.13; df = 95; p = .000; d = 2.48).

Results suggest that significant differences in preservation may have been the result of also significant differences regarding the intensity of combustion between cadavers and skeletons.

Table 3.3.15: Chi-square analysis of the prevalence of cadavers and skeletons according to the duration of combustion for the cuboid. Expected prevalence is presented in brackets.

	n	0 to 100’	101 to 200’	overnight	χ^2	p	Phi
Cadavers	57	12 (27)	20 (12)	25 (18)	39.27	.000	.64
Skeletons	40	34 (19)	1 (9)	5 (12)			
Totals	97	46	21	30			

3.3.1.6. The Navicular

3.3.1.6.1. The Cadavers

Results regarding the preservation of the standard measurements from the navicular on the sample of cadavers are given in figure 3.3.6. Preservation was very poor for both the navicular length and the navicular breadth. This prevented any statistical investigation in order to find significant differences between preserved (n = 1) and unpreserved (n = 56) features according to age, sex, duration of combustion and temperature of combustion.

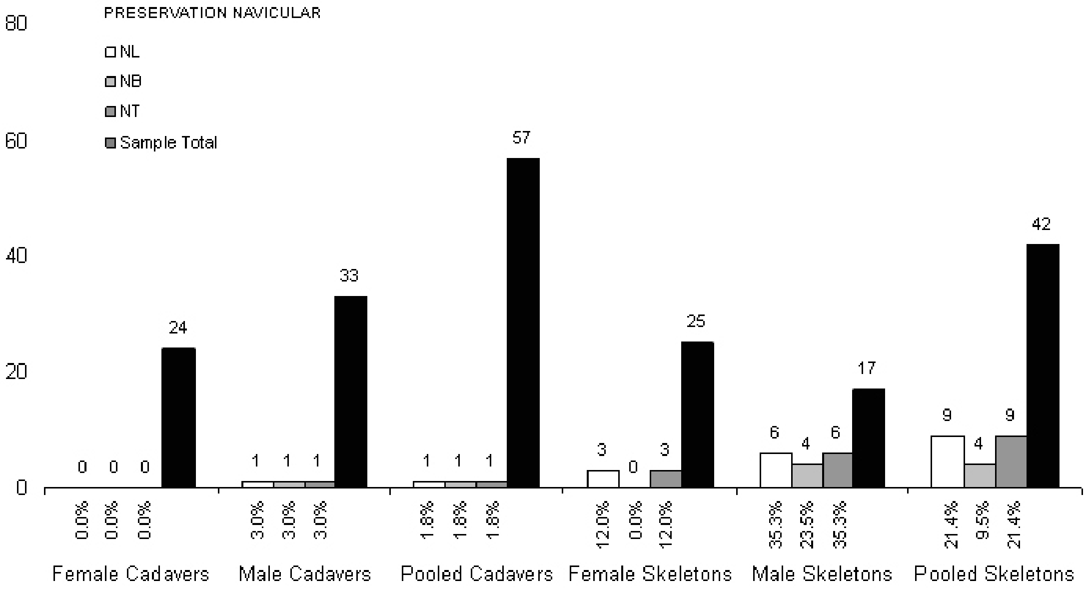

Figure 3.3.6: Absolute and relative frequencies of preserved navicular standard measurements after cremation. Key: navicular length (NL); navicular breadth (NB); amount of bones with at least one preserved standard measurement considering NL and NB = navicular total (NT); amount of bones observed for the NT analysis (Sample Total).

3.3.1.6.2. The Skeletons

The results for the preservation on the sample of skeletons regarding the standard measurements of the navicular are displayed in figure 3.3.6. Preservation was better for males than for females. The small size of the sample prevented inferential statistics. It included 9 preserved bones and 31 unpreserved bones.

3.3.1.6.3. The Pooled Sample

The state of preservation of the navicular features was better than expected for skeletons and worse than expected for cadavers (Table 3.3.16). This difference was significant and the effect size was medium to large according to Cohen (1988).

A statistically significant difference was found for duration and maximum temperature of combustion between cadavers and skeletons as previously demonstrated during the cuboid analysis. Therefore, significant differences in preservation could be related to also the significant differences regarding the intensity of combustion between cadavers and skeletons.

Table 3.3.16: Chi-square analysis of the prevalence of preserved and unpreserved navicular features according to the pre-cremation condition of the remains (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p	Phi
Cadavers	57	56 (51)	1 (6)	10.40	.001	.323
Skeletons	42	33 (38)	9 (4)			
Totals	99	89	10			

3.3.1.7. The Medial Cuneiform

3.3.1.7.1. The Cadavers

Figure 3.3.7 presents the results for the preservation of the medial cuneiform regarding the sample of cadavers. The length standard measurement was the better preserved feature. No inferential statistics were carried out because of the small size of the sample which was composed of 7 preserved bones and 50 unpreserved bones.

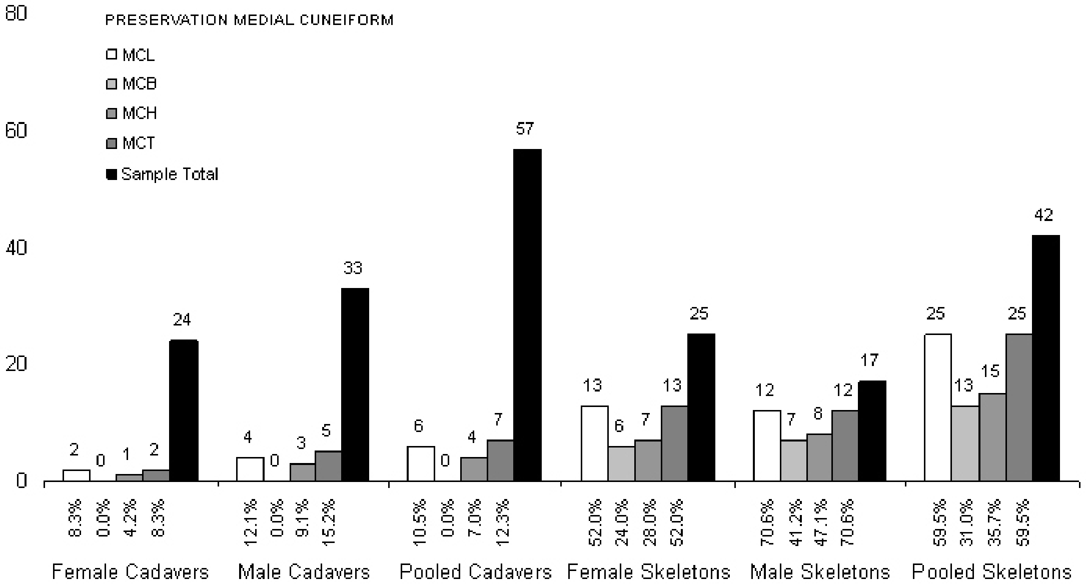

Figure 3.3.7: Absolute and relative frequencies of preserved medial cuneiform standard measurements after cremation. Key: medial cuneiform length (MCL); medial cuneiform breadth (MCB); medial cuneiform height (MCH); amount of bones with at least one preserved standard measurement considering MCL, MCB and MCH = medial cuneiform total (MCT); amount of bones observed for the MCT analysis (Sample Total).

3.3.1.7.2. The Skeletons

Preservation of the measurable features of the medial cuneiform on the sample of skeletons is given in figure 3.3.7. The length standard measurement was the most often preserved. Males presented preserved features more often than females.

The sample and the preservation ratio allowed for the elaboration of a logistic model composed of two independent variables – duration and maximum temperature of combustion (Peduzzi et al, 1996). The same procedure was not followed for age and sex because the sample size did not met the minimum requirements. The effect of age and sex on preservation was therefore investigated separately using basic inferential statistics. The sample was the same described earlier for the cuboid and included 23 bones with preserved features and 17 bones with unpreserved features.

Logistic regression analysis demonstrated that duration of combustion (χ^2 = 1.63; df = 1; p = .202) and maximum temperature of combustion (χ^2 = .311; df = 1; p = .577) were not significant predictors of the state of preservation when considered on its own. The model was not significant either (χ^2 = 1.80; df = 2; n = 40; p = .407).

The mean ages of the group of bones with preserved features (n = 14; median = 75.5; range = 62.0) and the group with unpreserved features (n = 11; median = 76.0; range = 31.0) were not significantly different (U = 76.5; p = .979). In addition, sex had no significant effect on preservation either (Table 3.3.17).

Table 3.3.17: Chi-square analysis of prevalence preserved and unpreserved features on the medial cuneiform according to sex (skeletons). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Females	25	13 (15)	12 (10)	1.45	.228
Males	17	12 (10)	5 (7)		
Total	42	25	17		

3.3.1.7.3. The Pooled Sample

Besides the significant difference regarding duration and maximum temperature of combustion between cadavers and skeletons previously observed, a statistically significant difference regarding the state of preservation of the features of the medial cuneiform was also found (Table 3.3.18). Preservation was better than expected for skeletons and worse than expected for cadavers. The effect size was large according to Cohen (1988).

Once more, results suggested that significant differences in preservation could be related to also significant differences regarding the intensity of combustion between cadavers and skeletons.

Table 3.3.18: Chi-square analysis of the prevalence of preserved and unpreserved features according to the pre-cremation condition of the remains for the medial cuneiform (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p	Phi
Cadavers	57	50 (39)	7 (18)	24.67	.000	.499
Skeletons	42	17 (28)	25 (14)			
Totals	99	67	32			

3.3.1.8. The Intermediate Cuneiform

3.3.1.8.1. The Cadavers

The results regarding the preservation of the intermediate cuneiform on the sample of cadavers are presented in figure 3.3.8. The length standard measurement was the most often preserved feature while the height standard measurement was the least often preserved feature. The preservation of features was better for the sample of males

The sample size and the preservation ratio supported a logistic regression with two independent variables included in the model (Peduzzi et al, 1996). Therefore, it was decided to test two variables at-a-time. First, the demographic profile was analysed by using age and sex as variables. Then, the intensity of combustion was also investigated. The sample was the same as the one described previously for the cadavers (see section 3.3.1.5.1). It was composed of 20 bones with preserved features and 37 bones with unpreserved features.

Considered on its own, age (χ^2 = .00; df = 1; p = .995) and sex (χ^2 = 3.70; df = 1; p = .054) were not significant factors for preservation. The logistic model was not significant either (χ^2 = 4.00; df = 2; n = 57; p = .135).

Considered on its own, duration of combustion (χ^2 = 2.54; df = 1; p = .111) and temperature of combustion (χ^2 = .487; df = 1; p = .485) were not significant factors for preservation. The logistic model was not significant (χ^2 = 3.28; df = 2; n = 57; p = .194).

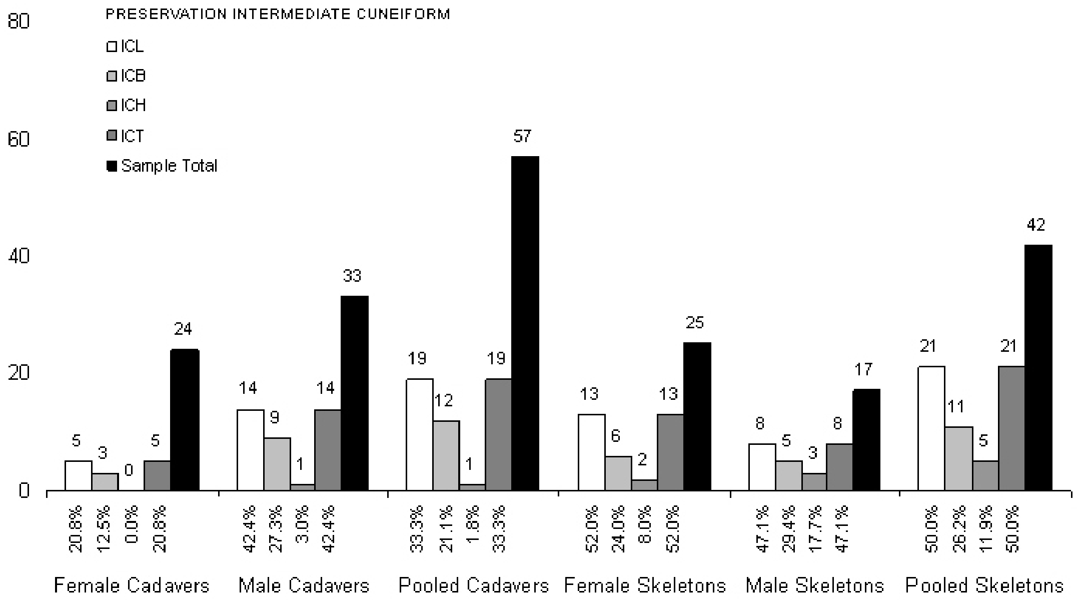

Figure 3.3.8: Absolute and relative frequencies of preserved intermediate cuneiform standard measurements after cremation. Key: intermediate cuneiform length (ICL); intermediate cuneiform breadth (ICB); intermediate cuneiform height (ICH); amount of bones with at least one preserved standard measurement considering ICL, ICB and ICH = intermediate cuneiform total (ICT); amount of bones observed for the ICT analysis (Sample Total).

3.3.1.8.2. The Skeletons

Figure 3.3.8 gives the results for the preservation of the features of the intermediate cuneiform on the sample of skeletons. The length standard measurement was the most often preserved feature.

The logistic model was composed of two variables following the recommendations of Peduzzi et al (1996) regarding sample size. The intensity of combustion was therefore analysed. However, the demographic profile was investigated separately due to the small sample size regarding age which did not allow for a two-variable logistic model. It demonstrated that duration of combustion ($\chi^2 = 2.32$; df = 1; p = .128) and maximum temperature of combustion ($\chi^2 = 1.79$; df = 1; p = .181) were not significant factors for the state of preservation when considered on its own. The logistic model was not significant as well (χ^2 = 3.21; df = 2; n = 40; p = .201). The sample included 21 bones with preserved features and 19 bones with unpreserved features. The sample has been previously described for the cuboid analysis (see section 3.3.1.5.2).

The effect of age on the preservation of the intermediate cuneiform was not investigated due to the small sample size (preserved n = 16; unpreserved n = 9). On the other hand, the effect of sex on preservation was not significant (Table 3.3.19).

Table 3.3.19: Chi-square analysis of the prevalence of preserved and unpreserved features on the intermediate cuneiform according to sex (cadavers). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Females	25	14 (13)	11 (12)	.32	.569
Males	17	8 (9)	9 (8)		
Total	42	22	20		

3.3.1.8.3. The Pooled Sample

Preservation of the intermediate cuneiform was better than expected for skeletons and worse than expected for cadavers but that difference was not significant (Table 3.3.20). In contrast, it has been previously demonstrated that cadavers and skeletons were significantly different regarding the duration and temperature of combustion. Therefore, no significant differences in preservation were detected although significantly different intensities of combustion were found between cadavers and skeletons.

Table 3.3.20: Chi-square analysis of the prevalence of preserved and unpreserved features according to the pre-cremation condition of the remains for the middle cuneiform (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Cadavers	57	38 (34)	19 (23)	2.79	.095
Skeletons	42	21 (25)	21 (17)		
Totals	99	59	40		

3.3.1.9. The Lateral Cuneiform

3.3.1.9.1. The Cadavers

Figure 3.3.9 presents the results for the preservation of the lateral cuneiform on the sample of cadavers. The length standard measurement was the most often preserved feature while the height measurement was the less often preserved feature.

The sample size and preservation ratio allowed for the testing of a logistic model with two variables (Peduzzi et al, 1996). Therefore, both the intensity of combustion – duration and maximum temperature of cremation – and the demographic profile – age and sex – were tested through logistic regression. The sample was the same described for the remaining small tarsals and was composed of 26 bones with preserved features and 31 bones with unpreserved features.

When considered on its own, age (χ^2 = .10; df = 1; p = .921) and sex (χ^2 = 2.52; df = 1; p = .112) were not significant factors for the preservation of the measurable features. The logistic model was also not significant (χ^2 = 2.74; df = 2; n = 57; p = .254).

When considered on its own, duration of combustion (χ^2 = 1.11; df = 1; p = .291) and maximum temperature of combustion (χ^2 = 2.34; df = 1; p = .126) were not significant factors for the preservation of the measurable features. The logistic model was not significant as well (χ^2 = 3.79; df = 2; n = 57; p = .150).

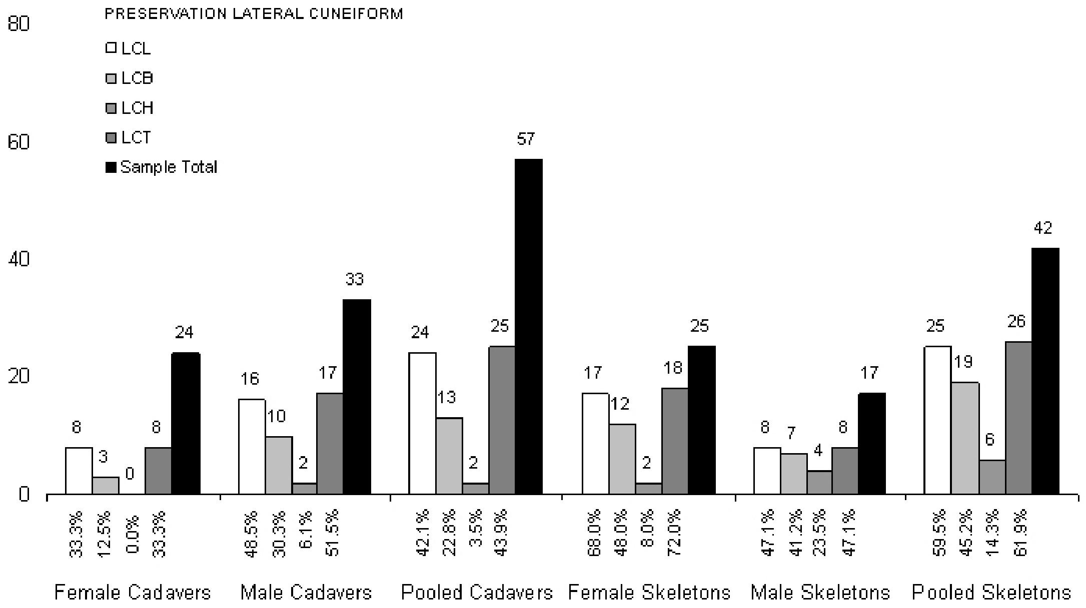

Figure 3.3.9: Absolute and relative frequencies of preserved lateral cuneiform standard measurements after cremation. Key: lateral cuneiform length (LCL); lateral cuneiform breadth (LCB); lateral cuneiform height (LCH); amount of bones with at least one preserved standard measurement considering LCL, LCB and LCH = lateral cuneiform total (ICT); amount of bones observed for the LCT analysis (Sample Total).

3.3.1.9.2. The Skeletons

The results for the preservation of the standard measurements of the lateral cuneiform on the sample of skeletons are presented in figure 3.3.9. As previously seen for the sample of cadavers, the length standard measurement was the most often preserved feature. Preservation of at least one measurable feature was found for more than half of the sample.

The logistic model included two independent variables as recommended by Peduzzi et al (1996). Although the intensity of combustion was assessed with a logistic regression, the small sample size for age did not allow following the same procedure to investigate the effect of the demographic profile on preservation.

When considered on its own, logistic regression demonstrated that duration of combustion (χ^2 = 1.07; df = 1; p = .301) and maximum temperature of combustion (χ^2 = 2.30; df = 1; p = .129) were not significant predictors of the state of preservation. The model was also not significant (χ^2 = 2.68; df = 2; n = 57; p = .262). The sample previously described for the small tarsals was used. It was composed of 25 preserved bones and 15 unpreserved bones.

The effect of age on preservation was not tested due to the small sample size (preserved n = 15; unpreserved n = 10). Sex was investigated and no significant effect was found (Table 3.3.21).

Table 3.3.21: Chi-square analysis of the prevalence of preserved and unpreserved features on the lateral cuneiform according to sex (skeletons). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Females	25	18 (16)	7 (10)	2.67	.102
Males	17	8 (11)	9 (7)		
Total	42	26	15		

3.3.1.9.3. The Pooled Sample

Although significant differences in duration and maximum temperature of combustion were present between cadavers and skeletons, no statistically significant difference regarding the state of preservation of the lateral cuneiform features was found (Table 3.3.22). Preservation was better than expected for skeletons and worse than expected for cadavers.

Table 3.3.22: Chi-square analysis of the prevalence of preserved and unpreserved features according to the pre-cremation condition of the remains for the lateral cuneiform (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Cadavers	57	32 (28)	25 (29)	3.15	.076
Skeletons	42	16 (20)	26 (22)		
Totals	99	51	42		

3.3.1.10. The Internal Auditory Canal

3.3.1.10.1. The Cadavers

The results for the post-cremation state of preservation of the humeral internal auditory canal (IAC) of the petrous bone on the samples of cadavers and skeletons are presented in figure 3.3.10.

The size of the sample and the ratio – 40 unpreserved; 66 preserved – regarding the preservation of the petrous bone feature on the sample of cadavers allowed for the inclusion of four variables in the logistic model (Peduzzi et al, 1996). When considered on its own, age (χ^2 = .71; df = 1; p = .790), sex (χ^2 = .002; df = 1; p = .964), duration of combustion (χ^2 = .014; df = 1; p = .905) and maximum temperature of combustion (χ^2 = .019; df = 1; p = .889) had no significant effect on preservation. When all independent variables were considered together, the model was also not significant (χ^2 = .119; df = 4; n = 118; p = .998).

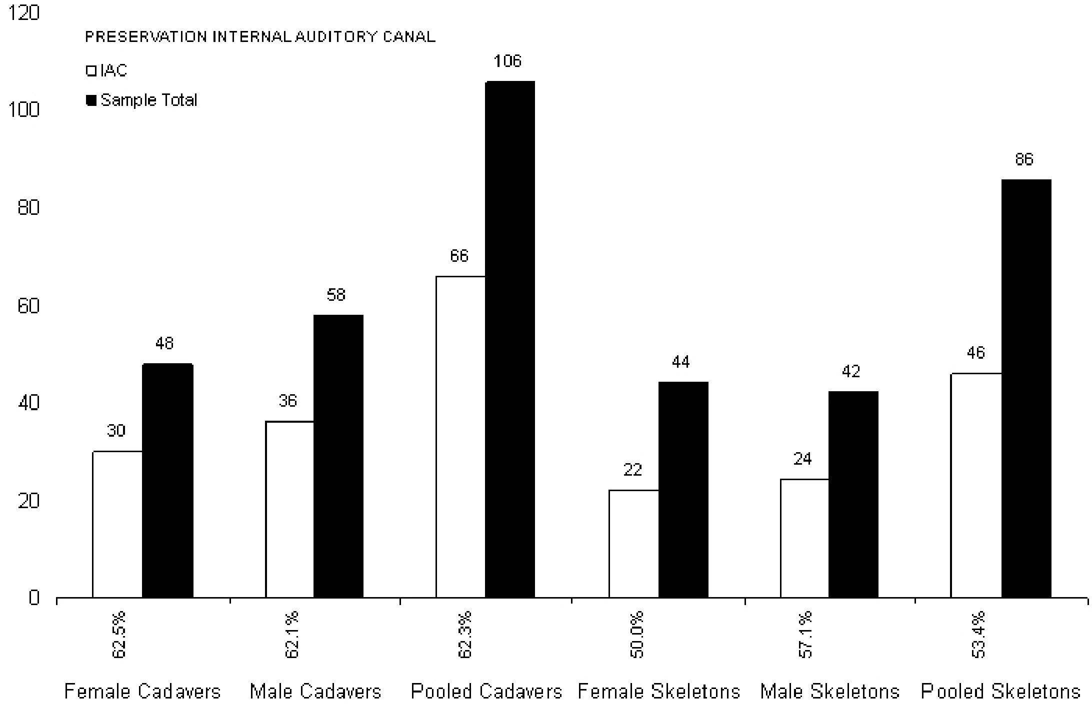

Figure 3.3.10: Absolute and relative frequencies of preserved internal auditory canals after cremation. Key: internal auditory canal (IAC); amount of bones observed for the IAC analysis (Sample Total).

3.3.1.10.2. The Skeletons

The results for the post-cremation preservation of the IAC are given in figure 3.3.10. The ratio on the sample of skeletons – 39 unpreserved; 47 preserved – allowed for the testing of a logistic model composed of three variables. Therefore, age was investigated separately. When considered on its own, sex (χ^2 = .125; df = 1; p = .724), duration of combustion (χ^2 = 2.257; df = 1; p = .133) and maximum temperature of combustion (χ^2 = .087; df = 1; p = .768) had no significant effect on preservation. The model was also not significant (χ^2 = 2.643; df = 4; n = 86; p = .450). Age was not significantly different between the group of bones with preserved features (mean = 71.9; sd = 20.5) and the group of bones with unpreserved features (mean = 69.5; sd = 16.4).

3.3.1.10.3. The Pooled Sample

No significant differences were found between cadavers and skeletons (Table 3.3.23) although the intensity of combustion was significantly different between both kinds of remains (see section 3.3.1.3.3).

Table 3.3.23: Chi-square analysis of the prevalence of preserved and unpreserved features according to the pre-cremation condition of the remains for the internal auditory canal (pooled sample). Expected prevalence is presented in brackets.

	n	Unpreserved	Preserved	χ^2	p
Cadavers	57	32 (28)	25 (29)	3.15	.076
Skeletons	42	16 (20)	26 (22)		
Totals	99	51	42		

3.3.2. Measurement Error

A sample of 17 individuals was assembled in order to calculate the intra- and inter-observer variation for the measurement of the lateral angle. The variation regarding other measurements addressed in this section has been estimated previously (see section 3.2.1).

The absolute technical error of measurement was of 3.47º for the intra-observations. The relative error of measurement was of 2.32% and the coefficient of reliability was of 0.92. As for the inter-observer variation, the absolute technical error of measurement was of 12.67º, the relative error of measurement was of 3.88% and the coefficient of reliability was of 0.51.

The relative error of measurement was less than 4% for both the inter and intra-observations thus demonstrating reasonable repeatability. The coefficient of reliability was close to 1.0 for the intra-observer variation indicating that only a small portion of the measurement variance present in the sample was the result of measurement error. However, the same indicator was much smaller for the inter-observations thus demonstrating that the replicability of the method was somewhat problematic.

3.3.3. Sample Coherence

Cadavers and skeletons were compared with each other according to bone dimensions to assess if both could be combined into one larger pooled sample. This was done by checking for differences between female cadavers and female skeletons and between male cadavers and male skeletons. Only the largest amples were tested. Results were contrasting for both females (Table 3.3.24) and males (Table 3.3.25). Although for most cases the difference between the means was not significant, the opposite was found for the humeral head vertical diameter on the female sample and for the lateral cuneiform length on both the female and male samples. The effect size was small to medium for the first standard measurement, large for the second on the female sample and medium to large for the second on the male sample according to Cohen (1988). Given that statistically significant differences between both samples were found for some cases, it was decided to analyse them independently from each other and therefore not risk to loose any coherence by creating a pooled sample.

3.3.4. Bilateral Asymmetry

In order to assess if bones from the left and the right sides were significantly different according to size, statistics were performed on a number of standard measurements which presented large enough samples on cadavers (≥ 10 pairs). Results indicated that the size of the left and right bones were not significantly different at the .01 level (Table 3.3.26). Given these results, the measurements from the right side were selected for the analysis regarding sexual dimorphism. Left-sided bones were used when the right ones were absent.

Table 3.3.24: Descriptive and inferential statistics regarding the standard measurements of female skeletons and cadavers (in mm).

Female Std. Measurement	Sample	n	Mean	SD	Median	Range	Mann Whitney	Sig.	Effect Size
HHVD	Skeletons	14	36.37	2.17	36.43	8.72	316.0	.028	-.24
	Cadavers	72	37.86	2.84	37.69	15.22			
	Pooled	86	37.61	2.79	37.45	15.22			
TML	Skeletons	29	44.32	2.88	45.14	11.58	508.0	.381	-
	Cadavers	40	45.14	2.77	45.08	15.76			
	Pooled	69	44.80	2.83	45.10	16.62			
CML	Skeletons	13	64.70	6.08	64.13	20.13	249.5	.068	-
	Cadavers	57	67.75	3.69	67.22	19.81			
	Pooled	70	67.24	4.32	66.90	25.18			
LCL	Skeletons	16	19.61	1.79	19.39	6.21	76.5	.140	-
	Cadavers	14	20.74	2.55	21.26	9.82			
	Pooled	30	20.14	2.21	19.90	9.82			
LCB	Skeletons	13	13.11	.95	12.86	3.18	19.0	.017	-.52
	Cadavers	8	14.03	.98	13.85	3.03			
	Pooled	21	13.46	1.04	13.28	4.14			

Table 3.3.25: Descriptive and inferential statistics regarding the standard measurements of male skeletons and cadavers (in mm).

Male Std. Measurement	Sample	n	Mean	SD	Median	Range	value	Sig.	Effect Size
HHVD	Skeletons	14	42.08	4.28	42.48	16.04	642.0	.161 [a]	-
	Cadavers	19	43.45	2.80	43.36	19.63			
	Pooled	33	43.31	3.00	43.27	20.10			
HEB	Skeletons	12	55.88	5.54	56.26	22.51	131.5	.088 [a]	-
	Cadavers	33	58.04	3.30	57.91	17.97			
	Pooled	45	57.47	4.06	57.37	22.90			
TML	Skeletons	28	50.05	3.47	50.14	14.46	-.661	.511 [b]	-
	Cadavers	62	50.55	3.22	50.52	16.48			
	Pooled	90	50.39	3.29	50.42	17.53			
CML	Skeletons	21	75.22	5.92	75.98	18.95	528.5	.274 [a]	-
	Cadavers	60	77.27	4.59	76.88	23.06			
	Pooled	81	76.74	5.01	76.56	24.30			
CL	Skeletons	12	33.20	2.73	33.37	10.32	94.0	.926 [a]	-
	Cadavers	16	33.66	3.77	33.14	12.70			
	Pooled	28	33.46	3.31	33.34	12.70			
MCL	Skeletons	17	23.34	2.08	23.19	7.14	96.0	.860 [a]	-
	Cadavers	13	23.23	3.84	23.75	14.06			
	Pooled	30	23.29	2.91	23.38	14.06			
LCL	Skeletons	11	21.05	1.46	21.32	4.42	79.0	.015 [a]	-.39
	Cadavers	29	22.42	1.23	22.54	4.88			
	Pooled	40	22.04	1.41	22.17	5.76			

[a] Mann-Whitney test; [b] t-test.

Table 3.3.26: Mean differences between left and right bones (in mm).

Std Measurement	Side	n	Mean	SD	Median	Range	Test	Sig
HHTD	Left	17	37.99	2.98	-	-	.258 [a]	.800
	Right	17	37.92	3.18	-	-		
HHVD	Left	41	42.43	3.00	-	-	-.006 [a]	.995
	Right	41	42.43	2.85	-	-		
FHTD	Left	12	38.69	3.40	39.56	9.72	-.314 [b]	.754
	Right	12	38.99	3.60	39.26	9.84		
FHVD	Left	33	41.53	3.32	40.66	13.66	-1.983 [b]	.047
	Right	33	42.02	3.15	41.52	14.28		
TML	Left	11	48.77	5.01	46.29	13.91	-.445 [b]	.657
	Right	11	48.99	4.60	49.04	13.94		
TTL	Left	10	29.05	3.31	28.19	11.56	-.357 [b]	.721
	Right	10	29.24	2.70	28.74	9.24		
CML	Left	10	72.38	8.53	71.19	28.03	-1.070 [b]	.285
	Right	10	73.40	6.82	72.94	20.73		
IAC	Left	14	43.45	11.86	40.40	46.70	-.722	.470
	Right	14	46.78	16.74	43.50	58.20		

[a] T-test; [b] Wilcoxon signed ranks test.

3.3.5. Sexual Dimorphism

The mean size of female and male features of the humerus, femur, talus and the calcaneus were investigated to assess if sexual differences were present on calcined bones of cadavers. This was carried out on samples with equal amount of females and males. Results are given in table 3.3.27 and demonstrated that statistically significant differences were present on all standard measurements. The magnitude of the difference between both sexes was large according to Cohen (1988).

Table 3.3.27: Descriptive and inferential statistics for the standard measurements (in mm) of the humerus, femur, talus and calcaneus (cadavers).

Standard Measurement	Sex	n	Mean	S.D.	t	df	Sig.	d
HHTD	Female	33	33.76	2.82	-9.03	64	.000	2.25
	Male	33	39.16	1.97				
	Pooled	66	36.46	3.64				
HHVD	Female	62	37.74	2.98	-10.93	122	.000	1.97
	Male	62	43.51	2.89				
	Pooled	124	40.63	4.11				
HEB	Female	25	50.48	3.35	-7.88	48	.000	2.23
	Male	25	58.32	3.67				
	Pooled	50	54.40	5.27				
HAW	Female	18	36.47	1.98	-6.74	34	.000	2.25
	Male	18	41.24	2.26				
	Pooled	36	38.85	3.20				
FHTD	Female	42	35.87	2.08	-9.49	82	.000	2.09
	Male	42	40.95	2.77				
	Pooled	84	38.41	3.53				
FHVD	Female	55	37.64	2.18	-9.99	108	.000	1.20
	Male	55	43.02	3.34				
	Pooled	110	40.33	3.89				
TML	Female	30	45.57	2.93	-6.88	58	.000	1.76
	Male	30	50.97	3.15				
	Pooled	60	48.27	4.06				
TTL	Female	26	27.78	2.37	-5.40	50	.000	1.50
	Male	26	31.48	2.58				
	Pooled	52	29.96	3.08				
CML	Female	47	67.71	3.95	-10.656	92	.000	2.20
	Male	47	76.92	4.42				
	Pooled	94	72.31	6.23				
CLAL	Female	21	40.47	2.63	-9.063	40	.000	2.80
	Male	21	47.41	2.33				
	Pooled	42	44.80	4.62				

Tables 3.3.28 and 3.3.29 give the descriptive statistics and results for the non-parametric tests regarding the difference between the means of females and males of additional standard measurements. The calcaneal load arm width was included in this table due to its small sized sample. Significant differences between sexes were found for the load arm width of the calcaneus, the length of the cuboid and the length and breadth of the lateral cuneiform with various degrees of effect size though. This was medium to large for the calcaneal feature, small to medium for the lateral cuneiform length and medium to large for the remaining standard measurements (Cohen, 1988).

Sexual dimorphism of the small tarsals was also assessed for the sample of skeletons which was larger than the sample of cadavers for some features. Results are presented in tables 3.3.30 and 3.3.31 and demonstrated a significant difference between females and males for all cases.

As for the IAC on the sample of cadavers, the female mean lateral angle (n = 26; mean = 49.57; sd = 13.07) and the male mean lateral angle (n = 28; mean = 50.30; sd = 17.00) were not significantly different from each other. The sex-pooled mean angle was of 49.95º (sd = 15.10). The sample of skeletons provided for somewhat different results. The female mean score (n = 15; median = 56.50; range = 44.40) was quite larger than the male mean score (n = 21; median = 48.60; range = 44.90). This difference was almost statistically significant at the .05 level (U = 97.0; p = .052). The sex-pooled mean lateral angle was of 49.78º (sd = 14.93). The samples used for the calculation of the sexual differences were much smaller than the amount of preserved bones because several casts were not good enough to allow for the measurement of the lateral angle.

Table 3.3.28: Descriptive and inferential statistics for the standard measurements (in mm) of the calcaneus, cuboid and navicular (cadavers).

Std. Measurement	Sex	n	Mean	S.D.	Median	Range	Mann Whitney	Sig.	r
CLAW	Female	7	34.19	2.33	35.57	5.63	3.000	.001	-.76
	Male	11	38.80	2.06	38.87	7.81			
	Pooled	18	37.01	3.12	37.08	13.09			
CL	Female	6	30.24	2.10	29.26	5.03	21.0	.046	-.43
	Male	16	33.66	3.77	33.13	12.70			
	Pooled	22	32.73	3.69	32.34	12.75			
CB	Female	2	22.30	.75	22.30	1.06	-	-	
	Male	9	25.23	2.89	26.24	9.29			
	Pooled	11	24.70	2.85	23.63	9.29			
CH	Female	4	21.21	1.44	21.28	2.81	-	-	
	Male	5	21.52	2.34	21.15	5.52			
	Pooled	9	21.38	1.88	21.15	5.52			
NL	Female	0	-	-	-	-	-	-	-
	Male	5	18.67	1.15	19.20	3.08			
NB	Female	2	34.19	2.77	34.19	3.91	-	-	
	Male	5	36.69	2.20	36.98	3.91			
	Pooled	7	35.97	2.45	36.14	6.90			

Table 3.3.29: Descriptive and inferential statistics for the standard measurements (in mm) of the cuneiforms (cadavers).

Std. Measurement	Sex	n	Mean	S.D.	Median	Range	Mann Whitney	Sig.	r
MCL	Female	4	19.80	1.28	19.78	2.49	-		
	Male	13	23.23	3.84	23.75	14.06			
	Pooled	17	22.42	3.69	22.89	14.06			
MCB	Female	0	-	-	-	-	-	-	-
	Male	2	19.81	5.73	19.81	8.10			
MCH	Female	2	25.36	1.64	25.36	2.32	-		
	Male	6	29.69	1.59	30.03	4.18			
	Pooled	8	28.61	2.49	29.33	6.87			
ICL	Female	7	15.13	1.22	15.67	3.14	35.5	.056	-
	Male	20	16.32	1.10	16.29	3.84			
	Pooled	27	16.01	1.23	16.10	5.02			
ICB	Female	5	13.74	1.18	13.95	2.98	-		
	Male	12	14.09	1.36	14.17	4.58			
	Pooled	17	13.99	1.29	14.03	4.58			
ICH	Female	0	-	-	-	-	-	-	-
	Male	1	20.53	-	-	-			
LCL	Female	14	20.74	2.55	21.26	9.82	121.0	.034	-.32
	Male	29	22.42	1.23	22.54	4.88			
	Pooled	43	21.87	1.91	21.87	1.91			
LCB	Female	8	13.85	3.03	13.85	3.03	27.0	.023	-.46
	Male	16	15.29	8.10	15.29	8.10			
	Pooled	24	14.80	8.10	14.94	1.70			
LCH	Female	0	-	-	-	-	-	-	-
	Male	3	18.53	4.65	20.78	8.44			

Table 3.3.30: Descriptive and inferential statistics for the standard measurements (in mm) of the cuboid and navicular (skeletons).

Standard Measurement	Sex	n	Mean	SD	Median	Range.	Mann Whitney U	Sig.	r
CL	Female	10	29.02	2.01	28.10	5.59	10.0	.001	-.70
	Male	12	33.20	2.73	33.37	10.32			
	Pooled	22	31.30	3.19	31.15	12.28			
CB	Female	4	19.61	2.10	18.79	4.48	-	-	-
	Male	6	24.69	3.00	24.59	7.46			
	Pooled	10	22.66	3.66	22.25	10.26			
CH	Female	8	19.30	1.22	19.39	4.08	10.0	.008	-.63
	Male	10	21.82	1.78	22.27	5.30			
	Pooled	18	20.70	1.99	20.13	6.87			
NL	Female	2	17.63	.96	17.63	1.65	-	-	-
	Male	8	16.94	2.28	15.89	5.81			
	Pooled	10	17.08	2.05	16.48	5.81			
NB	Female	1	36.25	-	-	-	-	-	-
	Male	7	34.59	2.99	35.19	9.29			
	Pooled	10	34.79	2.83	35.27	9.29			

Table 3.3.31: Descriptive and inferential statistics for the standard measurements (in mm) of the medial, middle and lateral cuneiforms (skeletons).

Standard Measurement	Sex	N	Mean	SD	Median	Range.	Value	Sig.	Effect Size
MCL	Female	15	20.42	1.89	-	-	4.137 [a]	.000	1.47
	Male	17	23.34	2.08	-	-			
	Pooled	32	21.97	2.46	-	-			
MCB	Female	8	14.25	1.11	14.06	3.58	6.0 [b]	.003	-.71
	Male	10	16.79	1.53	16.72	4.79			
	Pooled	18	15.66	1.85	15.45	6.64			
MCH	Female	9	26.27	2.60	25.52	9.17	18.0 [b]	.017	-.54
	Male	11	29.13	2.32	28.82	6.62			
	Pooled	20	27.84	2.80	27.47	10.82			
ICL	Female	11	14.60	1.42	14.37	4.90	20.0 [b]	.014	.54
	Male	10	16.56	2.05	16.02	6.42			
	Pooled	21	15.53	1.97	15.24	7.77			
ICB	Female	5	12.70	1.17	12.44	2.83			
	Male	7	15.07	1.80	15.34	4.77			
	Pooled	13	14.09	1.93	13.67	6.67			
ICH	Female	2	18.31	2.48	18.31	3.51			
	Male	5	18.23	3.28	18.92	8.59			
	Pooled	7	18.25	2.86	18.92	8.59			
LCL	Female	16	19.61	1.79	19.39	6.21	46.0 [b]	.038	.40
	Male	11	21.05	1.46	21.32	4.42			
	Pooled	27	20.20	1.78	20.02	6.21			
LCB	Female	13	13.11	.95	12.86	3.18	25.0 [b]	.050	-.43
	Male	8	14.01	13.58	13.58	3.51			
	Pooled	21	13.46	1.09	13.19	3.69			
LCH	Female	3	18.59	.58	18.85	1.07			
	Male	4	20.17	1.79	20.14	4.29			
	Pooled	7	19.50	1.56	19.00	4.42			

[a] T-test; [b] Mann-Whitney test.

3.3.6. Sex Classification

3.3.6.1. Discriminating Cut-off Points

Standardized cut-off points (Silva, 1995; Wasterlain and Cunha, 2000) were used for the sexing of cadavers of known-sex from a test-sample with the aim of documenting their reliability when applied to calcined bones. This test-sample was independent from the sample of cadavers which was used to investigate sexual dimorphism in section 3.3.5. This was done so that the cut-off points calculated from the latter could be tested on a different sample thus avoiding a biased testing and so that the results from both references could be compared to each other. In addition, both cut-off points were also used to classify according to sex the test-sample of skeletons. The latter was the same used for investigating sexual dimorphism on section 3.3.5.

Results regarding the Coimbra Standards are given in figures 3.3.11 and 3.3.12. Females were all correctly allocated on both test-samples of cadavers and skeletons. In contrast, the sex determination of males was very poor. The rate of correct classification of males was apparently worse for skeletons than for cadavers. However, some test-samples were especially small so any inference should be taken with caution. The epicondylar breadth allowed for the better results on the sex pooled sample with three quarters of the males being correctly classified. In summary, the standardized cut-off points did not reliably classify the test-samples according to sex.

The sex classification of the individuals composing the test-samples by using the sex pooled means from the sample of cadavers as cut-off points are given in figures 3.3.13 and 3.3.14. Classification remained very successful for females and improved substantially for males on the test-sample of cadavers. The talar maximum length was the only feature presenting less than 80.0% of correct classification of males. Results were not as positive for the test-sample of skeletons. Only the humeral articular width presented correct classification over 80.0% of both sexes but the amount of tested bones was extremely small. On the largest of all test-samples, a large misclassification of males was recorded for the talar maximum length.

Results indicated that the new cut-off points were more successful at classifying the test-samples according to sex than the Coimbra Standards developed from a collection of unburned skeletons. Contrastingly, the use of the new cut-off points demonstrated to be more successful for cadavers than for skeletons.

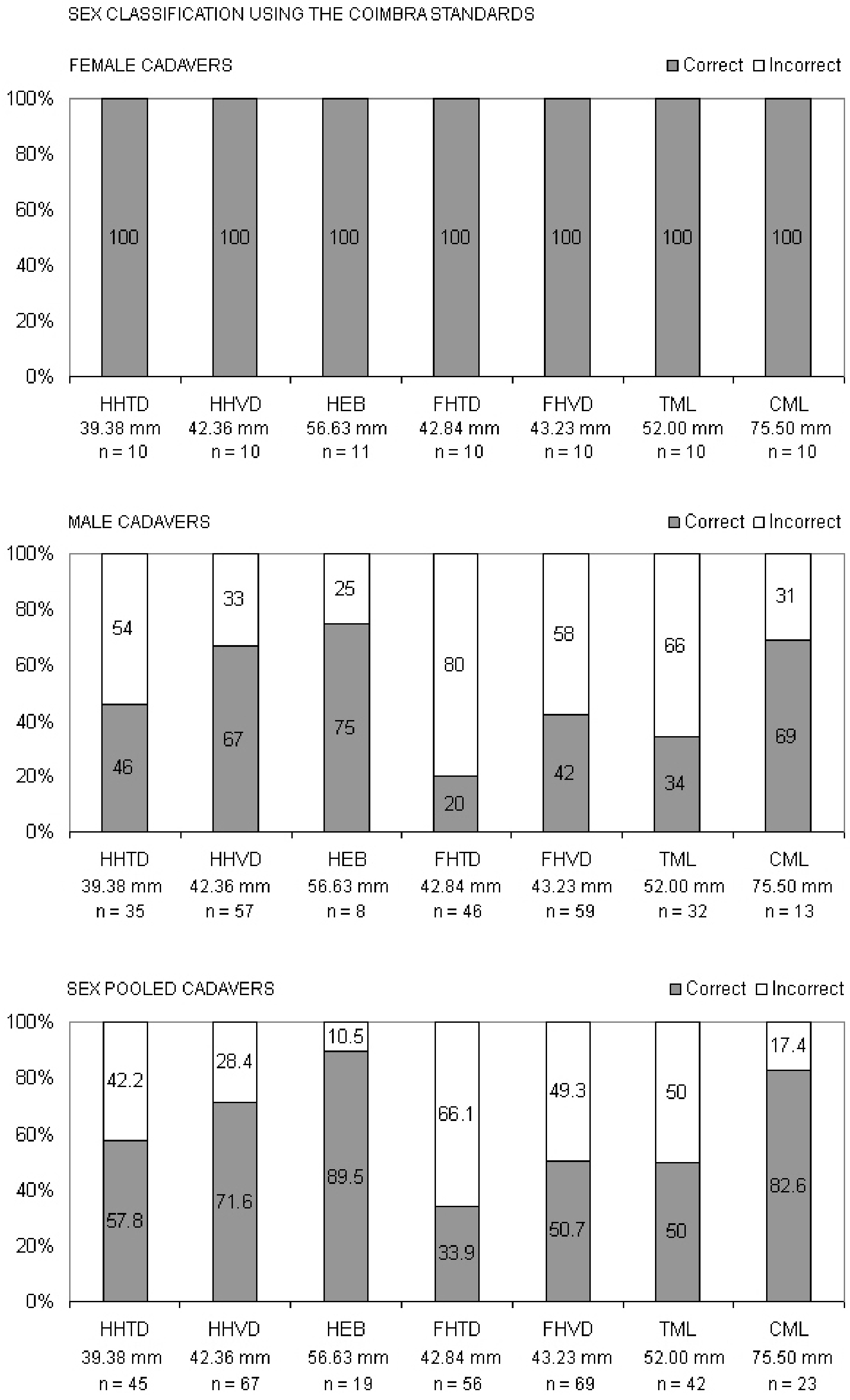

Figure 3.3.11: Sex classification of the cadavers' test-sample by using the cut-off points (given in mm) from the Coimbra standards.

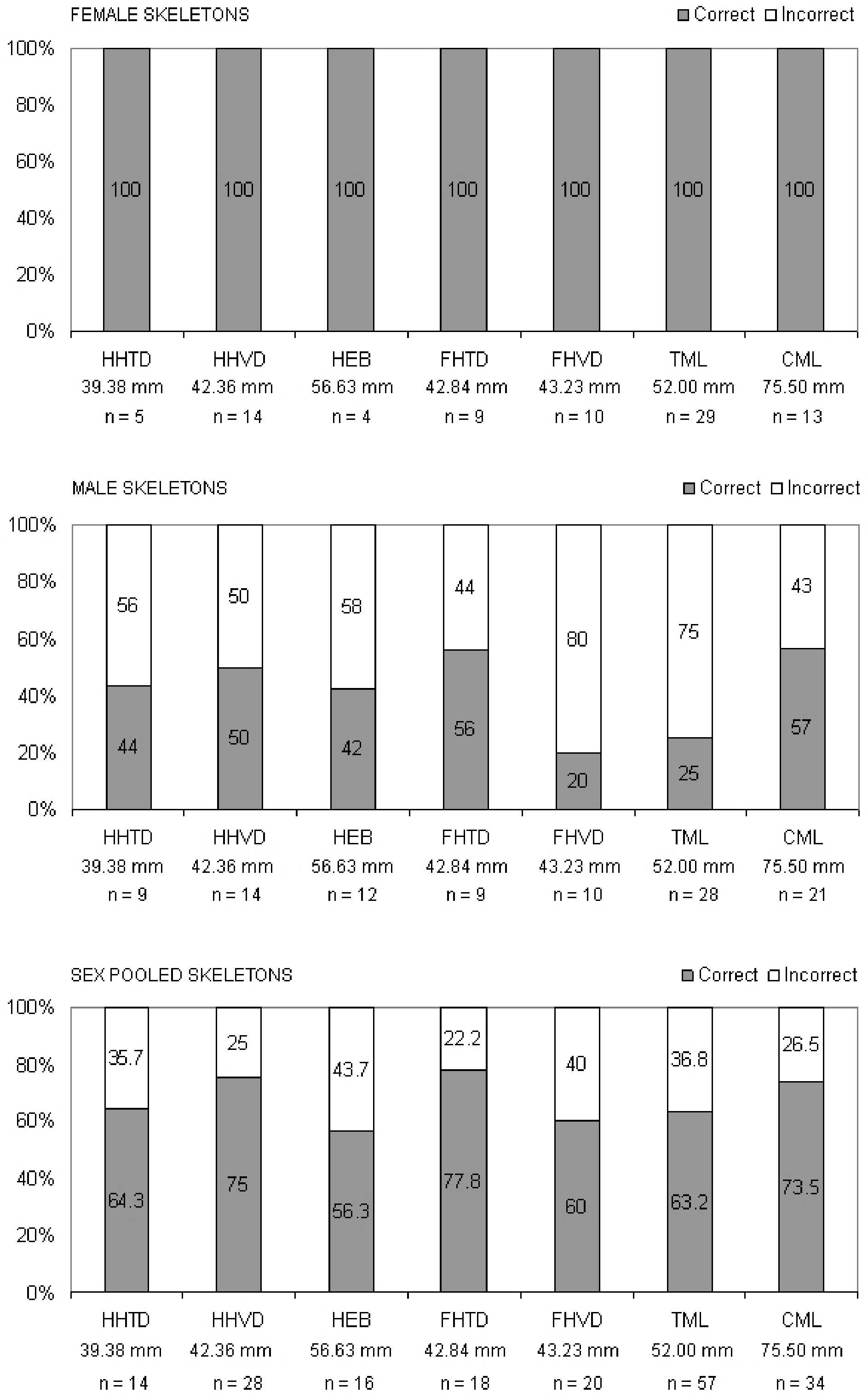

Figure 3.3.12: Sex classification of the skeletons' test-sample by using the cut-off points (given in mm) from the Coimbra standards.

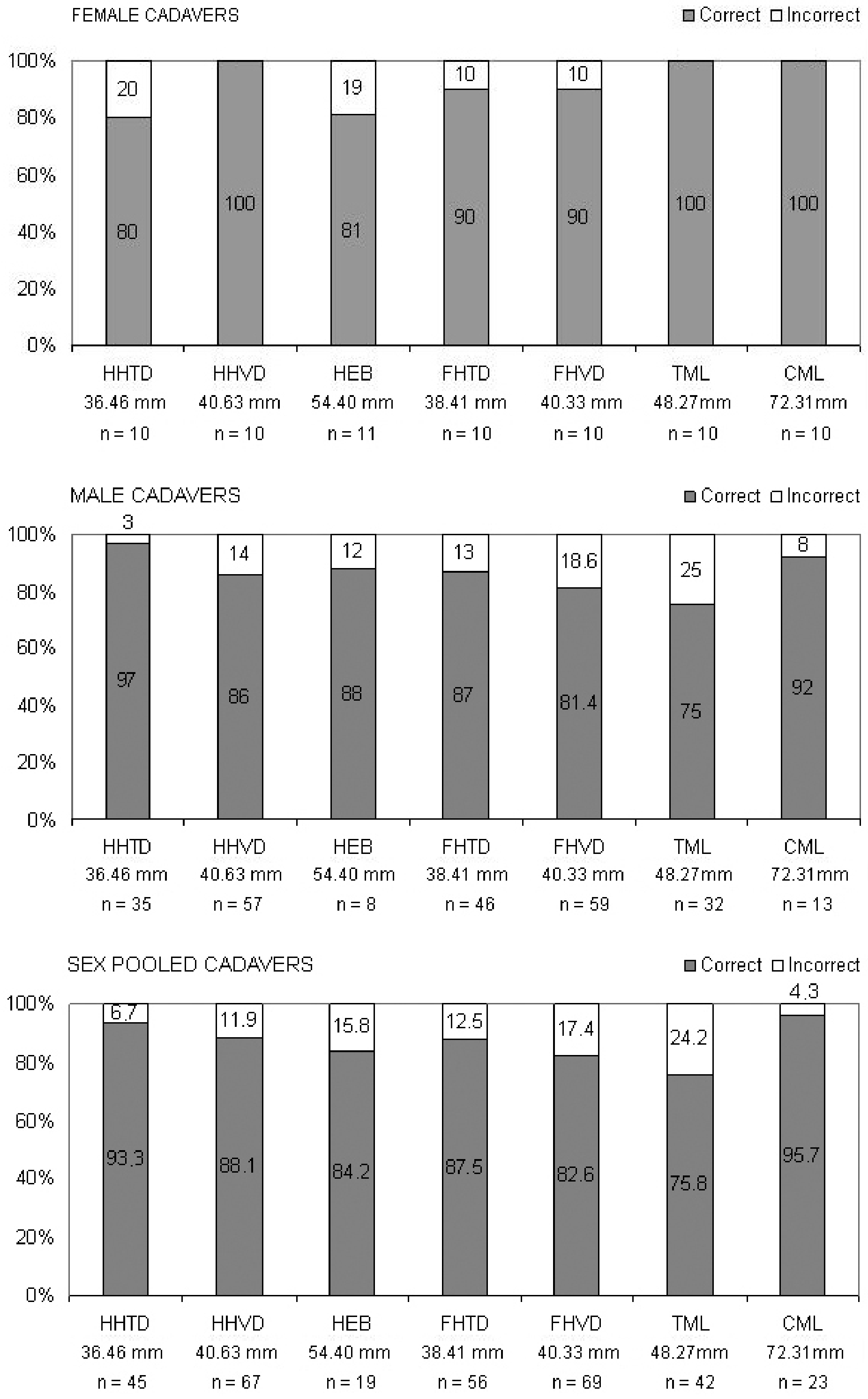

Figure 3.3.13: sex classification of the cadavers' test-sample by using the new cut-off point (given in mm) specific to calcined bones.

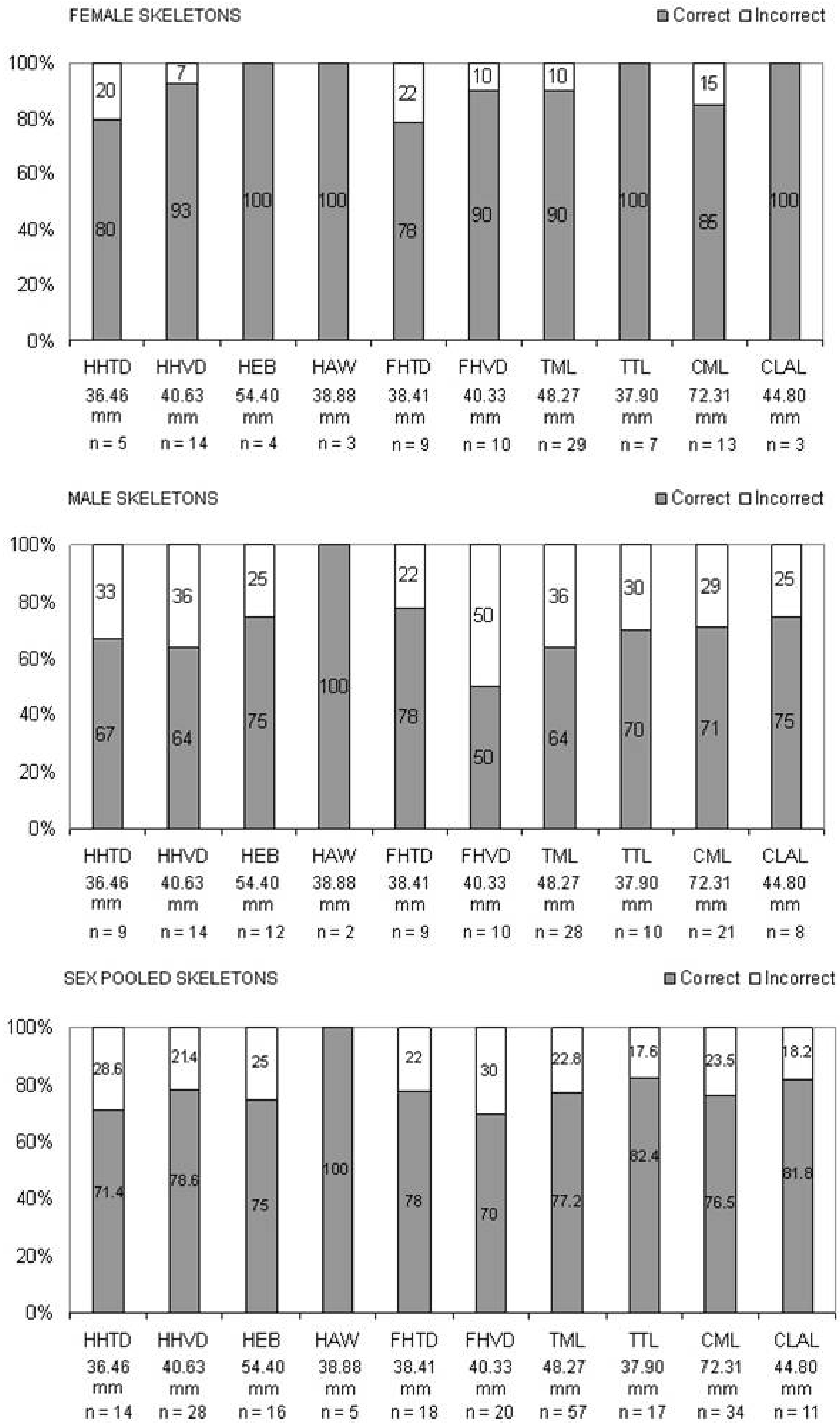

Figure 3.3.14: sex classification of the skeletons' test-sample by using the new cut-off point (given in mm) specific to calcined bones.

A small test was carried out in order to assess if the Coimbra Standards for unburned skeletons could be reliably used for the sex classification from pre-calcined bones. Therefore, the sex determination of 27 pre-calcined cases (24 females; 3 males) was attempted. From these, only 19 (70.4%) were correctly classified according to sex previously to the cremation. After it, the sex scoring attained for the pre-cremated bones was maintained for 23 of them and altered for the other 4. For the latter, the classification shifted from male to female. This shift allowed for the increase of the correct sex classification to 85.2%.

The sex classification of the sample of cadavers using the IAC was not attempted due to the lack of sexual dimorphism found on it. Sexual differences were very small for the sample of skeletons. Nonetheless, sex classification was attempted on the latter by using the 45° cut-off point recommended by Norén et al (2005) in order to investigate if those were sufficient to allow for sex determination. As a result, 73.3% of females (n = 15) and 38.1% of males (n = 21) were correctly classified. Only about half of the sex-pooled sample was correctly classified (52.8%). Therefore, the cut-off point of 45° revealed to have no sex discriminating power when used on burned skeletons.

3.3.6.2. Regression Analysis

3.3.6.2.1. The Humerus

The results for the logistic regression analysis regarding the prediction of sex using each humeral standard measurement are presented in table 3.3.32 and figure 3.3.15. Sex was successfully determined for more than 80.0% of the cases regarding the sample from which the regression coefficients have been calculated. The sex determination of a small independent test-sample provided for classification rates higher than 80.0% as well (Figure 3.3.15). The articular width prediction was not tested on an independent sample due to the small amount of cases that prevented the compilation of an independent sample.

Logistic regression was also conducted to assess if the combined measurements of the transverse and vertical diameter of the humeral head could distinguish between females and males. This sample was composed of 54 individuals (26 females; 28 males). The descriptive statistics are presented in table 3.3.33. When both independent variables were considered together, they significantly predicted whether or not an individual was a male (χ^2 = 43.03; df = 2; n = 54; p = .000). The Nagelkerke R^2 indicated that 73.3% of the variance in whether or not individuals were males could be predicted from the linear combination of the two independent variables. The standardized coefficients and the odds ratios are presented in table 3.3.33. This model correctly predicted 82.1% of the females and 80.8% of the males. The coefficients were applied to an independent test-sample of cadavers composed of 10 females and 10 males. All of them were correctly classified according to sex.

Table 3.3.32: Coefficients for the logistic regression regarding each humeral measurement calculated from the sample of cadavers.

	β	SE	Odds Ratio	Sig.
HHTD	.891	.213	2.437	.000
Constant	-32.753	7.878	.000	.000
HHVD	.661	.111	1.937	.000
Constant	-26.919	4.545	.000	.000
HEB	.904	.270	2.469	.001
Constant	-49.415	14.90	.000	.001
HAW	2.104	.820	8.202	.010
Constant	-81.727	31.91	.000	.010

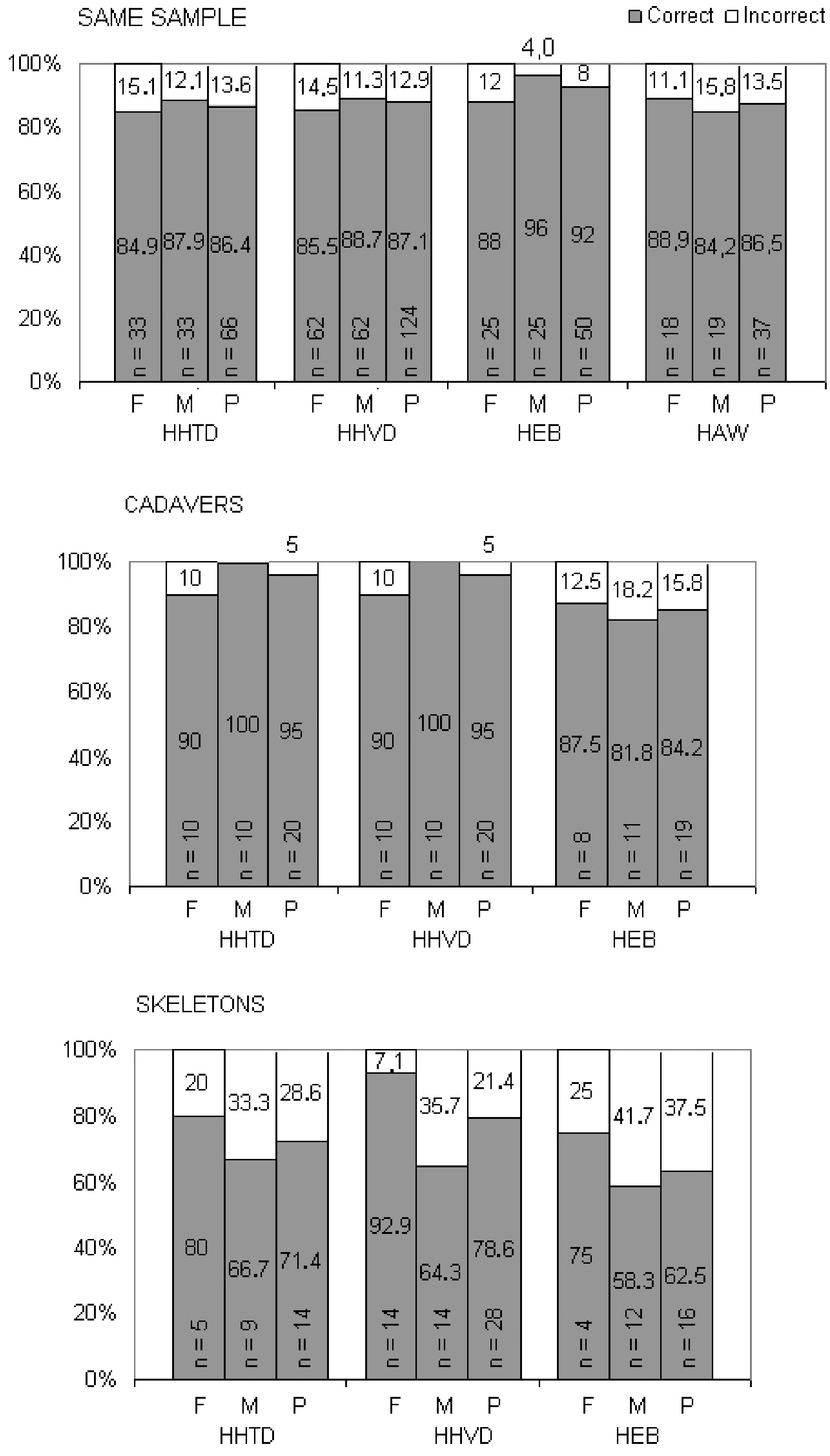

Figure 3.3.15: Accuracy of the logistic regression coefficients on the sex classification of the cadavers based on humeral standard measurements. The coefficients were tested

on the very same sample from which these were calculated and on two test-samples composed of cadavers and skeletons.

Table 3.3.33: Descriptive statistics and coefficients for the logistic model using the humeral head transverse and vertical diameters (cadavers).

	Sex	n	Mean	S.D.	β	SE	Odds Ratio	Sig.
HHTD	Female	26	33.81	2.80	.825	.302	2.28	.006
	Male	28	39.16	1.98				
HHVD	Female	26	37.92	2.96	.177	.217	1.19	.415
	Male	28	43.24	3.37				
Constant	-	-	-	-	-37.626	10.732	.000	.000

3.3.6.2.2. The Femur

The results for the logistic regression of each femoral standard measurement are presented in table 3.3.34 and figure 3.3.16. The correct sex classification was of 80.0% or higher for both sexes using the same sample from which the regression coefficients were calculated while this percentage increased to 90.0% when an independent test-sample was used.

Table 3.3.34: Coefficients for the logistic regression regarding each femoral measurement calculated from the sample of cadavers

	β	SE	Odds Ratio	Sig.
FHTD	.782	.160	2.187	.000
Constant	-29.896	6.105	.000	.000
FHVD	.759	.142	2.137	.000
Constant	-30.376	5.663	.000	.000

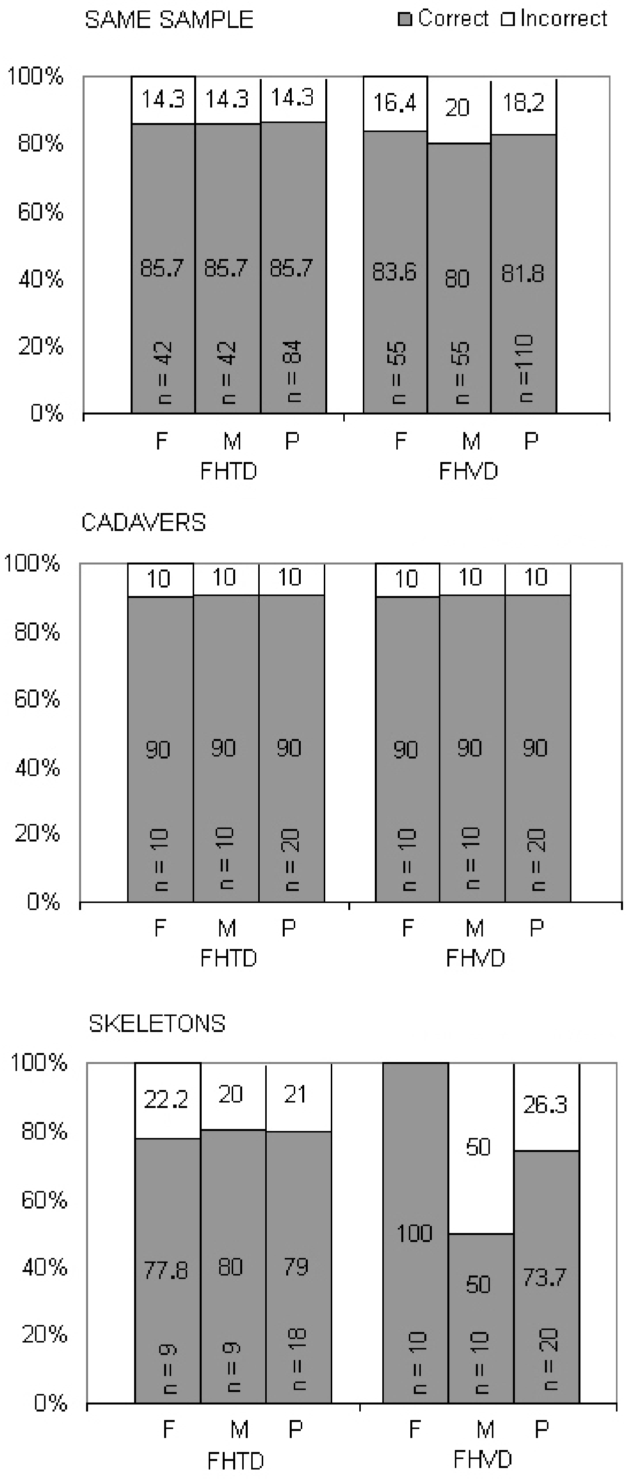

Figure 3.3.16: Accuracy of the logistic regression coefficients on the sex classification of the cadavers based on femoral standard measurements. The coefficients were tested on the very same sample from which these were calculated and on two test-samples composed of cadavers and skeletons.

The combination of the two femoral head standard measurements was used to assess if this logistic model successfully discriminated the sample of calcined bones according to sex. This was composed of 32 females and 37 males and the descriptive statistics are displayed on table 3.3.35. This model significantly discriminated females and males ($\chi^2 = 56.17$; df = 2; n = 69; p = .000). The Nagelkerke R^2 indicated that 74.4% of the variance in whether or not individuals were males could be predicted from the linear combination of the two independent variables. The standardized coefficients and the odds ratios are also presented in table 3.3.35. The latter suggest that the odds of correctly classifying an individual according to sex improved by 94% if the size of the transverse diameter was known and by 35% if the size of the vertical diameter was also known. This model correctly predicted 87.5% of the females and 86.5% of the males. Its application to an independent test-sample obtained 90.0% of correct sex classification for both the samples of females (n = 10) and the males (n =10).

Table 3.3.35: Descriptive statistics and coefficients for the logistic model using the femoral head transverse and vertical diameters (cadavers).

	Sex	n	Mean	S.D.	β	SE	Odds Ratio	Sig.
FHTD	Female	32	35.52	1.92	.664	.274	1.94	.015
	Male	37	41.05	2.77				
FHVD	Female	32	37.15	2.31	.299	.246	1.35	.225
	Male	37	42.80	2.98				
Constant	-	-	-	-	-36.860	8.840	.000	.000

3.3.6.2.3. The Talus

Results for the logistic regression of each standard measurement from the talus are presented in table 3.3.36 and figure 3.3.17. Although the p-value indicated that both are significant predictors, the trochlear length allowed for a classification rate under 70.0% for the female sample. In contrast, the regression for the maximum length allowed for successful sex allocations in more than 80.0% of the sample. The test of the logistic model of the talar maximum length on an independent sample was successful for 100.0% of females and 90.0% of males. An assessment of the sex determination power of the logistic regression including both the maximum length and the trochlear length was not carried out due to the small size of the combined sample.

Table 3.3.36: Coefficients for the logistic regression of the talar measurements calculated from the sample of cadavers.

	β	SE	Odds Ratio	Sig.
TML	.683	.175	1.980	.000
Constant	-32.849	8.421	.000	.000
TTL	.576	.145	1.780	.000
Constant	-16.613	4.262	.000	.000

3.3.6.2.4. The Calcaneus

The results for the logistic regression of the maximum length and the load arm length of the calcaneus are presented in table 3.3.37 and figure 3.3.18. Used separately, both standard measurements were significant predictors of sex allowing for accuracies higher than 80.0% regarding the sex allocation of the individuals composing the sample from which the regression coefficients were calculated. The independent sample testing was successful for all individuals when using the calcaneal maximum length. Independent testing was not carried out for the calcaneal load arm length because of the small size of the sample. The same reason prevented the further exploration of logistic regression regarding the addition of other independent variables.

Table 3.3.37: Coefficients for the logistic regression of the calcaneal measurements calculated from the sample of cadavers

	β	SE	Odds Ratio	Sig.
CML	.549	.111	1.732	.000
Constant	-39.628	8.018	.000	.000
CLAL	1.060	.333	2.885	.001
Constant	-46.607	14.81	.000	.002

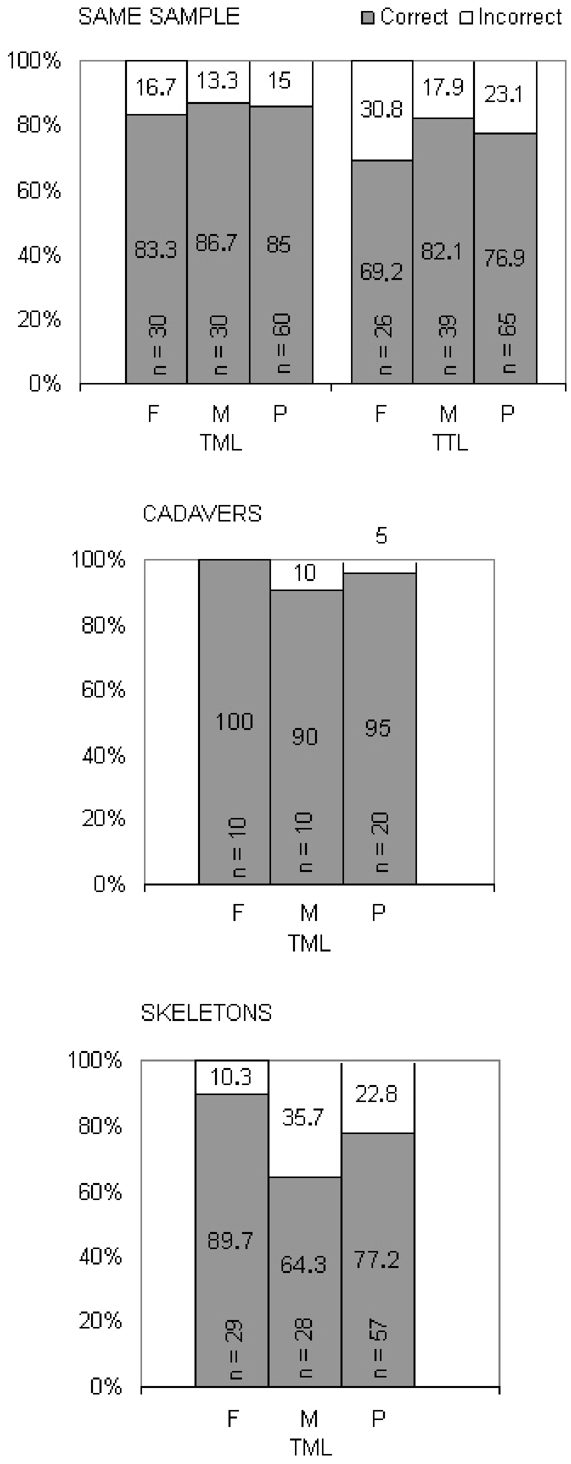

Figure 3.3.17: Accuracy of the logistic regression coefficients on the sex classification of the cadavers based on talar standard measurements. The coefficients were tested on the very same sample from which these were calculated and on two test-samples composed of cadavers and skeletons.

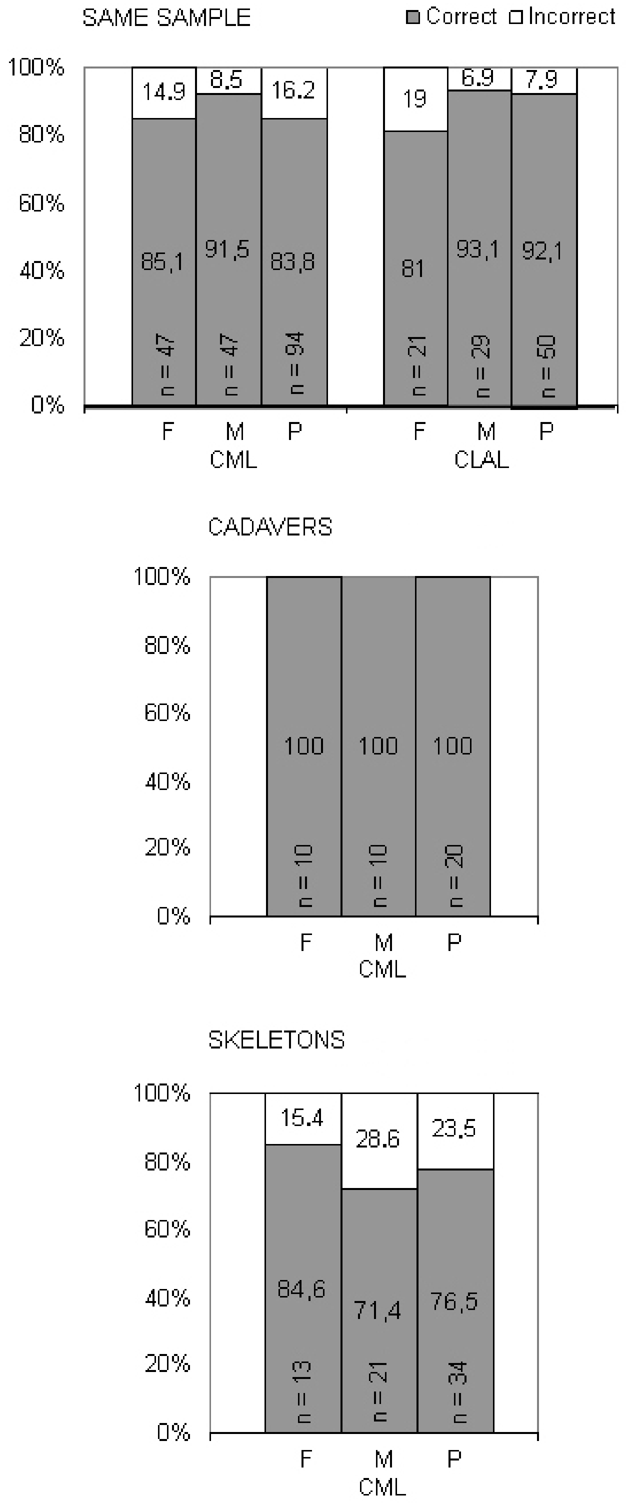

Figure 3.3.18: Accuracy of the logistic regression coefficients on the sex classification of the cadavers based on calcaneal standard measurements. The coefficients were tested on the very same sample from which these were calculated and on two test-samples composed of cadavers and skeletons.

3.3.6.3. The Calibration Method

The overall rate of shrinkage of the larger bones (see section 3.2.2) was applied to the recommended cut-off points of Silva (1995) and of Wasterlain and Cunha (2000) in order to evaluate if the new values were more successful in correctly classifying individuals according to sex. The re-configuration of the standard cut-off points into new values was done using a correction factor of 12% and is given in table 3.3.38.

In general, the new cut-off points promoted the under-classification of females on the sample of cadavers. Most of the males were classified according to sex but this result was very contrasting with the results obtained for the female sample. The femoral head vertical diameter was the only standard measurement allowing for successful classification rates above 80.0% for both sexes.

The poor sex classification obtained with the calibrated values could eventually be related to differences between the population from which the standard cut-off points were calculated and the contemporary population here analysed. Therefore, measurements were carried out on a relatively large sample of contemporary skeletons with the aim of assessing if secular trend was affecting the dimensions of the Portuguese population. In fact, all standard measurements presented larger dimensions for the contemporary population (Table 3.3.39). This difference was statistically significant for the transverse and vertical diameters of the humeral and femoral head and for the maximum length of the calcaneus (Table 3.3.39). In contrast, the larger dimensions for the maximum length of the talus and the humeral epicondylar breadth of the contemporary sample were not significantly different from those of the Coimbra Collection. Nonetheless, even in these cases the calibrated cut-off points adapted from the contemporary collection proved to be more adequate for the sex classification of the contemporary individuals (Table 3.3.38). Although sex determination was more successful, correct classification of the female sample was still low for all features but the femoral head vertical diameter.

Table 3.3.38: Sex classification of the sample of cadavers with cut-off points calibrated according to the rate of shrinkage of 12%. Calibration was carried out for the Coimbra Standards and the cut-off points from the Contemporary Sample.

	Coimbra Standards				Contemporary Sample			
	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males
HHTD	39.38	34.67	62.8% (n = 43)	100.0% (n = 68)	40.94	36.04	76.7% (n = 43)	95.6% (n = 68)
HHVD	42.36	37.29	41.7% (n = 72)	98.3% (n = 119)	44.42	39.10	70.8% (n = 72)	95.8% (n = 119)
HEB	56.63	49.85	41.7% (n = 36)	100.0% (n = 33)	57.71	50.80	58.3% (n = 36)	100.0% (n = 33)
FHTD	42.84	37.71	84.6% (n = 52)	86.4% (n = 88)	43.81	38.57	86.5% (n = 52)	84.1% (n = 88)
FHVD	43.23	38.06	61.5% (n = 65)	93.0% (n = 114)	44.29	38.98	75.4% (n = 65)	91.2% (n = 114)
TML	52.00	45.78	62.5% (n = 40)	91.9% (n = 62)	52.21	45.96	62.5% (n = 40)	91.9% (n = 62)
CML	75.50	66.46	38.6% (n = 57)	100.0% (n = 60)	78.45	69.06	63.2% (n = 57)	96.7% (n = 60)

In order to assess if the correction factor of 10% recommended by Buikstra and Swegle (1989) can be reliably used on the cremains of cadavers, both the Coimbra standards and the cut-off points from the Contemporary Sample were calibrated according to it. Results are presented in table 3.3.40 and demonstrated that sex classification was more successful and balanced according to sex than the results obtained by using the correction factor specifically calculated during this research. Correct classification above 80.0% was obtained by using the transverse and vertical diameters of the humeral head, the vertical diameter of the femoral head and the maximum length of the calcaneus. With the exception of the humeral epicondylar breadth, the remaining features allowed for accuracies near 80.0% for both sexes.

Table 3.3.39: Mean dimensions of the contemporary sample according to sex and t-test results for the difference between the Coimbra standards and the Contemporary values.

Standard Measurement	Sample	n	Mean Contemporary (mm)	S.D	Mean Coimbra (mm)	t-test Coimbra vs. Contemporary	Sig.	d
HHTD	Females	28	37.82	1.58				
	Males	35	43.44	2.93				
	Pooled	63	40.94	3.70	39.38	5.496	.000	-.89
HHVD	Females	31	40.94	2.06				
	Males	38	47.25	3.24				
	Pooled	69	44.42	4.19	42.36	4.075	.000	-.65
HEB	Females	32	52.49	3.62				
	Males	39	61.99	4.57				
	Pooled	71	57.71	6.31	56.63	1.439	.155	-
FTD	Females	35	40.83	2.36				
	Males	41	46.35	3.02				
	Pooled	76	43.81	3.88	42.84	2.172	.033	-.31
FVD	Females	35	41.31	2.18				
	Males	41	46.83	2.65				
	Pooled	76	44.29	3.68	43.23	2.507	.014	-.35
TML	Females	41	49.68	2.85				
	Males	38	54.94	3.49				
	Pooled	79	52.21	4.11	52.00	.454	.651	-
CML	Females	39	74.43	3.90				
	Males	37	82.69	6.18				
	Pooled	76	78.45	6.58	75.50	3.906	.000	-.55

Table 3.3.40: Sex classification of the sample of cadavers with cut-off points calibrated according to a correction factor of 10% (Buikstra and Swegle, 1989). The calibration was carried out for the Coimbra Standards and the cut-off points from the Contemporary Sample.

	Coimbra Standards				Contemporary Sample			
	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males
HHTD	39.38	35.44	72.1% (n = 43)	95.6% (n = 68)	40.94	36.85	86.1% (n = 43)	89.7% (n = 68)
HHVD	42.36	38.12	59.7% (n = 72)	98.3% (n = 119)	44.42	39.98	80.6% (n = 72)	94.1% (n = 119)
HEB	56.63	50.97	61.1% (n = 36)	100.0% (n = 33)	57.71	51.94	66.7% (n = 36)	97.0% (n = 33)
FHTD	42.84	38.56	86.5% (n = 52)	84.1% (n = 88)	43.81	39.43	92.3% (n = 52)	77.3% (n = 88)
FHVD	43.23	38.91	75.4% (n = 65)	91.2% (n = 114)	44.29	39.85	83.1% (n = 65)	85.1% (n = 114)
TML	52.00	46.80	77.5% (n = 40)	90.3% (n = 62)	52.21	46.99	77.5% (n = 40)	90.3% (n = 62)
CML	75.50	67.95	52.6% (n = 57)	98.3% (n = 60)	78.45	70.61	84.2% (n = 57)	96.7% (n = 60)

The documentation of the accuracy of the calibrated method regarding this research’s estimated rate of shrinkage for large bones (12%) on the sample of skeletons is presented on table 3.5.41. In general, the correct classification was low regardless of the references – Coimbra Standards or Contemporary Sample – used for the calibration.

Nonetheless, the results were more balanced regarding the sex allocation of females and males when the latter were used.

As for the documentation of the correct classification of the sample of skeletons by using the 10% correction factor recommended by Buikstra and Swegle (1989), the results are presented in table 3.5.42. All but the humeral head vertical diameter using the calibration from the Coimbra Standards were successful on less than 80% of the cases. Given the large sample of the talus, it is important to notice that this bone also allowed for relatively high rates of sex allocation.

Table 3.5.41: Sex classification of the sample of skeletons with cut-off points calibrated according to the rate of shrinkage of 12%. Calibration was carried out for the Coimbra Standards and the Contemporary cut-off points.

	Coimbra				Contemporary			
	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males
HHTD	39.38	34.67	60.0% (n = 5)	77.8% (n = 9)	40.94	36.04	80.0% (n = 5)	66.7% (n = 9)
HHVD	42.36	37.29	71.5% (n = 14)	85.7% (n = 14)	44.42	39.10	92.9% (n = 14)	78.6% (n = 14)
HEB	56.63	49.85	100.0% (n = 4)	91.7% (n = 12)	57.71	50.80	100.0% (n = 4)	83.3% (n = 12)
FHTD	42.84	37.71	66.7% (n = 9)	88.9% (n = 9)	43.81	38.57	77.8% (n = 9)	77.8% (n = 9)
FHVD	43.23	38.06	50.0% (n = 10)	70.0% (n = 10)	44.29	38.98	70.0% (n = 10)	70.0% (n = 10)
TML	52.00	45.78	69.0% (n = 29)	92.9% (n = 28)	52.21	45.96	72.4% (n = 29)	92.9% (n = 28)
CML	75.50	66.46	61.5% (n = 13)	90.5% (n = 21)	78.45	69.06	69.2% (n = 13)	81.0% (n = 21)

Table 3.5.42: Sex classification of the sample of skeletons with cut-off points calibrated according to a correction factor of 10% (Buikstra and Swegle, 1989). The calibration was carried out for the Coimbra Standards and the Contemporary cut-off points.

	Coimbra				Contemporary			
	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males	Cut-off (mm)	Calibrated Cut-off (mm)	Females	Males
HHTD	39.38	35.44	60.0% (n = 5)	77.8% (n = 9)	40.94	36.85	80.0% (n = 5)	66.7% (n = 9)
HHVD	42.36	38.12	92.9% (n = 14)	85.7% (n = 14)	44.42	39.98	92.9% (n = 14)	71.4% (n = 14)
HEB	56.63	50.97	100.0% (n = 4)	75.0% (n = 12)	57.71	51.94	100.0% (n = 4)	75.0% (n = 12)
FHTD	42.84	38.56	77.8% (n = 9)	77.8% (n = 9)	43.81	39.43	77.8% (n = 9)	77.8% (n = 9)
FHVD	43.23	38.91	70.0% (n = 10)	70.0% (n = 10)	44.29	39.85	80.0% (n = 10)	60.0% (n = 10)
TML	52.00	46.80	82.8% (n = 29)	78.6% (n = 28)	52.21	46.99	82.8% (n = 29)	78.6% (n = 28)
CML	75.50	67.95	61.5% (n = 13)	81.0% (n = 21)	78.45	70.61	84.6% (n = 13)	71.4% (n = 21)

3.4. Skeletal Weights

3.4.1. The Anatomical Identification

3.4.1.1. The Cadavers

Figure 3.4.1 presents the descriptive statistics regarding the mean rate of anatomically identified bone fragments (RAI). These values were obtained by dividing the absolute weight of the identified fragments by the total weight of the skeletal remains for each individual and then multiplying it by 100. The summary statistics are presented according to sex and to age group (≤70 years old; >70 years old). Males presented larger RAI than females for the >70 years-old group and the reverse scenario was found for the ≤70 years-old group.

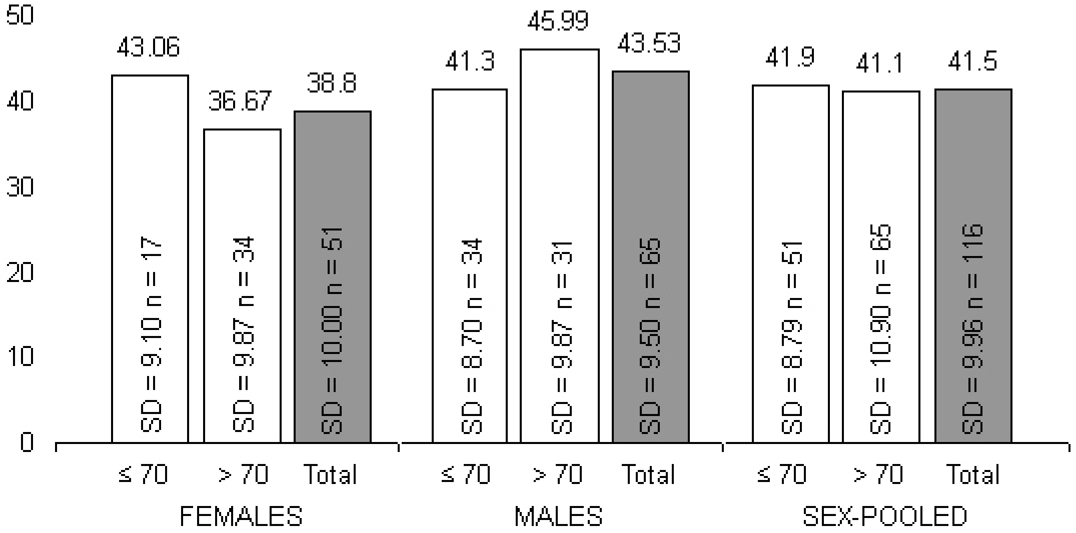

Figure 3.4.1: Descriptive statistics for the mean rate of anatomically identified bone fragments (%) according to sex and age group (cadavers). SD = standard deviation.

Multiple regression analysis was carried out in order to investigate the effect of age, sex, duration and maximum temperature of combustion on RAI. Although the *a priori* calculation of the sample size required it to be of at least 118 individuals when using four predictor variables (alpha level = .01; anticipated effect size = .15; statistical power level =.80), this was still carried out despite the sample only including 116 cases. Age and maximum temperature were used as ratio scaled variables. Sex was used as a dichotomous variable (male; not male) and duration of combustion was used as an ordinal variable with three levels (0-100’; 101-200’; overnight). The correlation matrix found a significant effect of sex and duration of combustion on the dependent variable (Table 3.4.1). In addition, it found some collinearity between sex and age thus indicating that these variables contained similar information.

The model significantly predicted RAI [F (4; 111) = 10.42; p = .000]. However, only sex and duration of combustion significantly contributed to the prediction (Table 3.4.2). The model only explained 24.7% of the variance in RAI.

Table 3.4.1: Means, standard deviations and intercorrelations for rate of anatomical identification (%) and predictor variables for the sample of cadavers (n = 116).

Variable	Mean	SD	1	2	3	4
Rate of Anatomical Identification	41.5	10.0	-.085	.237**	.459**	.056
Predictor Variable						
1. Age	71.2	15.1	-	-.194*	.085	-.013
2. Sex	.56	.50	-	-	.033	.054
3. Duration of Combustion	.99	.83	-	-	-	-.082
4. Maximum Temperature of Combustion	938.6	2.1	-	-	-	-

.*p< .05; **p< .01

The further investigation of the effect of sex on RAI found a significant difference between females and males (t = -2.603; df = 114; p = .010; d = .49) with a small to medium effect size according to Cohen (1988). Differences between age cohorts for each sex were also examined because some collinearity was found between sex and age. As a result, Mann-Whitney tests found a significant difference at the .05 level (U = 173.5; p = .021; r = -.32) between the ≤70 years-old age group (median = 40.9; range = 32.3) and the >70 years-old age group (median = 34.3; range = 53.35) for the female sample. The opposite was found for the male sample (U = 385.0; p = .062).

Table 3.4.2: Multiple regression analysis summary for age, sex, duration of combustion and maximum temperature of combustion predicting the rate of anatomical identification (cadavers).

Model	β	SE β	Beta	t	Sig.
Constant	25.200	12.977		1.942	.055
Age	-.056	.055	-.085	-1.023	.309
Sex	4.009	1.653	.201	2.425	.017
Duration of Combustion	5.600	.981	.466	5.709	.000
Maximum Temperature of Combustion	.013	.013	.082	1.014	.313

As for the duration of combustion, a one-way ANOVA was used to investigate the differences between the three levels according to RAI. A significant difference was found at the .01 level [F (2, 113) = 24.97, p = .000, eta = .31]. Post-hoc Games-Howell tests revealed that no significant difference was found between the 0-100’ and the 101-200’ levels (p = .838). In contrast, significant differences were found between the 0-100’ and the overnight levels (p = .000) and between the 101-200’ and the overnight levels (p = .000). The descriptive statistics are presented in figure 3.4.2.

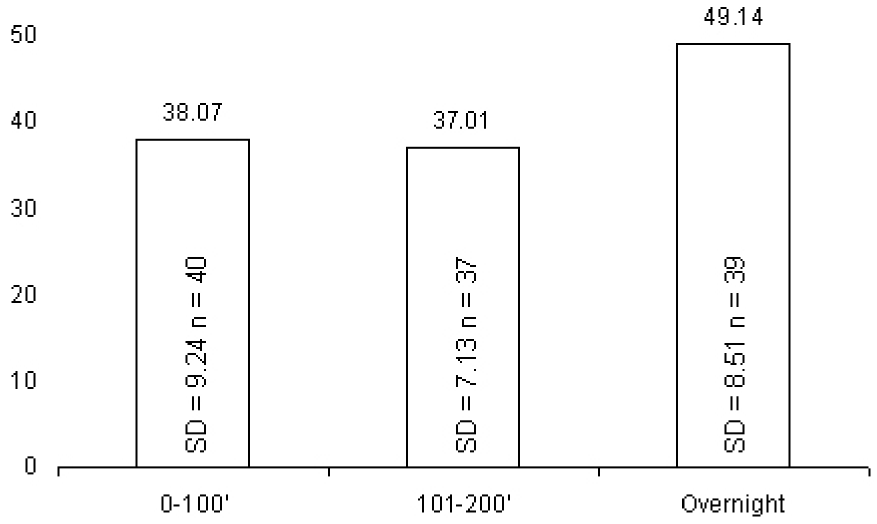

Figure 3.4.2: Descriptive statistics for the mean rate of anatomical identification (%) according to the duration of combustion (cadavers). SD = standard deviation.

3.4.1.2. The Skeletons

Figure 3.4.3 gives the descriptive statistics for the mean RAI on skeletons according to sex and age group. However, the “total” fields contemplate both skeletons of known-age and skeletons of unknown age. Multiple regression analysis was once again carried out, but this time age was left out of the equation because this parameter was unknown for several individuals. Therefore, the model included sex, duration of combustion and maximum temperature of combustion. The a priori calculation of the sample size required it to be of at least 76 individuals when using three predictor variables (alpha level = .05; anticipated effect size = .15; statistical power level =.80) which was compatible with the sample of 85 individuals. Sex was used as a dichotomous variable (male; not male). Duration of combustion was used as an ordinal variable with three levels (0-25’; 26-120’; overnight). Maximum temperature of combustion was used as a ratio scaled variable. The correlation matrix found no significant effect of any of the factors on the dependent variable (Table 3.4.3). As a result, the model did not significantly predict RAI [F (3; 81) = .855; p = .468].

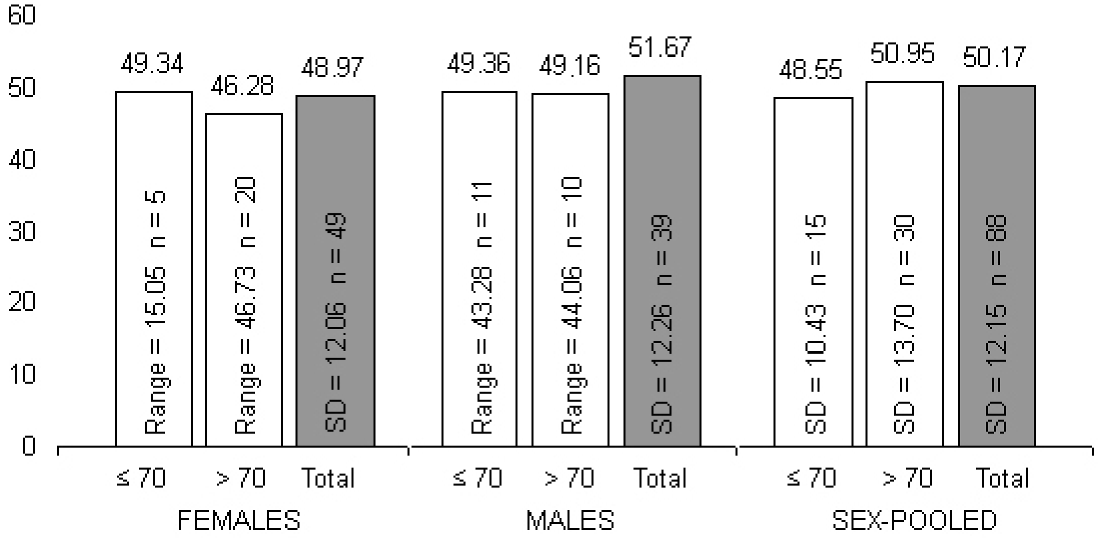

Figure 3.4.3: Descriptive statistics for the mean rate of anatomically identified bone fragments (%) according to sex and to age group. The total columns include both the known- and unknown-age skeletons. SD = standard deviation.

Table 3.4.3: Means, standard deviations and intercorrelations for rate of anatomical identification (%) and predictor variables for the sample of skeletons (n = 85).

Variable	Mean	SD	1	2	3
Rate of Anatomical Identification	50.37	12.29	.100	.125	.017
Predictor Variable					
1. Sex	.45	.50	-	-.146	-.103
2. Duration of Combustion	.68	.640	-	-	-.011
3. Maximum Temperature of Combustion	751.7	141.8	-	-	-

.*p< .05; **p< .01

3.4.1.3. The Pooled Sample

The descriptive statistics presented in figure 3.4.4 indicate that the mean RAI for the sample of skeletons was considerably higher than the one from the sample of cadavers. Significant differences between them were found for both females (t = 2.82; df = 98; p = .006; d = -.57) and males (t = 5.50; df = 102; p = .000; d = -1.28). The effect size was medium to large for females and large for males (Cohen, 1988).

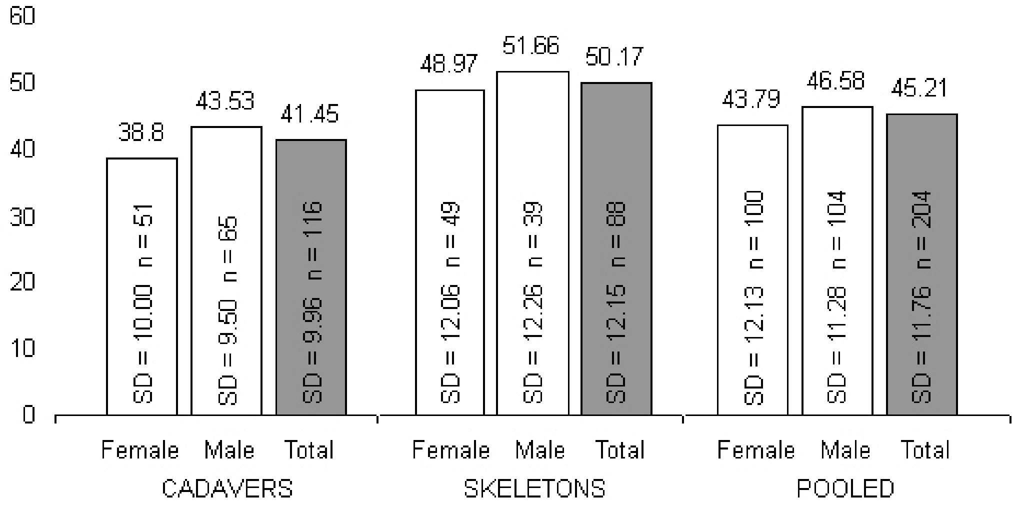

Figure 3.4.4: Descriptive statistics for the mean rate of anatomically identified bone fragments (%) according to sex. SD = standard deviation.

With the aim of investigating if duration of combustion was somewhat related to the weight differences regarding the pre-cremation condition of the remains, a Pearson chi-square test was carried out. The test confirmed a statistically significant difference between cadavers and skeletons on the duration of cremation (Table 3.4.4). The analysis indicated that cadavers were more likely left to burn for 101-200’ or overnight than for less than 100’. The opposite occurred for the skeletons.

Table 3.4.4: Chi-square analysis regarding the prevalence of cadavers and skeletons’ remains in function of duration of combustion. Expected prevalence is presented in brackets.

	n	0 to 100’	101 to 200’	overnight	χ^2	p	Phi
Cadavers	116	40 (67)	37 (22)	39 (27)	62.4	.000	.557
Skeletons	85	76 (49)	1 (16)	8 (20)			
Totals	201	116	38	47			

Figure 3.4.5 indicates that cadavers have been burned at higher temperatures than skeletons. A statistically significant difference at the .01 level was found between them regarding the mean maximum temperature of combustion ($t = 11.381$; $df = 199$; $p = .000$; $d = -1.83$). Therefore, skeletons were systematically burned at lower temperatures than cadavers.

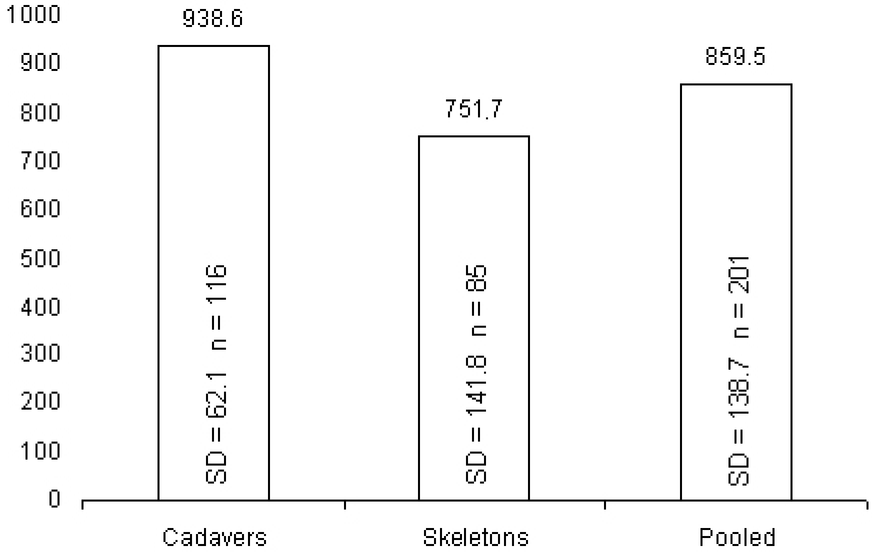

Figure 3.4.5: Descriptive statistics for the maximum temperature of combustion (ºC) according to the pre-cremation condition of the human remains. SD = standard deviation.

3.4.2. The Weight of Cremains

3.4.2.1. The Cadavers

Multiple linear regression was carried out in order to investigate the relationship of four factors – age, sex, duration of combustion and maximum temperature of combustion – with skeletal weight on 116 individuals. Age and maximum temperature of combustion were used as ratio scaled variables while sex was used as a dichotomous variable (male; not male) and duration of combustion was considered as an ordinal variable with three different levels following the procedure used in section 3.4.1.1. The model was significant [F (4, 116) = 33.86, p = .000] and explained 53.3% of the variation observed in skeletal weight (Table 3.4.5) which indicated a large effect (Cohen, 1988). All variables except for maximum temperature of combustion were significant factors in the model.

Table 3.4.5: Multiple regression analysis summary for age, sex, duration and maximum temperature of combustion predicting skeletal weight (cadavers).

	B	S.E.	β	t	Sig.
Constant	903.18	557.18		1.62	.108
Age	-216.23	73.50	-.191	-2.94	.004
Sex	736.97	73.56	.652	10.03	.000
Duration of Combustion	98.26	43.53	.144	2.26	.026
Temperature of Combustion	.855	.583	.091	1.47	.145

The significant factors indicated by the regression model were further investigated. Table 3.4.6 gives the descriptive statistics regarding mean weight of the skeletal remains of both females and males according to age group (≤70 years-old; >70 years-old). The mean weight of males was considerably larger than the mean weight of females for both age groups and for the age-pooled group. The difference between the pooled mean weights was of 789.1 g. The t-test found it to be statistically significant at the .01 level (t = -10.401; df = 114; p = .000; d = 1.98). When divided by age, significant differences between both sexes were also found for the ≤70 years-old age group (t = -5.44; df = 49; p = .000; d = 1.70) and for the >70 years-old age group (t = -8.607; df = 63; p = .000; d = 2.14). The effect size for sex and weight was large for every case according to Cohen (1988).

The results for the inferential statistics regarding the difference of the mean weight of the two age groups were contrasting. For the sample of females, that difference was statistically significant at the .01 level (t = 2.951; df = 49; p = .005; d = -.87) and the effect size was large. In contrast, the mean difference for the sample of males was not statistically significant (t = 1.526; df = 63; p = .132). Correlation statistics regarding weight and age as ratio scaled variables also did not find any significant relationship for the male sample at the .05 level [r (65) = -.232; p = .063].These results suggested that age was related to the variation on skeletal weights for the female sample but the same was not true for the sample of males.

Tale 3.4.6: Mean weight (g) of the skeletal remains excluding the < 2 mm fraction (cadavers).

	Females			Males			Sex-Pooled		
Age Group	0-70	>70	Pooled	0-70	>70	Pooled	0-70	>70	Pooled
N	17	34	51	34	31	65	51	65	116
Mean	1845.2	1556.0	1652.4	2520.5	2354.9	2441.5	2295.4	1937.0	2094.6
S.D.	344.2	322.9	354.5	449.4	422.7	441.4	524.0	547.0	563.8
Minimum	980.0	923.3	923.3	1486.7	1512.0	1486.7	980.0	923.3	923.3
Maximum	2419.6	2276.8	2419.6	3805.3	3286.8	3805.3	3805.3	3286.8	3805.3

Duration of combustion was divided into three different intervals (0 to 100’; 101 to 200’; overnight). The cadavers presented larger mean weights for the longest periods of duration of combustion. Weight was therefore checked for significant differences according to those intervals (Table 3.4.7). The result for the one-way ANOVA indicated an almost statistically significant difference for the sample of females. However, the Games-Howell post-hoc comparison found no significant differences between the levels of duration of combustion. No significant difference in bone weight was found for the sample of males as well. Additional testing of the female and male groups in function of age group for each sex was not carried out because this partition would turn the samples too small to allow for any reliable inferential statistics. Therefore, duration of combustion was indicated as a significant factor only when interacting with the remaining variables of the regression model.

The results for the weight of cremains including the < 2 mm fraction are presented in table 3.4.8. These are presented in order to allow for comparisons with other studies which have reported burned skeletal weights without excluding the < 2 mm fraction (Warren and Maples, 1995; Bass and Jantz, 2002; May, 2011). Although inferential statistics have been carried out, these must be considered with caution because the values potentially refer not only to bone weights but also to other non-human residues such as the ash from the wooden coffin or clay from the coating of the cremator. Sexual differences were significant at the .01 level (U = 432; p = .000; r = -

.63). In addition, weight differences for females between the ≤70 age group (median = 2507.5; range = 1950.7) and the >70 age group (median = 2092.7; range = 1739.1) were also significant at the .05 level (U = 163.0; p = .012; r = -.35). In contrast, male weight differences between the ≤70 age group (median = 3107.8; range = 2535.2) and the >70 age group (median = 2940.4; range = 1965.5) for the cremains weight including the < 2 mm fraction were not significant, at least at the 0.5 level (U = 384.0; p = .060).

As for the weight of the < 2 mm fraction itself, females weight (mean = 574.3; sd = 189.3) and males weight (mean = 591.5; sd = 139.6) were not significantly different (t = -.542; df = 114; p = .589). No significant differences (U = 249.0; p = .424) were found for the female sample between the ≤70 age group (median = 540.2; range = 649.6) and the >70 age group (median = 529.6; range = 696.9). The same result (t = 1.68; df = 63; p = .098) was found for the difference between the ≤70 age group (mean = 618.9; sd = 126.7) and the >70 age group (mean = 561.5; 148.7).

Table 3.4.7: One-way ANOVA results for the mean weight (g) of skeletal remains according to each interval of combustion time (cadavers).

	Duration of Combustion	N	Mean	S.D.	95% Confidence Interval	F	df	Sig
Female	0-100’	17	1498.1	388.8	1298.2; 1698.9	3.096	2 48	.054
	101-200’	19	1678.8	312.1	1528.4; 1829.2			
	Overnight	15	1793.8	315.6	1619.1; 1968.6			
Male	0-100’	23	2382.5	513.9	2160.3; 2604.7	.312	2 62	.733
	101-200’	18	2471.1	442.8	2250.9; 2691.2			
	Overnight	24	2475.9	373.2	2318.3; 2633.5			

Table 3.4.8: Mean weight (g) of the skeletal remains including the < 2 mm fraction (cadavers).

	Females			Males			Sex-pooled	
Age Group	≤70	>70	Pooled	≤70	>70	Pooled	≤70	>70
n	17	34	51	34	31	65	51	65
Mean	2451.1	2144.5	2226.7	3146.1	2916.4	3036.5	2914.5	2497.0
S.D.	464.5	437.5	470.1	479.1	470.8	485.8	574.9	604.5
Minimum	1286.7	1280.9	1280.9	2036.0	1901.9	1901.9	1286.7	1280.9
Maximum	3237.4	3020.0	3237.4	4571.2	3867.4	4571.2	4571.2	3867.4

3.4.2.2. The Skeletons

Multiple regression analysis was carried out with the aim of investigating the correlation of three independent variables – sex, duration and maximum temperature of combustion – with skeletal weight on 85 individuals. Sex was used as a dichotomous variable, duration of combustion was used as an ordinal scaled variable divided into three levels and maximum temperature of combustion was used as a ratio scaled variable following the procedure explained in section 3.4.1.2. Age was not included in the model because it would reduce considerably the sample size. It was thus analysed separately. The model was significant at the .01 level [F (3, 85) = 11.23, p = .000] and explained for 26.8% of the variance in skeletal weight. According to Cohen (1988), this was a medium to large effect. Only sex was a significant factor though (Table 3.4.9).

Table 3.4.9: Multiple regression analysis summary for sex, duration and maximum temperature of combustion predicting skeletal weight (skeletons).

	B	S.E.	β	t	Sig.
Constant	1580.82	250.17		6.32	.000
Sex	489.17	88.51	.525	5.53	.000
Duration of Combustion	-44.31	68.79	-.061	-.64	.521
Temperature of Combustion	-.125	.309	-.038	-.41	.686

Given the results obtained for the multiple regression, further analysis was carried out. Table 3.4.10 presents the descriptive statistics regarding the composition of the sample of skeletons. Excluding the < 2 mm fraction, the mean weight of males was larger than the mean weight of females. The mean difference between both sexes was statistically significant at the .01 level (t = -6.192; df = 86; p = .000; d = 1.33). The effect size was large (Cohen, 1988).

Table 3.4.10: Descriptive statistics for the mean weights (g) of the sample of skeletons according to sex.

	Without < 2 mm fraction			With < 2 mm fraction		
	Female	Males	Sex-pooled	Female	Males	Sex-pooled
n	49	39	88	49	39	88
Mean	1440.6	1967.4	1674.1	1803.6	2313.5	2029.6
S.D.	395.5	397.6	473.94	497.1	435.6	533.0
Minimum	688.3	1245.1	688.3	856.9	1389.0	856.9
Maximum	2263.2	2644.1	2644.1	2882.5	3160.4	3160.4

Descriptive statistics for the mean and median weights according to sex and to age group are presented in figure 3.4.6. Because the sample of skeletons of known-age was small, it was not possible to infer about the age-related differences regarding skeletal weight for each sex as was carried out previously for the sample of cadavers. Instead, correlation statistics were used to investigate the relationship between age and weight for both the female and male samples. The Pearson bivariate statistic found a statistically significant negative correlation for females at the .05 level [r (24) = -.440; p = .032]. Therefore, skeletal weight decreased along with the increase of age. As for males, no significant correlation was found [r (21) = -.255; p = .265].

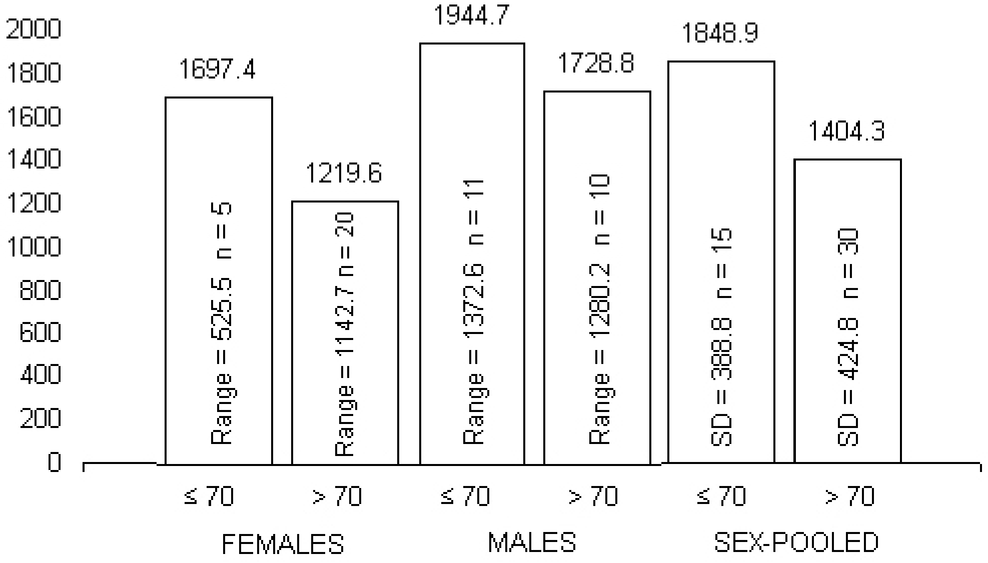

Figure 3.4.6: Median and mean weights (g) of the sample of skeletons according to sex and age group. SD = standard deviation.

As for the burned skeletal weights including the < 2 mm fraction, sexual differences were statistically significant at the .01 level (t = -5.05; df = 86; p = .000; d = 1.09) and the effect size was large according to Cohen (1988). The female < 2 mm fraction (median = 285.5; range = 978.7) and the male < 2 mm fraction (median = 348.7; range = 509.9) were not significantly different (U = 872.0; p = .483).

3.4.2.3. The Pooled Sample

Table 3.4.11 presents the descriptive statistics for the mean weights according to the pre-cremation condition of the remains, the age group and sex. For both females and males, the mean weight of the cadavers was larger than the mean weight of the skeletons whatever the age group being considered.

The mean weight difference between the samples of cadavers and skeletons was statistically significant for both females (t = 2.822; df = 98; p = 006; d = -.94) and males (t = 5.500; df = 102; p = 000; d = -1.13). The effect size was large for both samples (Cohen, 1988). In order to determine if the contrasting skeletal weights were caused by the dissimilar composition of the samples regarding age, the differences between both samples regarding the mean skeletal weight according to age group were assessed. This was done for both females and males. Results indicated that the statistically significant difference was also present when the samples were compared according to age groups. Therefore, the significantly different mean weights between cadavers and skeletons were not the result of the dissimilar age composition of both samples. The effect size was large according to Cohen (1988). The ≤70 female age group was not tested due to the small size of the sample of skeletons.

Table 3.4.11: Descriptive and inferential statistics for the mean weights (g) of the female and male samples according to the pre- cremation condition and to age group.

	Females				Males			
Age Groups	≤70		>70		≤70		>70	
Condition	Cad.	Skel.	Cad.	Skel.	Cad.	Skel.	Cad.	Skel.
n	17	5	34	20	34	11	31	10
Median	1894.8	1697.4	1585.1	1219.6	2466.5	1944.7	2353.2	1728.8
Range	1439.6	525.5	1353.5	1142.7	2318.6	1372.6	1774.8	1280.2
Mann-Whitney			132.0		57.0		57.0	
Sig.	-		.000		.001		.003	
Effect Size			r = -.51		r = -.51		r = -.47	

As seen for section 3.4.1.3., a statistically significant difference was found for the duration of combustion according to the pre-cremation condition of the remains. Cadavers were more likely left to burn for 101-200’ or overnight than for 0-100’. The opposite occurred for the skeletons.

The statistically significant difference regarding the mean maximum temperature of combustion to which cadavers and skeletons have been submitted to, was also previously presented (see section 3.4.1.3) and demonstrated that skeletons were systematically burned at lower temperatures than cadavers.

3.4.3. Skeletal Representation

3.4.3.1. The Cadavers

Figure 3.4.7 gives the descriptives statistics for the absolute mean weight in grams of each bone category. In all cases, the absolute mean weight of each bone category was larger for males than for females. This difference was statistically significant for most of the bone categories at the .01 level (check appendix A1). However, the skull presented significant differences only at the .05 level. When turned into percentage values – by calculating the relative weight of each bone according to the total weight of the remains – the male sample showed larger representation of almost all bone categories than females (Figure 3.4.8). The only exception to this scenario was the skull. In this case, females showed a larger representation than males. The significant differences at the .01 level observed for the absolute mean weights were also present for the relative mean weights of the skull, the hand, the tibiae and the fibulae categories (Appendix A2). The humerus, the radius and the foot presented significant sexual differences at the .05 level. The relative mean weight of these bones presented lesser significant differences than their absolute mean weight counterparts while the skull revealed the reverse scenario. No significant differences were found for all other bones.

Statistic tests were carried out in order to identify significant correlations between the representation of each skeletal region – cranium, trunk, upper limbs and lower limbs – and three factor variables – sex, age and RAI – on 84 individuals. Multiple regression analysis was then used for the multiple testing of variables. The sample was compatible in size with the testing of 3 independent variables (alpha level = .05; anticipated medium effect size = .15; statistical power = .80). Sex, age and RAI were the factors tested for the effect on the representation of each skeletal region. Sex was used as a dichotomous variable (male; not male). The remaining factors were used as ratio scaled variables.

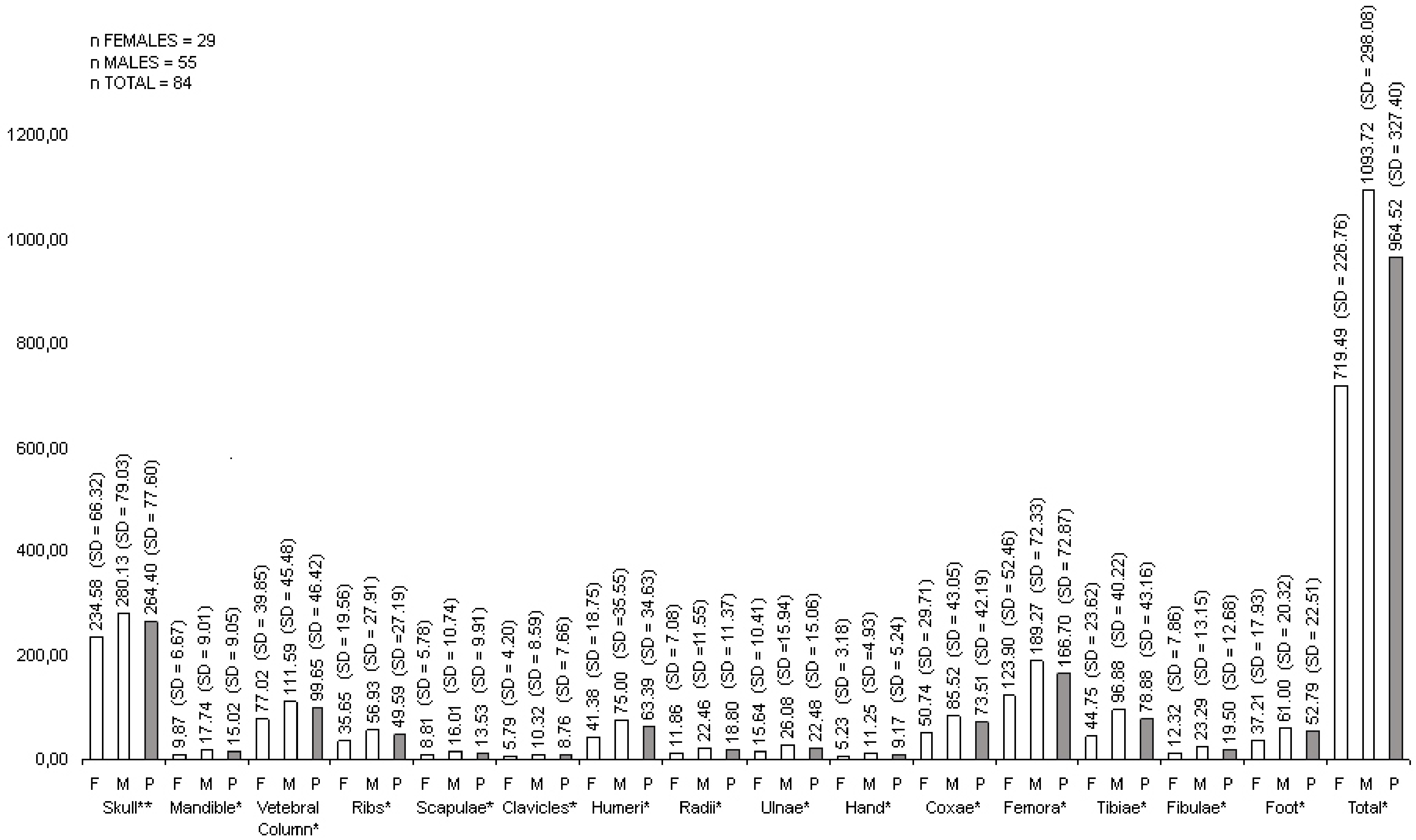

Figure 3.4.7: Descriptive statistics of the absolute bone mean weights of cadavers. [*]Significant difference at the .01 level between the relative mean weight of females and males; [**]Significant difference at the .05 level.

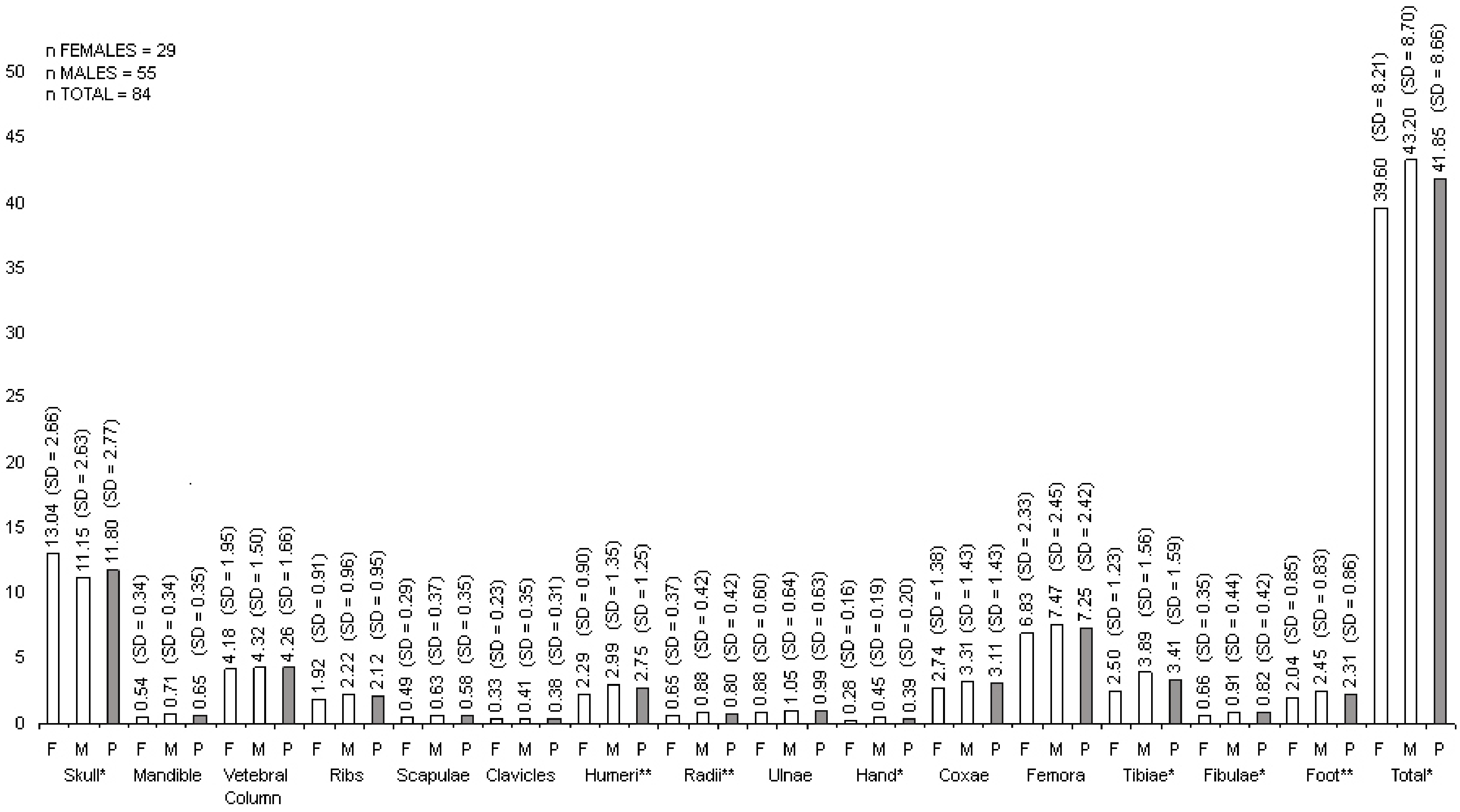

Figure 3.4.8: Descriptive statistics of the relative bone mean weights (%) of cadavers. *Significant difference at the .01 level between the relative mean weight of females and males; **Significant difference at the .05 level.

Sex and RAI were significantly correlated to the representation of the cranial region (Table 3.4.12). Table 3.4.13 shows that the model combining all factors was significant and had a large effect size according to Cohen (1988). Age was the only factor not contributing significantly for the equation. As for the trunk, its percentage was significantly correlated to RAI. The model was also significant for the trunk with a medium to large effect size (Cohen, 1988). Sex and age were not significant contributors to the model. The upper and lower limbs were both significantly correlated to sex and RAI. The models were able to significantly predict their relative representation and a large effect size was found according to Cohen (1988). The statistics for the multiple regressions can be consulted more comprehensively in the appendices (A3 to A6). These results demonstrated that age was not significantly correlated with the relative representation of any of the skeletal regions.

Table 3.4.12: Correlation pre-testing for the multiple regression statistics (cadavers).

		Cranium	Trunk	Upper Limbs	Lower Limbs
Sex	r	-.289	.093	.316	.337
	Sig.	.004	.200	.002	.001
Age	r	.144	-.145	-.077	.104
	Sig.	.096	.095	.244	.173
RAI	r	.498	.543	.767	.888
	Sig.	.000	.000	.000	.000

Table 3.4.13: Results for the multiple regression regarding the preservation of each skeletal region (cadavers). The prediction model includes the variables sex, age and rate of anatomically identified bone fragments.

	F	df	Sig.	Effect Size
Cranium	18.56	3; 80	.000	.39
Trunk	12.85	3; 80	.000	.30
Upper Limbs	44.51	3; 80	.000	.61
Lower Limbs	122.8	3; 80	.000	.82

Given the results, the relative mean weights of both females and males were checked for differences regarding the four skeletal regions. As a result, the t-tests explained in more detail the role of sex on their relative mean weights. With the exception of the cranium, all other regions presented larger representation for males (Table 3.4.14). Significant sexual differences were found for all regions with the exception of the trunk. The effect size was medium to large according to Cohen (1988). Results thus demonstrated that the cranium had a larger representation on the female sample than on the male sample. In contrast, the opposite was found for the upper and the lower limbs.

The sex-pooled relative mean weight of each skeletal region was compared with the sex-pooled relative mean weight observed by Silva et al (2009) with the aim of statistically investigating the differences between them. This was done by calculating a series of one-sample t-tests. A significant difference at the .01 level was found for the cranium (t = -22.85; df = 84; p = .000; d = 2.81), the trunk (t = -41.03; df = 84; p = .000; d = 6.33), the upper limbs (t = -46.28; df = 84; p = .000; d = 8.60) and the lower limbs (t = -54.67; df = 84; p = .000; d = 9.97). The magnitude of the difference between all cases was large according to Cohen (1988). In fact, it was extremely large for the trunk and the limbs regions which presented effect sizes much greater than the cranium. This result suggests that the latter was more successfully identified on the burned remains than the other regions.

The RAI was divided into three groups (25-36.99%; 37-46.99%; 47%-70%). Each group comprised 28 individuals. Table 3.4.15 gives the descriptive statistics for these groups according to the mean representation of each skeletal region. Given that correlation tests identified RAI as a significant factor, this division was done with the aim of investigating if any significant differences could be found between the three levels of RAI regarding the four skeletal regions. As a result, a one-way ANOVA statistic was carried out for the cranium, the trunk and the upper limbs (Table 3.4.16). A Kruskall-Wallis test was calculated for the lower limbs because the assumption regarding the homogeneity of variances was not met. The comparison with Silva et al

(2009) was carried out, this time for each of the three groups on each skeletal region (Table 3.4.15).

Table 3.4.14: Descriptive and inferential statistics for the relative mean representation of the cranium, trunk, upper limbs and lower limbs (cadavers).

	Sample	n	Mean	S.D.	Median	Range	CI 99%		Test	Sig.	Effect Size
							Min.	Max.			
Cranium	Females	29	13.58	2.71	-	-	12.19	14.97	2.735[a]	.008	-.63
	Males	55	11.86	2.75	-	-	10.87	12.85			
	Total	84	12.45	2.84	-	-	11.63	13.27			
Trunk	Females	29	6.09	2.68	-	-	4.72	7.47	-.847[a]	.440	-
	Males	55	6.54	2.04	-	-	5.80	7.27			
	Total	84	6.38	2.28	-	-	5.73	7.04			
Upper Limbs	Females	29	4.92	1.73	-	-	4.03	5.80	-3.012[a]	.001	.73
	Males	55	6.41	2.34	-	-	5.56	7.25			
	Total	84	5.89	2.26	-	-	5.24	6.54			
Lower Limbs	Females	29	15.01	4.45	13.72	19.70	12.72	17.29	428.0[b]	.001	.38
	Males	55	18.40	4.62	18.40	19.79	16.73	20.06			
	Total	84	17.23	4.81	17.70	20.15	15.84	18.61			

[a] T-test; [b] Mann-Whitney test.

The representation of each skeletal region augmented with increasing RAI. A significant difference between the three levels of RAI was found for the representation of all skeletal regions with large effect sizes (Cohen, 1988). The Tukey HSD and Mann-Whitney post hoc calculations, after Bonferroni adjustment of the p-value, indicated that this significant difference was present in every pairwise comparison. The exception to this was the mean difference between the first and the second RAI groups for the cranial region. In addition, the significant difference for the pairwise comparison of the first and second RAI groups and the second and third RAI groups of the trunk were significantly different only at the .05 level. The results suggest that at least for the two first levels of RAI, the anatomical identification of cranial fragments was not as affected by cremation related fragmentation as were the trunk and the limbs’ bone fragments. The statistical comparison of the relative mean weights for each skeletal region with the values observed by Silva et al (2009) on the identified collection of unburned skeletons from the University of Coimbra (Portugal) found a significant difference in all cases.

Table 3.4.15: Descriptive statistics regarding the relative mean representation of the skeletal regions according to the rate of anatomically identified bone fragments. One-sample t-tests for comparison with Silva et al (2009) are also presented (cadavers).

	RAI	n	Mean	S.D.	Median	Range	CI 99%		Silva et al (2009)	
							Min	Max	T-test	Sig.
Cranium	[25;37[	28	11.27	2.76	-	-	9.83	12.72	-15.854	.000
	[37;47[	28	11.94	2.50	-	-	10.63	13.25	-16.055	.000
	[47;65]	28	14.15	2.50	-	-	12.84	15.46	-14.145	.000
Trunk	[25;37[	28	4.96	1.82	-	-	4.01	5.91	-33.786	.000
	[37;47[	28	6.34	1.96	-	-	5.31	7.37	-27.635	.000
	[47;65]	28	7.85	2.10	-	-	7.85	7.37	-21.930	.000
Upper Limbs	[25;37[	28	4.09	1.46	-	-	3.32	4.85	-47.806	.000
	[37;47[	28	5.65	1.38	-	-	4.93	6.38	-44.652	.000
	[47;65]	28	7.93	1.97	-	-	6.90	8.96	-25.171	.000
Lower Limbs	[25;37[	28	12.28	1.74	12.28	1.74	11.37	13.19	-102.345	.000
	[37;47[	28	17.57	3.39	17.57	3.39	15.79	19.34	-44.337	.000
	[47;65]	28	21.83	3.05	21.83	3.05	20.23	23.43	-41.857	.000

Table 3.4.16: Inferential statistics regarding the relative mean representation of the skeletal regions according to the rate of anatomically identified bone fragments (cadavers).

	RAI	Value	df	Sig.	Eta	Pairwise Comparison	Sig
Cranium	[25;37[	9.429 [a]	2 81	.000	.44	1	.599 [c]
	[37;47[					2	.000 [c]
	[47;65]					3	.006 [c]
Trunk	[25;37[	15.206 [a]	2 81	.000	.52	1	.027 [c]
	[37;47[					2	.000 [c]
	[47;65]					3	.014 [c]
Upper Limbs	[25;37[	39.734 [a]	2 81	.000	.70	1	.002 [c]
	[37;47[					2	.000 [c]
	[47;65]					3	.000 [c]
Lower Limbs	[25;37[	80.781[b]	2	.000	.81	1	.000 [d]
	[37;47[					2	.000 [d]
	[47;65]					3	.000 [d]

Pairwise comparison: 1 = [25;37[and [37;47[; 2 = [25;37[and [47;70]; 3 = [37;47[and [47;70]. [a] One-way ANOVA; [b] Kruskall-Wallis test; [c] Tukey HSD; [d] Mann-Whitney test after Bonferroni adjustment of the level of significance to .017.

3.4.3.2. The Skeletons

Figure 3.4.9 gives the descriptive statistics regarding the absolute mean weights of each bone category according to sex. Significant differences between females and males are flagged (Appendix A3). Males showed heavier bones than females in all categories. The difference was statistically significant in all cases excepting for the os coxae. However, these results were only significant at the .05 level for the skull, the mandible, the vertebral column, the ribs, the scapulae and the tibiae.

When turned into relative values, the representation of each bone was larger for males than for females in most cases (Figure 3.4.10). However, the skull, the vertebral column and the os coxae were more represented on the female sample. The hand was the only bone category presenting significant sexual differences at the .01 level (Appendix A4). The skull, the humeri, the radii and the fibulae presented sexual differences at the .05 level. All other bones had no statistically significant differences.

Multiple regressions were carried out in order to determine if sex and RAI were significantly correlated to each one of the skeletal regions. This time, age was not included in the regression model due to the small sample of skeletons of known-age. Results for the paired correlations are presented in table 3.4.17 and the results using the regression model are shown in table 3.4.18. Sex and RAI were significantly correlated to the representation of the cranial and the upper limbs regions (Appendices A9-A12). The model for the cranium was significant with a small to medium effect size while the model for the upper limbs was significant as well with a large effect size according to Cohen (1988). Only RAI was significantly correlated with the trunk and the lower limbs regions and was the only significant contributor to the equation which had a large effect size in both cases (Cohen, 1988).

Table 3.4.17: Correlation pre-testing for the multiple regression statistics (skeletons).

		Cranium	Trunk	Upper Limbs	Lower Limbs
Sex	r	-.297	-.071	.327	.180
	Sig.	.010	.294	.005	.083
RAI	r	.344	.703	.811	.834
	Sig.	.003	.000	.000	.000

Table 3.4.18: Results for the multiple regression regarding the preservation of each skeletal region (skeletons). The prediction model includes the variables sex and rate of anatomically identified bone fragments.

	F	df	Sig.	Effect Size
Cranium	8.09	2; 58	.001	.19
Trunk	29.65	2; 58	.000	.49
Upper Limbs	82.56	2; 58	.000	.73
Lower Limbs	72.62	2; 58	.000	.71

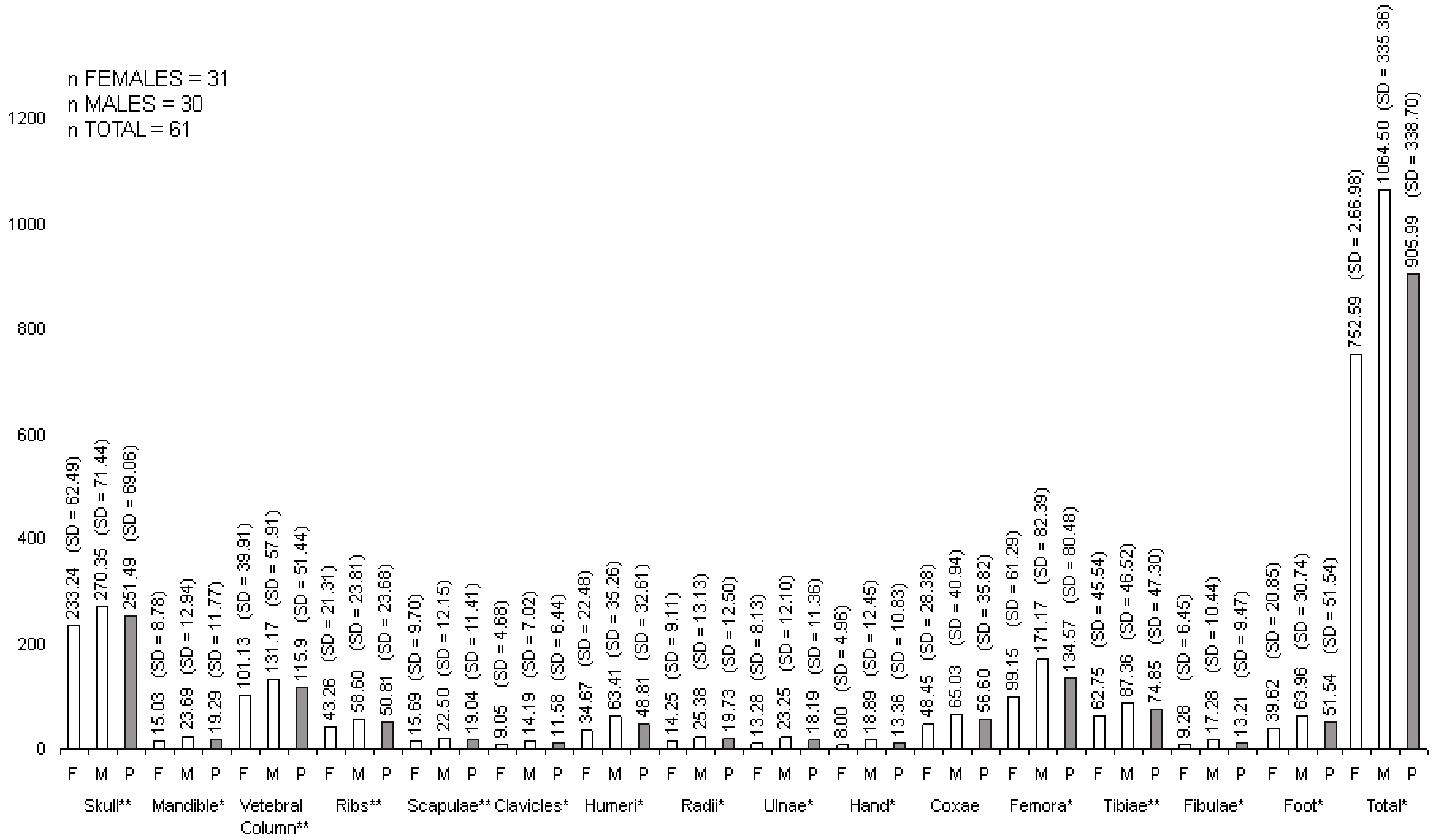

Figure 3.4.9: Descriptive statistics of the absolute bone mean weights (g) of the skeletons. *Significant difference at the .01 level between the absolute mean weight of females and males; **Significant difference at the .05 level.

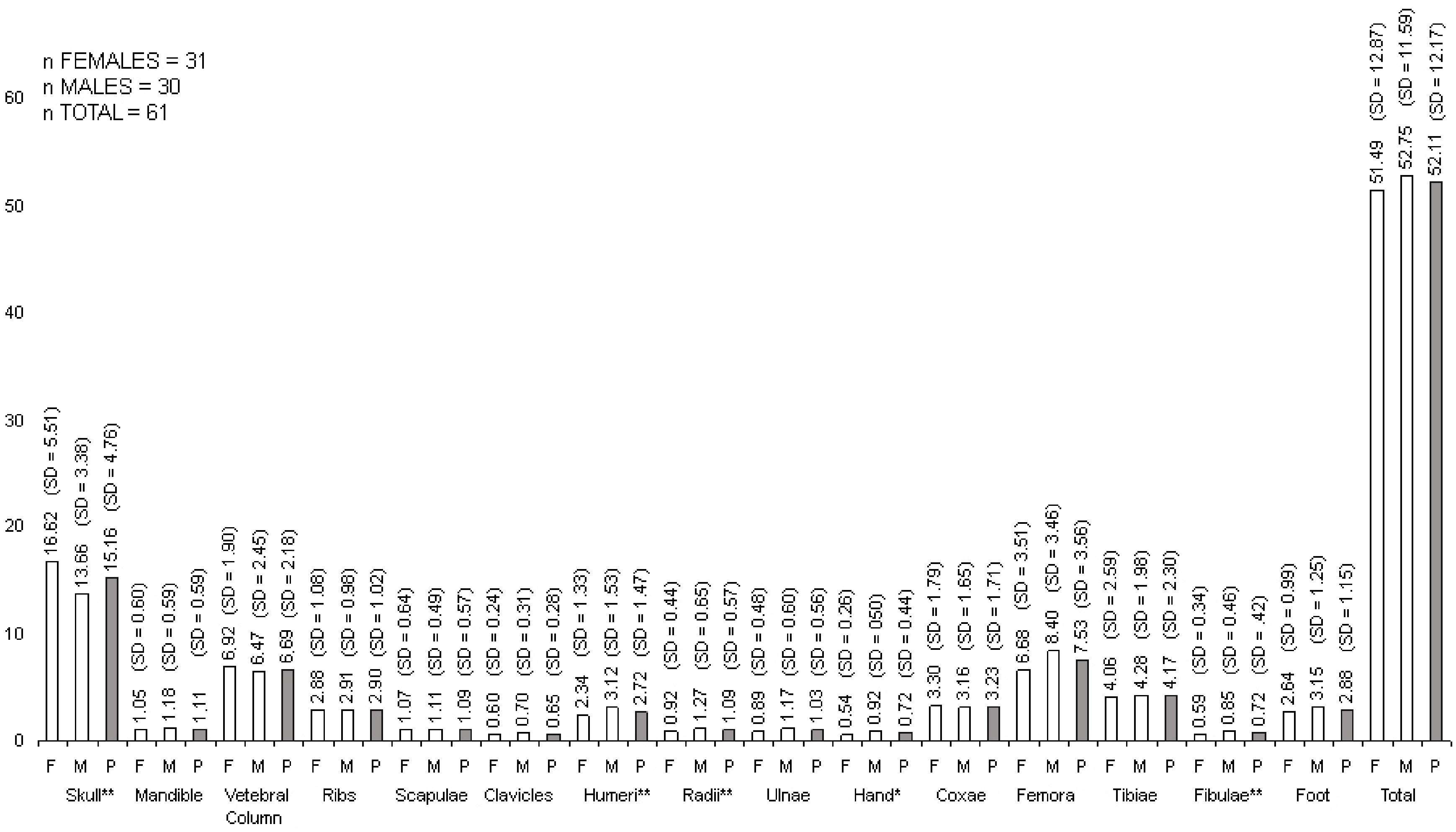

Figure 3.4.10: Descriptive statistics of the relative bone mean weights (%) of the skeletons. [*]Significant difference at the .01 level between the absolute mean weight of females and males; [**]Significant difference at the .05 level.

With the aim of further understanding the results of the multiple regressions, an investigation into the sexual differences of each skeletal region was carried out. In comparison with the male sample, the significantly larger representation of the cranium on the female sample of cadavers was also present on the sample of skeletons (Table 3.4.19). The reverse scenario observed for the limbs on the sample of cadavers was also present on the sample of skeletons. Sexual differences were significant for both cases. In contrast to the observations made on the cadavers, females presented a larger relative mean weight of the trunk in comparison to males. Nonetheless, this difference was not statistically significant.

A series of one-sample t-tests was carried out in order to investigate the differences between the sex-pooled relative mean weights of each skeletal region of the sample of skeletons and the relative mean weights provided by Silva et al (2009). A significant difference was found for the cranium ($t = -5.321$; $df = 60$; $p = .000$; $d = .93$), the trunk ($t = -18.028$; $df = 60$; $p = .000$; $d = 3.50$), the upper limbs ($t = -26.422$; $df = 60$; $p = .000$; $d = 5.98$) and the lower limbs ($t = -29.245$; $df = 60$; $p = .000$; $d = 6.62$). The magnitude of the differences was large according to Cohen (1988), although it was much smaller for the cranial region than for the other regions. This suggests that the anatomical identification was more successful for the cranium than for the trunk and the limbs.

The RAI was identified as a significant factor of the relative mean weight of all skeletal regions by the correlation matrices. Therefore, a post-hoc comparison of three different levels of RAI was completed to assess for differences between them. The descriptive statistics for this analysis are presented in table 3.4.20 and the one-way ANOVA results are given in table 3.4.21. The levels of RAI compiled for the sample of skeletons were different from the levels of RAI compiled for the sample of cadavers due to clear differences in the successful anatomical identification of the remains. Skeletons presented greater RAI than cadavers so the levels had to be built differently to allow for more equal sized samples. Results demonstrated that the relative mean weight of the cranium presented no significant differences according to the level of RAI. The opposite was found for the other skeletal regions. This also suggested that the anatomical identification of cranial fragments was not as affected by cremation related fragmentation as were the other skeletal regions.

Table 3.4.19: Descriptive and inferential statistics of the relative mean representations (%) of the cranium, trunk, upper limbs and lower limbs (skeletons).

	Sample	n	Mean	S.D	CI 99%		T-Test	Sig.	Effect Size
					Max.	Min.			
Cranium	Females	31	17.66	5.48	15.65	19.67	2.392	.020	-.63
	Males	30	14.84	3.51	13.53	16.15			
	Total	61	16.27	4.80	15.04	17.50			
Trunk	Females	31	9.94	2.78	8.92	10.96	.543	.589	-
	Males	30	9.53	3.17	8.35	10.71			
	Total	61	9.74	2.96	8.98	10.50			
Upper Limbs	Females	31	6.36	2.29	5.52	7.20	-2.647	.011	.69
	Males	30	8.28	3.26	7.06	9.50			
	Total	61	7.30	2.95	6.55	8.06			
Lower Limbs	Females	31	17.52	7.06	14.93	20.11	-1.403	.166	-
	Males	30	20.11	7.32	17.37	22.84			
	Total	61	18.79	7.25	16.94	20.65			

The comparison of the results obtained in this investigation with the relative mean weights for each skeletal region from Silva et al (2009) indicated a significant difference in all cases but one (Table 3.4.20). When the third level of RAI (55% to 78%) was considered, the cranial region presented no statistically significant difference between both relative mean weights. Therefore, the results suggest that although complete anatomical identification of the burned remains was not accomplished, most of the cranial region was successfully identified. The same was not observed for the remaining skeletal regions.

Table 3.4.20: Descriptive statistics for the relative mean weight (%) of the cranium, trunk and limbs according to the levels of the rate of anatomically identified bone fragments (RAI) on the sample of skeletons.

	RAI	n	Mean	S.D.	Median	Range	CI 99%		Silva et al (2009)	
							Min	Max	T-test	Sig.
Cranium	[28;47[	20	15.42	4.86	-	-	12.31	18.52	-3.799	.001
	[47;55[	21	15.18	3.62	-	-	12.93	17.42	-5.528	.000
	[55;78]	20	18.28	5.38	-	-	14.84	21.72	-1.045	.309
Trunk	[28;47[	20	7.36	1.59	-	-	6.52	8.56	-54.122	.000
	[47;55[	21	9.30	2.36	-	-	7.84	10.77	-30.999	.000
	[55;78]	20	12.40	2.55	-	-	10.77	14.03	-14.418	.000
Upper Limbs	[28;47[	20	4.60	1.34	4.79	4.91	3.74	5.45	-25.348	.000
	[47;55[	21	7.44	1.93	7.55	8.55	6.24	8.64	-14.095	.000
	[55;78]	20	9.87	2.67	9.60	9.45	8.16	11.57	-7.330	.000
Lower Limbs	[28;47[	20	11.99	2.81	11.44	10.95	10.20	13.79	-42.476	.000
	[47;55[	21	18.49	4.06	18.59	14.62	15.97	21.01	-23.364	.000
	[55;78]	20	25.92	6.21	27.47	24.86	21.94	29.89	-12.438	.000

3.4.3.3. The Pooled Sample

An attempt to estimate the differences between the sample of cadavers and the sample of skeletons regarding the relative mean weight of the skeletal regions was carried out. The descriptive statistics for the absolute mean weight of each skeletal region according to the pre-cremation condition of the remains are presented in table 3.4.22 for the female sample and in table 3.4.23 for the male sample. The difference between cadavers and skeletons was not statistically significant in all cases but the trunk in the female sample. A significant difference at the .05 level was found for this skeletal region with a medium effect size according to Cohen (1988).

Table 3.4.21: One-way ANOVA results for the relative mean weight of each skeletal region according to the rate of anatomically identified bone fragments (RAI) on the sample of skeletons.

	RAI (%)	Value	df	Sig.	Eta	RAI	Post hoc
Cranium	[28;47[	2.782[a]	2 58	.070	-	-	-
	[47;55[					-	-
	[55;78]					-	-
Trunk	[28;47[	24.856[a]	2 58	.000	.68	1	.021[c]
	[47;55[					2	.000[c]
	[55;78]					3	.001[c]
Upper Limbs	[28;47[	35.940[b]	2	.000	.77	1	.000[d]
	[47;55[					2	.000[d]
	[55;78]					3	.005[d]
Lower Limbs	[28;47[	37.219[b]	2	.000	.79	1	.000[d]
	[47;55[					2	.000[d]
	[55;78]					3	.000[d]

Pairwise comparison: 1 = [28;47[and [47;55[; 2 = [28;47[and [55;80]; 3 = [47;55[and [55;80]. [a] One-way ANOVA; [b] Kruskall-Wallis test; [c] Tukey HSD; [d] Mann-Whitney test after Bonferroni adjustment of the level of significance to .017.

When the absolute mean weights were turned into relative values, the insignificant difference found for most of the skeletal regions on the former analysis was only maintained by the lower limbs on the latter for both females and males (Tables 3.4.24 and 3.4.25). The other regions presented a significant difference between cadavers and skeletons. For both sexes, a significantly larger relative mean weight of the cranium, the trunk and the upper limbs was found for the sample of skeletons in comparison with the sample of cadavers.

Table 3.4.22: Descriptive and inferential statistics of the absolute mean weight (in grams) of each skeletal region according to the pre-cremation condition of the remains on the female sample.

Females	Sample	n	Mean	S.D	CI 99%		T-Test	Sig.	Effect Size
					Max.	Min.			
Cranium	Cadavers	29	244.45	69.17	208.96	279.94	-.224	.824	-
	Skeletons	31	248.27	62.98	217.16	279.37			
	Total	60	246.42	65.51	223.91	268.93			
Trunk	Cadavers	29	113.11	56.83	83.95	142.26	-2.215	.031	.57
	Skeletons	31	146.31	59.09	117.12	175.49			
	Total	60	130.26	59.90	109.68	150.84			
Upper Limbs	Cadavers	29	88.71	36.62	69.92	107.50	-.583	.562	-
	Skeletons	31	94.95	45.40	72.52	117.37			
	Total	60	91.93	41.16	77.79	106.08			
Lower Limbs	Cadavers	29	273.22	106.38	218.64	327.80	.319	.751	-
	Skeletons	31	263.07	137.13	195.34	330.80			
	Total	60	267.98	225.95	310.01				

As observed previously for the study of the total weight in section 3.4.1.3, a Pearson Chi-square test revealed a statistically significant difference between cadavers and skeletons regarding the duration of combustion (Table 3.4.4). The analysis indicated that cadavers were more likely left to burn for 101-200’ or overnight than for 0-100’ while the opposite occurred for the skeletons. Also, figure 3.4.5 indicated that cadavers were significantly burned at higher temperatures than skeletons. Therefore, the greater RAI values for the sample of skeletons were possibly related to the lower intensity of the cremation process.

Table 3.4.23: Descriptive and inferential statistics of the absolute mean weight (in grams) of each skeletal region according to the pre-cremation condition of the remains on the male sample.

Males	Sample	n	Mean	S.D	CI 99%		T-Test	Sig.
					Max.	Min.		
Cranium	Cadavers	55	297.86	82.82	268.04	327.68	.210	.834
	Skeletons	30	294.04	75.38	256.10	331.97		
	Total	85	296.51	79.84	273.79	319.34		
Trunk	Cadavers	55	169.67	64.23	146.54	192.79	-1.471	.145
	Skeletons	30	192.93	78.85	153.25	232.61		
	Total	85	177.88	70.17	157.82	197.94		
Upper Limbs	Cadavers	55	161.12	64.65	137.84	184.39	-.411	.682
	Skeletons	30	167.63	78.55	128.10	207.16		
	Total	85	163.41	69.48	143.55	183.28		
Lower Limbs	Cadavers	55	465.07	145.05	412.85	517.29	1.511	.135
	Skeletons	30	409.91	186.72	315.94	503.88		
	Total	85	445.60	162.07	399.27	491.93		

Table 3.4.24: Descriptive and inferential statistics of the relative mean weight (%) of each skeletal region according to the pre-cremation condition of the remains on the female sample.

Females	Sample	n	Mean	S.D	Median	Range	CI 99%		Value	Sig.	Effect Size
							Max.	Min.			
Cranium	Cadavers	29	13.58	2.71	13.63	9.60	12.19	14.97	228.0[a]	.001	-.42
	Skeletons	31	17.66	5.48	18.33	23.16	14.96	20.37			
	Total	60	15.68	4.80	-	-	14.04	17.34			
Trunk	Cadavers	29	6.09	2.68	-	-	4.72	7.47	-5.450[b]	.000	1.41
	Skeletons	31	9.94	2.78	-	-	8.57	11.32			
	Total	60	8.08	3.33	-	-	6.94	9.23			
Upper Limbs	Cadavers	29	4.92	1.73	-	-	4.03	5.80	-2.749[b]	.008	.72
	Skeletons	31	6.36	2.29	-	-	5.23	7.49			
	Total	60	5.66	2.15	-	-	4.93	6.40			
Lower Limbs	Cadavers	29	15.01	4.45	13.72	19.70	12.72	17.29	371.0[a]	.246	-
	Skeletons	31	17.52	7.06	16.33	27.36	14.03	21.01			
	Total	60	16.31	6.03	-	-	14.24	18.38			

[a] Mann-Whithey test; [b] T-test.

Table 3.4.25: Descriptive and inferential statistics of the relative mean weight (%) of each skeletal region according to the pre-cremation condition of the remains on the male sample.

Males	Sample	n	Mean	S.D	Median	Range	CI 99%		Value	Sig.	Effect Size
							Max.	Min.			
Cranium	Cadavers	55	11.86	2.75	-	-	10.87	12.85	-.4.316[a]	.000	.95
	Skeletons	30	14.84	3.51	-	-	13.07	16.60			
	Total	85	12.91	3.34	-	-	11.95	13.87			
Trunk	Cadavers	55	6.54	2.04	6.29	9.57	5.80	7.27	345.0[b]	.000	-.48
	Skeletons	30	9.53	3.17	9.13	12.72	7.93	11.12			
	Total	85	7.59	2.86	-	-	6.77	8.41			
Upper Limbs	Cadavers	55	6.41	2.34	6.43	9.17	5.56	7.25	.549.9[b]	.011	-.28
	Skeletons	30	8.28	3.26	7.66	12.69	6.64	9.92			
	Total	85	7.07	2.83	-	-	6.26	7.88			
Lower Limbs	Cadavers	55	18.40	4.62	19.79	19.69	16.73	20.06	720.5[b]	.337	-
	Skeletons	30	20.11	7.32	19.43	17.82	16.42	23.79			
	Total	85	19.00	5.73	-	-	17.36	20.64			

[a] T-test; [b] Mann-Whitney test.

3.4.4. Estimating the Proportion of Skeletal Regions

Linear regression analysis was carried out in order to predict the proportion of each skeletal region according to the rate of anatomically identified bone fragments. As a result, RAI (mean = 46.1; sd = 13.7) was a significant predictor for all skeletal regions at the .01 level (Table 3.4.26). The effect size was medium for the cranium and large for the remaining skeletal regions. The coefficients for the linear regressions are presented in table 3.4.27.

Table 3.4.26: Results for the predicting value of the rate of anatomically identified bone fragments (RAI) on the proportions of the cranium, the trunk and the limbs.

	Mean (%)	SD	F	df	Sig.	Effect Size
Cranium	13.89	4.22	43.16	1; 130	.000	.24
Trunk	7.72	3.33	178.20	1; 130	.000	.58
Upper Limbs	6.41	3.04	373.19	1; 130	.000	.74
Lower Limbs	18.06	7.25	450.53	1; 130	.000	.77

The testing of the coefficients was carried out on an independent sample composed of 20 contemporary cremated individuals. Using the Wilcoxon signed ranks test, no significant mean differences were found between the prediction values obtained from the equation and the actual proportions reported for the cranium (Z = -1.045; p = .296), the trunk (Z = -.821; p = .411), the upper limbs (Z = -.597; p = .550) and the lower limbs (Z = -1.605; p = .108). In addition, the Pearson bivariate statistic found a significantly positive correlation at the .05 level between each prediction value obtained from the equation and the respective actual proportion reported for the cranium (r = .458; p = .042), the trunk (r = .491; p = .028), the upper limbs (r = .461; p = .041) and the lower limbs (r = .714; p = .000). Therefore, the prediction was fairly accurate for the test-sample composed of 20 cases.

The standard deviation of each skeletal region (Table 3.4.26) was added and then subtracted to the predicted value to establish the upper and lower bounds for the interpretative intervals. For comparison, the un-calibrated references from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) were also used for the interpretation of the test-sample to check for its reliability by using the percentage values adapted by Richier (2005).

Table 3.4.27: Summary of the linear regression analysis for rate of anatomically identified bone fragments (RAI) predicting the proportions of the cranium, the trunk, the upper limbs and the lower limbs.

		B	SE B	B
Cranium	RAI	.154	.023	.499*
	Constant	6.785	1.126	
Trunk	RAI	.185	.014	.760*
	Constant	-.795	.665	
Upper Limbs	RAI	.191	.010	.861*
	Constant	-2.386	.475	
Lower Limbs	RAI	.466	.022	.881*
	Constant	-3.434	1.056	

* Significant at the .01 level.

The calibrated method using the regression coefficients fairly predicted the proportions of the skeletal regions on cremains (Tables 3.4.28 to 3.4.31). As a result, these proportions were almost all interpreted as normal when using the intervals based on the ±1SD. However, 8.8% of the cases were outside the ±1SD intervals. When using the ±2SD intervals, all proportions were interpreted as normal and therefore correctly classified. The analysis using the un-calibrated method revealed to be unsuitable for the classification of an important part (27.5%) of the test-sample (Tables 3.4.28 to 3.4.31). Although the cranial region was always successfully classified, the other skeletal regions were misclassified in some cases. This was especially so for the limbs for which the major part of the cases were incorrectly classified. The use of the weight references from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) systematically interpreted each misclassified skeletal region as being under-represented thus demonstrating that those were not suitable for the analysis of cremains with small to medium RAI.

Table 3.4.28: Test of the regression coefficients for the cranium on the contemporary sample. The results regarding the un-calibrated method are also presented.

#	Sample	Sex	RAI (%)	Expected %	Observed %	±1 SD	±2 SD	LL50%
184	Cadaver	Female	49.40	14.39	17.63	Normal	Normal	Normal
186	Cadaver	Female	60.51	16.10	13.30	Normal	Normal	Normal
315	Cadaver	Male	54.57	15.19	15.15	Normal	Normal	Normal
332	Skeleton	Female	73.14	18.05	24.84	Over	Normal	Normal
345	Cadaver	Male	65.23	16.83	17.71	Normal	Normal	Normal
350	Skeleton	Male	51.31	14.69	22.73	Over	Normal	Normal
356	Cadaver	Male	63.59	16.58	16.29	Normal	Normal	Normal
360	Skeleton	Male	63.86	16.62	15.49	Normal	Normal	Normal
367	Skeleton	Male	50.06	14.49	13.54	Normal	Normal	Normal
368	Skeleton	Male	54.36	15.16	18.32	Normal	Normal	Normal
375	Skeleton	Male	52.48	14.87	19.55	Over	Normal	Normal
426	Skeleton	Female	50.9	14.62	13.66	Normal	Normal	Normal
437	Cadaver	Female	50.18	14.51	16.46	Normal	Normal	Normal
448	Cadaver	Female	50.34	14.54	13.63	Normal	Normal	Normal
449	Cadaver	Male	53.38	15.01	12.90	Normal	Normal	Normal
463	Cadaver	Female	53.19	14.98	17.94	Normal	Normal	Normal
480	Skeleton	Female	69.89	17.55	21.04	Normal	Normal	Normal
482	Cadaver	Male	53.35	15.00	12.50	Normal	Normal	Normal
490	Skeleton	Female	53.98	15.10	11.97	Normal	Normal	Normal
530	Skeleton	Female	59.74	15.98	16.10	Normal	Normal	Normal

Table 3.4.29: Test of the regression coefficients for the trunk on the contemporary sample. The results regarding the un-calibrated method are also presented.

Number	Sample	Sex	RAI (%)	Expected %	Observed %	±1 SD	±2 SD	LL50%
184	Cadaver	Female	49.40	8.34	5.03	Normal	Normal	Under
186	Cadaver	Female	60.51	10.40	11.93	Normal	Normal	Normal
315	Cadaver	Male	54.57	9.30	7.18	Normal	Normal	Under
332	Skeleton	Female	73.14	12.74	13.85	Normal	Normal	Normal
345	Cadaver	Male	65.23	11.27	8.00	Normal	Normal	Under
350	Skeleton	Male	51.31	8.70	9.87	Normal	Normal	Normal
356	Cadaver	Male	63.59	10.97	10.90	Normal	Normal	Normal
360	Skeleton	Male	63.86	11.02	10.51	Normal	Normal	Normal
367	Skeleton	Male	50.06	8.47	10.69	Normal	Normal	Normal
368	Skeleton	Male	54.36	9.26	7.49	Normal	Normal	Under
375	Skeleton	Male	52.48	8.91	9.88	Normal	Normal	Normal
426	Skeleton	Female	50.9	8.62	12.33	Over	Normal	Normal
437	Cadaver	Female	50.18	8.49	8.72	Normal	Normal	Normal
448	Cadaver	Female	50.34	8.52	9.34	Normal	Normal	Normal
449	Cadaver	Male	53.38	9.08	8.23	Normal	Normal	Under
463	Cadaver	Female	53.19	9.05	11.99	Normal	Normal	Normal
480	Skeleton	Female	69.89	12.13	12.02	Normal	Normal	Normal
482	Cadaver	Male	53.35	9.07	8.34	Normal	Normal	Under
490	Skeleton	Female	53.98	9.19	10.60	Normal	Normal	Normal
530	Skeleton	Female	59.74	10.26	12.52	Normal	Normal	Normal

Table 3.4.30: Test of the regression coefficients for the upper limbs on the contemporary sample. The results regarding the un-calibrated method are also presented.

Number	Sample	Sex	RAI (%)	Expected %	Observed %	±1 SD	±2 SD	LL50%
184	Cadaver	Female	49.40	7.05	6.16	Normal	Normal	Under
186	Cadaver	Female	60.51	9.17	6.40	Normal	Normal	Under
315	Cadaver	Male	54.57	8.04	7.96	Normal	Normal	Under
332	Skeleton	Female	73.14	11.58	11.97	Normal	Normal	Normal
345	Cadaver	Male	65.23	10.07	10.19	Normal	Normal	Normal
350	Skeleton	Male	51.31	7.41	5.69	Normal	Normal	Under
356	Cadaver	Male	63.59	9.76	11.90	Normal	Normal	Normal
360	Skeleton	Male	63.86	9.81	10.35	Normal	Normal	Normal
367	Skeleton	Male	50.06	7.18	8.31	Normal	Normal	Under
368	Skeleton	Male	54.36	8.00	9.96	Normal	Normal	Normal
375	Skeleton	Male	52.48	7.64	9.07	Normal	Normal	Normal
426	Skeleton	Female	50.9	7.34	7.55	Over	Normal	Under
437	Cadaver	Female	50.18	7.20	7.28	Normal	Normal	Under
448	Cadaver	Female	50.34	7.23	7.61	Normal	Normal	Under
449	Cadaver	Male	53.38	7.81	11.02	Over	Normal	Normal
463	Cadaver	Female	53.19	7.77	4.25	Under	Normal	Under
480	Skeleton	Female	69.89	10.96	8.40	Normal	Normal	Under
482	Cadaver	Male	53.35	7.80	12.01	Over	Normal	Normal
490	Skeleton	Female	53.98	7.92	8.02	Normal	Normal	Under
530	Skeleton	Female	59.74	9.02	6.75	Normal	Normal	Under

Table 3.4.31: Test of the regression coefficients for the upper limbs on the contemporary sample. The results regarding the un-calibrated method are also presented.

Number	Sample	Sex	RAI (%)	Expected %	Observed %	±1 SD	±2 SD	LL50%
184	Cadaver	Female	49.40	19.59	20.58	Normal	Normal	Under
186	Cadaver	Female	60.51	24.76	28.88	Normal	Normal	Normal
315	Cadaver	Male	54.57	22.00	24,27	Normal	Normal	Normal
332	Skeleton	Female	73.14	30.65	22.48	Under	Normal	Under
345	Cadaver	Male	65.23	26.96	29.33	Normal	Normal	Normal
350	Skeleton	Male	51.31	20.48	13.02	Under	Normal	Under
356	Cadaver	Male	63.59	26.20	24.49	Normal	Normal	Normal
360	Skeleton	Male	63.86	26.32	27.51	Normal	Normal	Normal
367	Skeleton	Male	50.06	19.89	17.51	Normal	Normal	Under
368	Skeleton	Male	54.36	21.90	18.59	Normal	Normal	Under
375	Skeleton	Male	52.48	21.02	13.98	Normal	Normal	Under
426	Skeleton	Female	50.9	20.29	17.36	Normal	Normal	Under
437	Cadaver	Female	50.18	19.95	17.70	Normal	Normal	Under
448	Cadaver	Female	50.34	20.02	19.77	Normal	Normal	Under
449	Cadaver	Male	53.38	21.44	21.23	Normal	Normal	Under
463	Cadaver	Female	53.19	21.35	19.01	Under	Normal	Under
480	Skeleton	Female	69.89	29.13	28.42	Normal	Normal	Normal
482	Cadaver	Male	53.35	21.43	20.51	Normal	Normal	Under
490	Skeleton	Female	53.98	21.72	23.39	Normal	Normal	Normal
530	Skeleton	Female	59.74	24.40	24.36	Normal	Normal	Normal

The calibrated method was also tested on a sample of archaeological cremation burials (Table 3.4.32). Although a tendency for atypical representation of the skeletal regions was often found using the ±1SD intervals, only in four cases that was confirmed by using the ±2SD intervals. The trunk was under-represented on two cremation burials from Sainte-Croix-en-Plane - S-O/1 and 36. The upper limbs were over-represented in one urned burial from Altera (MT12) and another urned burial from Sainte-Croix-en-Plane (64/1). These results contrast with the ones obtained from using the un-calibrated method which, in comparison with the calibrated method, inflated the number of cases presenting abnormal distribution of skeletal regions. It indicated an under-representation of at least one skeletal region on 11 burials. The un-calibrated method was not able to find any case of over-representation.

Table 3.4.32: Test of the regression coefficients on archaeological cremation burials. The results regarding the un-calibrated method are also presented.

		Cranium					Trunk					Upper Limbs					Lower Limbs				
Case	RAI	Exp. %	Obs. %	±1	±2	LL	Exp. %	Obs. %	±1	±2	LL	Exp. %	Obs. %	±1	±2	LL	Exp. %	Obs. %	±1	±2	LL
Bustum	41.4	13.2	11.8	N	N	N	6.9	3.5	U	N	U	5.5	4.2	N	N	U	15.9	21.9	N	N	U
ESA-U3	29.5	11.3	11.5	N	N	N	4.8	3.9	N	N	U	3.3	1.8	N	N	U	10.3	12.3	N	N	U
ESA-U4	65.6	16.9	15.4	N	N	N	11.1	12.3	N	N	N	10.1	7.8	N	N	U	27.1	30.1	N	N	N
ESA-U5	37.5	12.6	13.0	N	N	N	6.2	5.5	N	N	U	4.8	5.7	N	N	U	14.0	13.4	N	N	U
NCF1	58.7	15.8	11.8	N	N	N	9.9	13.8	O	N	N	8.8	4.6	U	N	U	23.9	28.6	N	N	N
NCF2	31.6	11.7	10.2	N	N	N	5.1	0.9	U	N	U	3.7	9.3	O	N	N	11.3	11.2	N	N	U
MT12	36.9	12.5	8.5	N	N	U	6.1	0.9	U	N	U	4.7	13.7	O	O	N	13.8	13.7	N	N	U
PF00	72.7	18.0	18.8	U	N	N	12.4	16.7	O	N	N	11.5	5.5	U	N	U	30.4	21.7	U	N	U
PF01	66.8	17.1	10	U	N	U	11.3	5.5	U	N	U	10.4	11.8	N	N	N	27.7	39.6	O	N	N
SB-7	83	19.6	16	N	N	N	14.2	12	N	N	N	13.5	14	N	N	N	35.2	41	N	N	N
SB-80	85	19.9	18	N	N	N	14.5	16	N	N	N	13.9	13	N	N	N	36.2	38	N	N	N
SB-136	77	18.6	13	U	N	N	13.1	18	O	N	N	12.3	12	N	N	N	32.5	34	N	N	N
SB-479	68	17.3	15	N	N	N	11.5	11	N	N	N	10.6	15	O	N	N	28.3	27	N	N	N
S-O/1	69.3	17.5	25.4	O	N	N	11.8	3.0	U	U	U	10.9	15.0	O	N	N	28.9	25.9	N	N	N
S-O/2	86.7	20.1	22.2	N	N	N	14.8	11.0	U	N	N	14.2	20.1	O	N	N	37.0	33.4	N	N	N
36	76.0	18.5	17.2	N	N	N	13.0	5.6	U	U	U	12.1	16.3	O	N	N	32.0	36.9	N	N	N
64/1	71.3	17.8	17.0	N	N	N	12.1	11.7	N	N	N	11.2	18.4	O	O	N	29.8	24.2	N	N	N

4. Discussion

4.1. Heat-induced Warping and Thumbnail Fractures

The results demonstrated that heat-induced warping and thumbnail fractures do not exclusively occur on fleshed and green bones. Although detected on a minority of cases, those features were also present on dry skeletons with a prevalence of 8.0% in the case of warping and 21.6% in the case of thumbnail fractures. The latter feature was more frequently found than bone warping which was especially uncommon on female skeletons. No significant factors were linked to the occurrence of these heat-induced bone changes with the exception of maximum temperature.

These results confirmed previous findings regarding the detection of heat-induced warping on burned dry bones (Buikstra and Swegle, 1989; Spennemann and Colley, 1989; Whyte, 2001; Gonçalves et al, 2011b) and contrast with the divergent observations made by some other researchers based on small samples (Baby, 1954; Binford, 1963; Etxeberria, 1994). In addition, these results also did not confirm the presence of thumbnail fractures as an exclusive indicator of the burning of fleshed and green bones (Binford, 1963; Buikstra and Swegle, 1989). This investigation demonstrated that, both these features seem to occur independently of the osteobiographic profile, the combustion protocol and the condition of the remains prior to cremation. However, their occurrence is much more frequent for fleshed bones than for dry bones.

As stated above, no specific osteobiographic parameters – age and sex – appeared to be related to the occurrence of warping. Binford (1963) suggested that this could be related to the contraction of muscles on fleshed cadavers but Thompson (2005) stated that contracting muscles would hardly be able to bend bones. Spennemann and Colley (1989) found this feature on a burned human dry humerus and proposed that warping could result from excessive heat trapped on the bone medullary cavity. This could thus occur during the burning of both dry and non-dry bones. Thompson (2005) disputed this hypothesis stating that the porous nature of bone would prevent the trapping of heat on the medullary cavity. Alternatively, Thompson (2005) argued that warping could be the result of the contraction of the periosteum or the anisotropy in the collagen distribution within the bone cortex. Gonçalves et al (2011b) investigated part of the sample here analysed and proposed that it could be related to the preservation of the collagen-apatite bonds and that this would in turn be consequently related to age and sex. The explanation for this being that collagen degradation begins during life and gradually increases with age (Collins et al, 2002; Zioupos et al, 1999) and that post-menopausal women are more prone to experience osteoporosis and consequent loss of skeletal strength (Brickley, 2002). As a result, warping events should in theory be more uncommon on the dry bones from females when compared to the dry bones of males. Sexual differences regarding its relative frequency were not statistically analysed due to the small sample size so no definite conclusions can be inferred. Despite this, warping was indeed more frequent for males than for females – in both samples of cadavers and skeletons – thus being in compliance with that explanation.

As for age, no significant effect on warping was detected thus contrasting with the hypothesis proposed by Gonçalves et al (2011b). Nonetheless, this may be the result of the age composition of the sample. The mean age was of 69.7 (n = 56; sd = 17.3; min. = 23; max. = 99) and only eight individuals were less than 50 years-old. Given that younger individuals were poorly represented, it is possible that the sample was too age biased thus preventing the statistical analyses to detect eventual significant age-related effects. The time span from death to cremation was also investigated. It was used as one way to approximately account for postmortem collagen degradation – which increases with time – and thus infer about its influence on the occurrence of heat-induced bone warping. However, no significant effect was found.

The effect of the intensity of combustion on the occurrence of warping was also investigated. Although no significant relationship was detected regarding the duration of the cremation, the reverse scenario was found for the maximum temperature attained throughout the burning. In general, the skeletons presenting warping were burned at lower temperatures than those for which such feature was absent. This event apparently makes little sense. In theory, if warping is more prone to occur at lower temperatures, bones burned at higher temperatures should also display such feature given that they have also experienced those lower temperatures at a given time of the combustion. However, the occurrence of warping may be less related to the degree of temperature and more related to the fluctuation of temperature and its effects on collagen. When submitted to a gradually increasing temperature, collagen will merely contract, but will develop a contractile force if heated at a constant temperature (Zioupos et al, 1999). This force will drag along the mineral component if the collagen-apatite bonds are still well preserved (Bartsiokas, 2000). Such event may explain the contrasting mean temperatures between the group of skeletons displaying warping and the group of skeletons not displaying warping. In some cases, temperature may have increased rapidly thus preventing the collagen to develop the abovementioned contractile force. Nonetheless, this is merely a speculative explanation because the temperature fluctuation was not entirely recorded on this research. Therefore, it was not possible to know in detail the heat-related dynamics for any of the cremations and compare it with the occurrence of heat-induced features.

As for the thumbnail fractures, the results from this investigation contrast with previous researches that found no such features on burned dry bones (Binford, 1963; Buikstra and Swegle, 1989). Therefore, those do not support the allegations linking this feature to the exclusive burning of fleshed and green bones (Binford, 1963; Guillon, 1987; Herrmann and Bennett, 1999; Whyte, 2001). As stated previously, no significant age and sex-related associations with its occurrence were detected. The feature was found on both sexes and on adults ranging from 23 to 92 years-old. The time span from death to cremation was added to the logistic model so that eventual degradation of both pre- and postmortem collagen could be approximately accounted for. However, no significant relationship with thumbnail fractures was found for it as well, when considered on its own. In addition, the model was also not significant thus indicating that the interaction between the three variables was not able to explain the variation regarding the occurrence of the thumbnail fractures.

The maximum temperature was once more indicated as a significant predictor for the logistic model regarding the intensity of combustion. In contrast, the duration of combustion had no detectable significant effect on the occurrence of the thumbnail fractures. The results indicated that skeletons presenting this feature were burned at lower temperatures than the skeletons in which they were absent. The same scenario was found for the heat-induced warping so this may suggest that both features actually have the same aetiology and therefore are related with the preservation of collagen-apatite bonds. Both features could correspond to two different manifestations regarding the bone response to the same mechanical stress-related event which in this case was heat. If this hypothesis is correct, the contractile force experienced by bone when heated at a constant temperature (Zioupos et al, 1999) could lead to different features depending on the strength of the collagen-apatite bonds. If so, bones would warp to some extent if these bonds were well preserved or otherwise fracture at once when exposed to stress exceeding their ultimate strength. In fact, this reproduces the bone biomechanics observed in vivo for bending fractures (Cullinane and Einhorn, 2002). However, one may argue that the situations are not comparable because bending loads do not produce thumbnail fractures on living patients. As illustrated by figure 4.1.1, those merely cause a transverse fracture and leave a small isolated bone fractured fragment on the concave side of the bending (Cullinane and Einhorn, 2002). This probably takes place because heat-induced bone warping is basically different from antemortem bone bending. The latter is due to mechanical loading extrinsic to the bone while the former is due to the contractile force intrinsic to bone that manifests itself during cremation. Therefore, these produce two different kinds of fractures. In fact, mechanical loads would hardly be able to form sequenced fractures so close to each other as often seen for heat-induced thumbnail fractures. Further research specifically focussed on the eventual association of warping and thumbnail fractures is required to confirm this explanation.

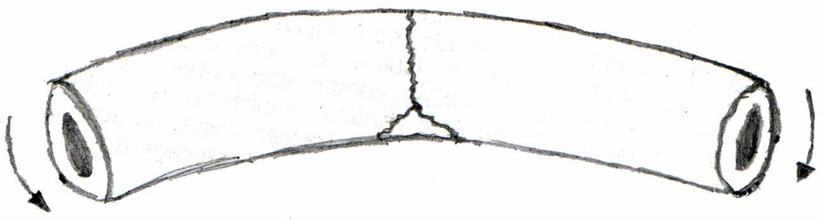

Figure 4.1.1. Bending fracture.

As stated previously, this research was not carried out under laboratorial conditions. It was susceptible to the requirements of commercial cremations which obviously are not compliant with scientific experimental analysis. The remains were burned at a wide range of temperatures and durations according to the needs of each specific cremation. In addition, while some skeletal remains were placed in the cremator inside a wooden box, others were only contained by a shroud. Although it was not possible to follow a homogeneous procedure, this at least allowed demonstrating that the occurrence of heat-induced warping and thumbnail fractures is not linked to very specific burning conditions. In contrast, these events were documented for a much diversified set of burning conditions.

The results obtained on this research confirmed the occurrence of heat-induced warping on burned dry bones. Although some authors had already documented it (Buikstra and Swegle, 1989; Spennemann and Colley, 1989; Whyte, 2001; Gonçalves et al, 2011b), contrasting results have been published in the past (Baby, 1954; Binford, 1963; Etxeberria, 1994). In addition, thumbnail fractures were also found on the same kind of human remains, although it had not been observed on previous researches (Binford, 1963; Buikstra and Swegle, 1989). The contradictions regarding the warping events added to the failure to document the presence of the thumbnail fractures on the precedent attempts could be related to the small sample sizes used until now. Both these heat-induced features – especially warping – were quite rarely observed on the sample of 88 skeletons. Therefore, much smaller samples prevented their detection on burned dry bones. In contrast, heat-induced warping and thumbnail fractures were very frequently found on fleshed burned bones and therefore confirms the results from previous researches (Baby, 1954; Binford, 1963; Buikstra and Swegle, 1989; Etxeberria, 1994; Whyte, 2001).

The confirmation regarding the occurrence of heat-induced warping and thumbnail fractures events in burned dry bones helped to deconstruct the preconceived belief that those were exclusively linked to the burning of fleshed and green bones. This led to the possible misinterpretation of some archaeological funerary practices (Rubini, 1997; Bartsiokas, 2000; Gonçalves, 2007; Ubelaker and Rife, 2007; Curtin, 2008; Duncan et al, 2008). Ideally, the estimation of the pre-cremation condition of the remains should therefore be supported by other indicators such as the representation of the skeletal elements – if most bones are accounted for, then the secondary cremation of disarticulated bones is not as probable – or the presence of clothing-related artefacts like buttons or fibulae – which are suggestive of the presence of a dressed cadaver.

Instead of being directly related to the presence of soft tissues, heat-induced warping and thumbnail fractures are more probably linked to the preservation of the collagen-apatite bonds and consequent preservation of bone mechanical properties such as toughness and elasticity. As a result, the loss of these bonds prevents most dry bones from responding to heat-induced stress in the same manner that fleshed and green bones usually do. However, its preservation on dry bones may still be good enough to allow for the occurrence of heat-induced warping and thumbnail fractures and therefore mislead the researcher to think that the cremation was carried out on fleshed or green skeletal remains.

4.2. Heat-Induced Dimensional Changes

The visual inspection of bone colour successfully discriminated between bones presenting less shrinkage and bones presenting more shrinkage. Colour inspection could thus be useful in order to pinpoint calcined bones strongly affected by heat-induced shrinkage. However, some pre-calcined bones presented shrinkage similar to the one observed for the calcined bones so colour did not unequivocally discriminate bones according to degree of heat-induced dimensional change.

This research contributed for additional documentation regarding heat-induced dimensional change. As expected, calcined bones presented larger degrees of shrinkage than pre-calcined bones. The overall shrinkage for the former (-14.5%) was more than three times larger than the latter (-4.1%). These results were very similar to previous researches regarding dimensional change on carbonized bones (Herrmann, 1977; Holland, 1989, Bradtmiller and Buikstra, 1984; Thompson, 2005) and on calcined bones (Herrmann, 1976 In Fairgrieve 2008; Herrmann, 1977; Shipman et al, 1984; Thompson, 2005). However, no size increase was found for the latter as did Thompson (2005). Pre-calcined and calcined bones do differ in the degree of heat-induced dimensional changes and several factors are significantly linked to this. Herrmann (1976 In Fairgrieve 2008; 1977) pinpointed the distribution of bone types as one of those factors. Until now, investigation has strongly suggested that compact bone shrinks lesser than spongy bone (Van Vark, 1974; McKinley, 1994; Thompson, 2005; Fairgrieve, 2008). This may be related to compositional differences regarding these two types of bone. Although there has been some contrasting results, the literature review carried out by Guo (2001) indicates that compact bone has a higher density tissue and ash fraction than cancellous bone. Although the phosphorus content is similar for both, the former has a significantly larger calcium component. In addition, the water content is larger for cancellous tissue (27%) than for cortical tissue (23%). This lower density of cancellous bone may be related with the fact that it is more actively remodelled and thus less mineralized than cortical bone (Guo, 2001). The results of the present research were all obtained on spongy bones so the issue of differential shrinkage between these and compact bones was not specifically addressed. When calcination was achieved, larger bones – humerus, femur, talus and calcaneus – experienced 12% of shrinkage while the small tarsals experienced more than 16% of shrinkage. Some important variations were thus detected within spongy bones according to their size. It is possible that different distribution of cortical and trabecular tissues on those specific bones led to different percent shrinkages. However, we can only speculate if it had anything to do with this.

Temperature was also pointed out as a factor with a significant effect on shrinkage by Herrmann (1976, In Fairgrieve 2008; 1977). This was confirmed by Shipman et al (1984) who reported a positive correlation between both variables. In fact, the results obtained during the present investigation also demonstrated that shrinkage significantly increased with temperature and thus confirmed that the latter has a significant effect on the rate of dimensional change. The duration of combustion was not indicated by Herrmann as a criterion but a significant effect of this factor regarding dimensional change was detected this time. However, the results were not linear. Although the percent shrinkage increased with time, bones burned and left to cool overnight (11.8%) presented similar mean percent shrinkage than those burned for the smallest amounts of time (10.9%).

The increasing shrinkage according to increasing time of combustion that was found in this research has been previously reported by Thompson (2005). However, he had no equivalent sample regarding the overnight sample so no direct comparison with his investigation can be carried out on this issue. He reported that as bones cooled down, the shrinkage event was still occurring. Fairgrieve (2008) stated that the thermodynamic laws imply that a contraction on the dimension of bone is expected until it achieves the temperature at which the pre-cremation measurements were recorded. Apparently, the results for the overnight sample do not fit into this explanation if they are based only on the duration of combustion. Although it has been left to cool down for several hours, the mean shrinkage was not significantly larger than the other samples burned for lesser amounts of time. This suggests that the explanation probably lies on the interaction of time and temperature of combustion. Many of the skeletal remains processed overnight were left on the cremator – which was switched off – taking advantage of the already heated setting which was attained on the preceding cremations. Therefore, instead of being subject to increasing temperature, those remains were subject to decreasing temperatures. Thompson (2003) states that heat-induced expansion of bone occurs especially at low intensity burnings but that it is often overridden by heat-induced shrinkage. The results obtained in the present investigation are in compliance with this statement, given that the overnight bones experienced less shrinkage. Thompson (2003) argues that the degree of shrinkage would be more substantial in the absence of heat-induced expansion. In the present case, the bones were not measured at different moments of the burning so the results are just based on the final measurements carried out after the combustion. As a result, the dynamics regarding each bone heat-induced dimensional changes throughout the cremation were not documented. The events reported by Thompson (2005) and further explained by Fairgrieve (2008) must have also been experienced by the samples used in the present investigation, but a more detailed record of them was regrettably not achieved.

As for the relationship between bone mineral content and shrinkage, Herrmann (1976, In Fairgrieve 2008; 1977) found higher percent shrinkages for males in comparison to females which were associated to higher percentages of bone mineral. However, no similar scenario was found on the present research. In fact, females tended to display more shrinkage than males although the difference was not statistically significant. In addition, Herrmann's findings seem to contrast with other researches. Huxley and Kósa (1999) estimated the percent shrinkage of carbonized and calcined bones from foetuses and found a decrease in bone contraction with increasing age and therefore, with consequent increase in mineralization (Guo, 2001). In addition, the mean shrinkage rates observed in foetuses were quite larger than the ones found for adults in the present research and in the investigations of several other authors (Herrmann, 1977; Bradtmiller and Buikstra, 1984; Holland, 1989). These findings suggest that as the process of mineralization progresses, bones become less vulnerable to heat-induced shrinkage. Therefore, this occurrence does not fit into the abovementioned conclusion presented by Herrmann (1976, In Fairgrieve 2008; 1977).

Given that so many factors apparently have a significant effect on dimensional change, the failure to find a predictive equation through multiple linear regression was not surprising. The predictive power of the duration and maximum temperature of combustion was investigated but it only accounted for 21% of the variation observed for the shrinkage rate. As a result, the equation failed to predict dimensional change on a test-sample. Thompson (2005) had already reached to this conclusion stating that such an attempt was unworkable given the too many variables that must be accounted for and the little knowledge that we have of them.

The limitations of these results are mainly related with the research design. It was not possible to constantly monitor the cremation and the effect of thermodynamic events on the dimension of bones. Therefore, the data refer only to the final stage of those events. In addition, the measurement of the features was not always the same regarding the time elapsed since the removal of the remains from the cremator. This could vary from a few minutes to several hours. Therefore, the analytical circumstances were much diversified and there is no way to know how this may have affected the data collection. Nonetheless, the percent shrinkages for both pre-calcined and calcined bones were consistent with previous researches so those limitations probably did not affect significantly the results.

The data regarding the shrinkage rate could eventually allow for the calibration of standardized osteometric references into adapted tools suited for reliable sex determination using calcined bones (as seen in section 3.3.5). Such course of action has already been suggested by Buikstra and Swegle (1989) which recommended a correction factor of 10%. This would be an important finding because such procedure could be adopted worldwide and applied to already existent population-specific standards.

4.3. Osteometric Sexual Dimorphism

4.3.1. The Post Cremation Preservation of Diagnostic Features

Results demonstrated that the demographic profile (age and sex) of the individuals and the intensity of the burning (duration and maximum temperature of combustion) do not completely explain the variance on the preservation of the measurable features of calcined bones. Although in several cases, some of these variables were significantly linked to preservation, this did not occur systematically in all cases.

Age had no significant effect on the preservation of measurable features in most cases. It was only for the humeral features that younger people showed better preserved features than older people on the sample of cadavers. Nonetheless, even in this case the mean ages revealed that both groups were mainly composed of elderly. The significant effect of age may have been thus concealed by the aged composition of the sample which did not include many young and middle adults. The research found no significant effect of sex on the preservation of any of the bones. Although males are usually more robust than females, this apparently had no significant effect on preservation. Whenever the demographic profile was tested by assessing the power of the interaction of age and sex on the preservation of bone features, no significant effect was found as well. These conclusions applied to both samples of cadavers and skeletons.

As for the intensity of combustion, the results were a little more heterogeneous. For cadavers, the duration of combustion had a significant effect on the preservation of the talar and the calcaneal features. On this case, bones burned and left to cool down overnight presented more preserved features than expected. However, no such significant effect was found for the intermediate and for the lateral cuneiforms – the other two features investigated on this issue. In theory, the better preservation of bones subject to cremation for longer periods of time – despite the cremator being switched off – was somewhat unexpected. These have been allowed to cool off gradually during the night and it is possible that although they become more brittle when hot, bones structurally re-acquire some resilience as heat decreases. While burning, bone is perhaps more vulnerable to mechanical stress thus promoting fragmentation. McKinley (1993) actually states that, on her own research, bones were less brittle when cooled. Maximum temperature had no significant effect on the preservation of any of the bones from the sample of cadavers. However, a sampling problem similar to the one regarding age may be responsible for this. Most cadavers had been burned at temperatures above 800º C so a comparison with cadavers burned at lower temperatures was not carried out. As a result, this prevented the detection of any eventual significant difference between them. The interaction of duration and maximum temperature of combustion was also significant for the calcaneus and insignificant for both cuneiforms. On the calcaneus, this interaction did not reveal a stronger relationship with preservation than time of combustion on its own.

For skeletons, the intensity of combustion also revealed contrasting results. Although a significant effect on preservation was found for the humerus, the opposite result was obtained for all other bones for which testing were carried out. In the first case, better preservation was recorded for the bones burned for a period up to 25 minutes. As for maximum temperature, this had no significant effect on the preservation of most of the bones. However, a contrasting result was found for the femur for which bones heated at lower temperatures presented better preservation. This effect was merely significant at the .05 level though. A spectrum of temperatures larger than the one from the sample of cadavers was recorded for the skeletons and this may have contributed for the statistical detection of the effect of temperature on the femoral preservation. Nonetheless, this result was not corroborated by the results obtained on other bones. Despite these results for the humerus and the femur, no significant effect was found for the model regarding the intensity of combustion.

Whenever the logistic regression included three variables, no significant effect on preservation was found for the model. The only exception was the logit model for the talus on the sample of cadavers. However, the only significant predictor on this case was the duration of combustion and none of the other variables – sex and maximum temperature of combustion – contributed significantly for the predictive power of the model.

The comparison of the sample of cadavers and the sample of skeletons demonstrated that the latter had been burned for significantly shorter periods of time and lower temperatures. This had contrasting effects on the preservation of bone features. Although no significant difference was found regarding the preservation of both samples for some bones – humerus, femur, calcaneus and lateral cuneiform – the opposite was found for the remaining ones. In these cases, bone features were better preserved on the skeletons' sample than on the cadavers' sample. The reversed scenario was not found on any case which suggests that both duration and maximum temperature of combustion may actually have an effect on preservation. However, the relationship between the intensity of combustion and fragmentation may be non-linear. Preservation apparently decreased along with the increase of duration and maximum temperature of combustion. However, fragmentation seemed to be not as severe if bones were allowed to gradually cool off and retrieved at substantially lower temperatures. Further research is needed to better understand bone resilience to heat. Only then, it will be possible to validate or nullify this observation.

Results suggest that unknown variables may have played a part on the preservation of bone measurable features because the monitored variables were not able to fully explain the observations. Two aspects regarding the cremation were recorded – the demographic profile and the combustion parameters – but not all factors have been investigated. For example, the biological profile did not include eventual pathologies affecting bone resilience and the combustion parameters did not include the differential use of the burners. In addition, a third aspect was overlooked – removal of the remains from the cremator. As stated in section 2.3.3, this was not included in the research because no consistent manner regarding the scoring of this procedure was outlined. However, it interfered substantially with the preservation of the burned skeletal remains. Therefore, the complexity of the investigation of heat-related preservation was not entirely addressed by the research design. The results obtained with this investigation were thus merely indicative and hardly included all factors – known or unknown – responsible for the preservation of bone features.

Despite all, the results suggest that preservation of measurable features from bones mainly composed by trabeculae was reasonably frequent for both the cadavers and the skeletons. This had already been stated by Warren and Maples (1997). In addition, the internal auditory canal of the petrous bones was also very often preserved. At least one measurable feature was thus found for 97% of the cadavers and 95% of the skeletons. If the petrous bone is not included, then the presence of at least one measurable feature in each cremated individual was of 93% for cadavers and of 95% for skeletons. If the petrous bone and the small tarsals are not included, then the presence of at least one measurable feature in each cremated individual was of 78% for cadavers and of 71% for skeletons. Therefore, the post-cremation preservation of osteometric features confirmed that there is good potential regarding the adoption of univariate analysis based on them. However, taphonomic processes other than burning do frequently contribute to worsen preservation, especially when dealing with archaeological material. Therefore, although the results demonstrated good potential for osteometric analysis of calcined bones, the actual preservation of measurable features will certainly be less satisfactory.

4.3.2. Sexual Dimorphism and Sex Determination

4.3.2.1. Discriminating Cut-off Points

The research demonstrated that sexual dimorphism was still present despite differential heat-induced shrinkage and that osteometric sex determination could thus be carried out quite successfully on calcined bones. This finding applied to almost all bone features of the humerus, the femur, the talus and the calcaneus for which parametric analysis was carried out. In addition, non-parametric analysis also found significant differences for other features regarding some of the smaller tarsals. Only the internal auditory canal exhibited no significant sexual dimorphism.

The Coimbra Standards for sex determination (Silva, 1995; Wasterlain and Cunha, 2000) were used to discriminate samples of cadavers and skeletons of known-sex in order to investigate if the sexual dimorphism present on calcined bones had any potential for sex determination. However, its use was not successful on calcined skeletal remains. Indeed, the allocation of individuals according to sex by using the humerus, the femur, the talus and the calcaneus resulted on the under-classification of males and the over-classification of females. This was the result of heat-induced shrinkage interfering with the calibration of the standards that were developed on collections of unburned skeletons. Shrinkage has been previously observed on burned bones by several researchers (Malinowski, 1969; Bradtmiller and Buikstra, 1984; Shipman et al, 1984; Holland, 1989; Gruppe and Hummel, 1991). It has been stated that shrinkage rate can be of 30% when bones are exposed to temperatures above 700º C (Bradtmiller and Buikstra, 1984; Gruppe and Hummel, 1991). This was also documented for the present research so the inadequacy of the Coimbra Standards for unburned skeletons from the Coimbra collection (Silva, 1995; Wasterlain and Cunha, 2000) was somewhat expected. Nonetheless, this research corroborated and strengthened the results from other investigations that had previously demonstrated or at least implied the potential of osteometry for the sex determination from burned bones (Gejvall, 1969; Schutkowski, 1983; Schutkowski and Herrmann, 1983; Warren and Maples, 1997; Van Vark et al, 1996; Thompson, 2002).

Despite the effect of shrinkage, it was hypothesised that a positive secular trend of 8.93 cm affecting the Portuguese population on the last century (Padez, 2003 and 2007) could have eventually re-calibrated the Coimbra Standards to fit into the osteometric dimensions of contemporary cremated individuals. Those standards were developed on a collection of skeletons from individuals from the 19th and early 20th centuries (Silva, 1995; Wasterlain and Cunha, 2000). In theory, the growth in stature of the Portuguese population since then could thus have led the standardized sexual discriminating cut-off points to be indeliberately adjusted for the sex determination of shrunk calcined bones. However, nothing of the sort was confirmed by this research. Shrinkage was too large to be successfully coped by an eventual re-calibration due to positive secular trend.

Although sex determination was unsuccessful when using the Coimbra Standards, the adoption of the sex-pooled mean from the sample of cadavers as cut-off points proved to be very effective. This was a very important result because it demonstrated that osteometry is valuable for the bioanthropological analysis of calcined bones despite heat-induced changes. However, the results also demonstrated that correct classification differed from cadavers to skeletons. In general, male skeletons were more often misclassified than male cadavers. Most test-samples of skeletons according to each standard measurement were small in size so no consistent comparisons can therefore be made regarding them. However, low classification rates were also obtained for the groups with larger samples – humeral head vertical diameter, the talar maximum length and the calcaneal maximum length. This suggests that the cut-off points calculated from the sample of cadavers were not adequate for the sex determination of calcined bones resulting from the cremation of dry skeletal remains. In fact, the mean sizes recorded for the sample of skeletons were almost always smaller than the ones from the sample of cadavers thus suggesting that this difference – although not statistically significant in most cases – may have been related to the contrasting results obtained for each sample. Most measurements differed less than 1 mm between both samples, but differences ranging from 2 to 3 mm like the ones observed for the calcaneal maximum length of both females and males or for the humeral epicondylar breadth of males were apparently large enough to interfere with the discriminating power of the cut-off points. However, such statement is mere speculation and parametric testing did not support it, although it was clear that sex determination of both samples was somewhat contrasting. Therefore, these two results were apparently incongruous.

If both samples were indeed dissimilar in mean size, this may have been inherent to them previously to cremation and therefore: be either produced by population differences; be the result of postmortem change interfering with bone size; or otherwise result from differential cadavers and skeletons response to heat. These were contemporary to each other – also belonging to similar age groups – and most of the individuals were from the same geographic region so no substantial mean size differences between them were to be expected. However, population differences could not be investigated because the pre-cremation bone dimensions of the cadavers were obviously not taken. Therefore, actual variation on the size of cadavers and skeletons may have been present right at the start. As for the postmortem changes in bone size, post-depositional bone shrinkage occurs due to the gradual loss of the organic component of bone (Piepenbrink, 1986; Jans et al, 2002). Therefore, it could be speculated that the heat-induced shrinkage on skeletons was added to the already present shrinkage that took place while bones were inhumated. As a result, this could lead the skeletons to present larger percent shrinkages than the cadavers. Another explanation is related to the clear difference regarding both kinds of human remains. Cadavers had soft tissues while skeletons were composed of disarticulated dry bones. These were thus much more susceptible to the effect of heat than the cadavers. In this case, bones were protected by soft tissues for a large part of the cremation (McKinley, 1989; Bohnert et al, 1998; Pope and Smith, 2004; Hanson and Cain, 2007) and this could hypothetically have led to smaller rates of shrinkage. Because the research did not specifically address this issue, it is not possible to state that any of these hypotheses or even the combination of all of them can explain the size differences between cadavers and skeletons. Further research is needed to clarify this issue.

Either way, it seems clear that small population differences interfered severely with the reliability of the discriminating cut-off points. Therefore, these are probably only adequate for contemporary Portuguese populations and its use on other contemporary or archaeological populations was not tested. In fact, mean sizes of the humeral and femoral head vertical diameters of calcined bones from Sweden and American samples provided for larger dimensions than the ones from the Portuguese sample (Van Vark et al, 1996; Warren and Maples, 1997). These results suggest that the population differences between Swedish, Americans and Portuguese are substantial enough to prevent the application of population-specific osteometric references to other populations (Table 4.3.1). In part, this should be related to differences in height between each population. The Portuguese male sample was 70.1 years-old in average so this means that 1940 was approximately their mean date of birth. Padez (2003) found that male military recruits born in the 1940's had an approximate mean stature of 166.0 cm when they were 18 years-old. As for the Swedish, the sample was composed of individuals who died in 1971. Silventoinen et al (2001) found a mean stature of 175.8 cm for Swedish males born between 1920 and 1929 who would be 40-50 years-old by 1971. In the case of Swedish females, the average stature was of 163.7 cm. The American sample presented a mean age of 69 years-old in 1997. Therefore, their mean decade of birth should be 1920-1930. The mean stature of males born in this decade was of about 175.0-177.0 cm while the female mean stature was of 162.0-163.0 cm according to Trotter and Gleser (1951). In summary, large differences in mean stature between the Portuguese and the other two populations are also visible in the humeral and femoral head dimensions of calcined bones. However, although the latter present similar mean heights, the calcined bones have somewhat different mean sizes. Therefore, other factors beside stature must explain this. Activity patterns interfering with the size of these anatomical regions and differential shrinkage may be some of those factors. This reinforces the allegation that population-specific osteometric references for calcined bones must be used instead of extrapolating from the Swedish (Van Vark et al, 1996) or the Portuguese references.

In addition to the testing of calcined bones, an attempt to determine the sex of pre-calcined bones on a small sample was carried out by using the Coimbra Standards. Although not as severe as for calcined bones, the test demonstrated that sex allocation is also affected by heat-induced changes although the degree of shrinkage is significantly less substantial for pre-calcined bones than for calcined bones as seen in section 3.2. Therefore, the use of standards developed on unburned skeletons must still be interpreted critically.

Table 4.3.1.: Mean humeral and femoral head diameters of burned bones from Portuguese (2011), Swedish (1971) and American 1997) populations.

Population	Males		Females	
	HHVD (mm)	FHVD (mm)	HHVD (mm)	FHVD (mm)
Portuguese	43.51 (n = 62)	43.02 (n = 55)	37.74 (n = 62)	37.64 (n = 55)
Swedish (Van Vark et al, 1996)	44.10 (n = 104)	45.90 (n = 104)	38.71 (n = 98)	39.96 (n = 99)
American (Warren and Maples, 1997)	45.80 (n = 28)	44.20 (n = 17)	38.16 (n = 10)	38.10 (n = 6)

The lack of significant sexual differences regarding the lateral angle of the internal auditory canal contrasts with the results from other authors who tested this method on unburned skeletons (Norén et al, 2005; Graw et al, 2005; Gonçalves et al, 2011a). The sex determination of the sample of skeletons by using the cut-off point recommended by Graw et al (2003) and by Norén et al (2005) was attempted because sexual dimorphism was almost significant at the .05 level. However, the correct sex classification using this method was not better than chance alone. The failure regarding this method is probably related to its complex replicability and to eventual heat-induced changes interfering with sexual dimorphism. In fact, sexual differences were still somewhat present on the sample of skeletons in contrast to what was observed for the cadavers. Given that the former had been submitted to lower mean intensities of combustion, it is possible that its effect on the sexual dimorphism was not as severe as it was for the cadavers. The lateral angle method has been proposed as a potentially useful support for sex determination of burned bones due to its good resilience to heat (Norén et al, 2005). Regrettably, the results did not confirm the potential of that method.

4.3.2.2. Regression Analysis

Logistic regression developed from a sample of cadavers also allowed for very satisfactory predictions of sex based on all standard measurement. The testing of the regression coefficients on independent samples composed of 20 cadavers allowed for successful rates of sex allocation ranging from 81.8% to 100.0%. The accuracy was slightly better than the results obtained with the cut-off-points. However, the samples were larger for the latter so its results are possibly more reliable. The testing of logistic models combining two different measurements was also quite successful for the humerus and the femur but did not improve the results obtained with the single regressions for the sample of cadavers.

The accuracy of logistic regression was not satisfactory for the test-sample of skeletons thus demonstrating again that a difference in mean size was present between these and the cadavers. The classification of females was usually better than the classification of males suggesting that the coefficients were not calibrated enough to allow for balanced sex determination of both groups on the sample of skeletons. The use of the femoral head transverse diameter obtained the best classifications according to sex, although in this case the classification of females was correct on less than 80.0% of the sample.

4.3.2.3. Shrinkage Correction Factors

The calibration of the Coimbra Standards into cut-off points specifically adapted to burned bones provided for somewhat contrasting results. The 10% correction factor of Buikstra and Swegle (1989) allowed for considerably more successful sex classification than the 12% correction factor resulting from the direct estimation of heat-induced shrinkage (section 3.2). In this case, although most males were correctly allocated according to sex, an important amount of females were misclassified. This occurred for both calibration procedures using the Coimbra Standards and the references especially developed for this research from the Contemporary Sample. However, the latter provided for more balanced results regarding females and males albeit still unsatisfactory.

In contrast, the correction factor recommended by Buikstra and Swegle (1989) allowed for calibrated values that correctly classified near or more than 80% of both females and males for most of the standard measurements. However, this was so only when using the references from the Contemporary Sample. Only the humeral epicondylar breadth presented correct classification much lower than 80% for the female sample. These results were obtained on large samples so they were not due to chance. Nonetheless, the 10% correction factor (Buikstra and Swegle, 1989) was not adequately used to calibrate the Coimbra Standards thus demonstrating that slight size differences strongly interfere with its value.

The explanation for the failure regarding the application of the correction factor specifically developed during this research can be related with the fact that the mean sizes of the skeletons – from which the rate of shrinkage was obtained – and of the test-sample of cadavers were basically different. Some explanations for this have been proposed earlier in section 4.3.2.1. Given that skeletons were smaller than cadavers, then the mean percent shrinkage obtained from the former may actually be too large to allow for its accurate use on the latter. Its inadequacy as a correction factor may thus explain the unsatisfactory results regarding sex determination. One way to investigate this hypothesis would be to assess if the calibrated cut-off points would more successfully classify a sample of skeletons in comparison with the sample of cadavers. Regrettably, the sample of skeletons was often too small to allow for reliable conclusions regarding this matter. The exceptions to this were the humeral head vertical diameter, the talar maximum length and the calcaneal maximum length. More correct sex classification results were obtained for the skeletons than for the cadavers thus suggesting that the correction factor of 12% was indeed more adjusted to skeletons than to cadavers. Nonetheless, correct classification was still under 80% for one of the sexes for most standard measurements thus demonstrating that the calibration was not ideal.

The major difficulty of this research was related to the fragmentation of calcined bones. It was extremely hard to compile a large enough sample to allow for statistical inferences regarding all standard measurements. This was especially true for the sample of skeletons. The samples of cadavers could have been larger if it had been decided to use unequal samples of females and males. However, equal samples were used to avoid biased results. This shortened the samples because females were usually less frequent than males. In addition, the test-samples were small for most of the female cases because it was decided to, as much as possible, enlarge the samples used for inferential statistics. Although the testing of the discriminating procedures was quite comprehensive for most of the features on the male sample, the testing of female individuals was somewhat limited. Therefore, the documentation regarding the correct classification of females was not as strongly supported as the one for males but is still indicative of the reliability of the osteometric standards specific to calcined bones that were developed under this research. Further testing on larger samples is required to replicate and confirm these results. The limited size of samples was even more problematic for the sample of skeletons. A more comprehensive study regarding burned skeletons would have permitted the calculation of sample-specific standards thus allowing for a comparison between these and the standards obtained from the sample of cadavers. Regrettably, it was not possible to follow that procedure due to the small number of skeletons.

Another shortcoming of this research was related to the age structure of the sample. Because part of the analysis was carried out on newly deceased, the mean age of the individuals was quite large. As a result, no age groups comparison was carried out in order to investigate if differences in size and therefore secular trend could be detected on the sample of cadavers.

In summary, results demonstrated that heat-induced shrinkage does not interfere with osteometric sexual dimorphism on calcined bones. The cut-off points and the regression coefficients provided by this research are population-specific, but the recommended correction factor of 10% for calcined bones (Buikstra and Swegle, 1989) may eventually be applied to adapt current standards for unburned bones into references for burned bones. This must be carried out with caution though because slight metric variations have an important effect on the accuracy provided by the cut-off points.

The elaboration of new standards specific to burned cadavers is probably the more reliable way to achieve sex determination on unknown burned human skeletal remains. Although these osteometric methods are more population-specific than the morphognostic approach, they are not as impaired by heat-related fragmentation. The reliability of methods based on sexually dimorphic morphology improves with the increase of features being analysed. This means that several of these features must be preserved to allow for a reliable determination of sex – a scenario seldom available when dealing with burned skeletal remains. In contrast, osteometric methods require only the preservation of one feature to allow for the diagnosis of sex. In the case of logistic regression, this method additionally allows to estimate the odds regarding the accuracy of that diagnosis. Univariate methods are therefore extremely advantageous on skeletal assemblages so poorly preserved as burned bones because it enhances the chance of achieving sex determination.

4.4. Skeletal Weights

4.4.1. The Anatomical Identification

The anatomical identification of the cremains was significantly different between both sexes. The burned skeletal remains of males were more extensively identified than females. It is important to note that age had also a significant effect on RAI for females making it more successful for younger than for older individuals. In contrast, age had no such effect on the group of male individuals. The duration of combustion had a statistically significant effect on RAI as well. Bones burned and left to cool overnight were more easily identified according to anatomy than bones burned under other combustion protocols. In addition, males presented higher RAI than females for the 0-100 minutes' time interval.

Anatomical identification was severely affected by heat-related fragmentation. Given the results for RAI, it is safe to say that fragmentation affected differentially females (38.8%) and males (43.5%) on the sample of cadavers. The skeletal remains from females were apparently more prone to fragmentation than the ones from males.

For some reason, male bones seemed to be more resilient to cremation. Considering the old age of the sample used in this investigation, this may be related to the fact that post-menopausal women are usually more affected by osteoporosis than men. As a consequence, bone tissue undergoes architectural rearrangement leading to the loss of skeletal strength (Brickley, 2002; Gonçalves et al, 2011b). This could also explain why significant differences between both female age groups have been found as well. Bone strength derives from the combined effect of toughness provided by collagen and the stiffness provided by its mineral component (Zioupos et al, 1999; Viguet-Carrin et al, 2006). Collagen degradation occurs during life and becomes more severe with age (Zioupos et al, 1999; Viguet-Carrin et al, 2006) so this event boosts skeletal heat-induced fragmentation. The results for the effect of the intensity of combustion followed the results already discussed for the preservation of measurable bone features in section 4.3. RAI was higher for the remains burned and left to cool down overnight. Apparently, bones already cooled were less brittle and therefore less fragmented. As mentioned previously, this very same observation was stated by McKinley (1993) on her own research. Therefore, although maximum temperature had no significant effect on the anatomical identification of bone fragments, the key factor here may be related to the gradual cooling of the remains. Possibly, this allows for some kind of structural re-arrangement of bone which enhances its resilience. It has been reported that bone loses mechanical strength during the decomposition stage of heat-induced transformation which occurs at temperatures between 300º C and 800º C (Thompson, 2004). However, some mechanical strength is regained during the fusion stage which occurs at temperatures above 700º C (Thompson, 2004). However, these analyses have been carried out on already cooled samples (Thompson, 2003) and we do not know if bones were more brittle while heated.

In contrast to the sample of cadavers, RAI was not significantly different in function of sex, duration and maximum temperature of combustion on the sample of skeletons. The pooled analysis of cadavers and skeletons demonstrated that the anatomical identification of the bone fragments from skeletons was significantly more successful than the RAI for cadavers regardless of sex. Such difference may have been related to the different intensities of combustion reported for the two kinds of remains. This was significantly lower for skeletons thus suggesting that its better RAI values may have been related to less destructive cremation procedures.

Fragmentation is not the exclusive result of the cremation process. Although it was not possible to account for the fragmentation caused by the removal of the skeletal remains from the cremator, it appeared to be quite substantial. This was done with a metal rake which forces the remains to fall from platform to platform until being finally assembled inside a metal tray next to the posterior lower gate of the cremator. Such a procedure was therefore responsible for non heat-related fragmentation and probably presented considerable variation from cremation to cremation. Regrettably, this variation was not accounted for on the present research. This variable was certainly important and the analysis would have benefit from its inclusion in the research design. The only way to tackle this issue would be to guarantee a non-destructive recovery of the skeletal remains. However, this would only be achievable under a laboratorial controlled environment which is not a possibility at the reach of any research carried out on commercial crematoria. As a result, the present results must be handled with caution.

Another potential problem regarding this specific investigation is related to the impossibility to calculate the intra- and inter-observer variation. Anatomical identification of bone fragments is a subjective procedure and depends on the skills of the observer. This is especially true when dealing with burned skeletal remains for which fragmentation can be extreme. In this investigation, all observations were made by the same observer. The results for anatomical identification presented some variation depending on the degree of fragmentation of the remains and on the time available for their analysis – this varied between 50 and 90 minutes.

Despite the abovementioned problems, the results advocate that females and males are differentially affected by fragmentation, although this was not so at lower intensities of combustion. Nonetheless, the resilience of the skeleton to heat appeared to depend on sex and age related idiosyncrasies.

4.4.2. The Weight of Cremains

Females and males were significantly different regarding the weight of their burned skeletal remains. In addition, older females were significantly lighter than younger females although no similar event has been detected for males. The intensity of combustion was not significantly related to the differences observed inter- and intra-sex for skeletal weight, although it should be mentioned that the temperature range experimented by the human remains was not representative of low temperature burnings. Therefore, a comparison based on a more representative sample was not carried out. All these observations applied to both cadavers and skeletons, although the mean weights of these two groups were considerably different.

Skeletal weights have already been investigated in previous researches (Sonek, 2002 In Bass and Jantz, 2002; McKinley, 1993; Warren and Maples, 1997; Bass and Jantz, 2002; Chirachariyavej et al, 2006; Van Deest et al, 2011; May, 2011). However, recent investigation carried out in Europe has been almost non-existent. McKinley (1993) was the main exception and analysed the cremains weight of 15 individuals (9 males and 6 females) with a mean age of 79.1 years-old. At some point, the author accounted for weights excluding the 2 mm fraction and this procedure was followed in the present research. However, the results obtained for the Portuguese sample were quite different from the ones obtained on the British sample. McKinley (1993) obtained 1271.9 g for the female mean weight and 1861.9 g for the male mean weight. This implies that the female and male cremains on the Portuguese sample were, respectively, 380.5 g and 576.9 g heavier than the cremains from that previous study. Like for the Portuguese sample, McKinley's sample was also quite aged and this could eventually explain their small weight. However, even the >70 years-old age group in the present research was considerably heavier than the results obtained by McKinley.

As for earlier work, Malinowski (1969) also presented results regarding the mean weight of cremains which was of 1539 g for females and of 2004 g for males. However, he did not mention clearly the methodology used for the weighing nor the amount of individuals composing the Polish sample. Herrmann (1976, In Duday et al 2000) obtained a mean weight of 1700 g for 226 females and of 1842 g for 167 males on a sample from Germany.

Other researchers have presented results for the weight of cremains. Most of them carried out their investigations on populations from the United States. In these cases, the results referred to the total weight of the remains thus accounting this time for the 2 mm fraction. Therefore, the Portuguese results regarding the total cremains weight including the 2 mm fraction need to be used for the comparison with the American populations. The cremains mean weight for the Portuguese population was of 2226.7 g (n = 51) on the female sample and of 3036.5 g (n = 65) on the male sample. Sonek (1992, In Bass and Jantz, 2004) obtained 1874.8 g for 63 females and 2801.4 g for 76 males from San Diego, California. These results were very similar to the cremains mean weight presented by Warren and Maples (1997) that analysed a sample of 40 females and 51 males with a mean age of 69 years-old from Florida. Female mean weight of the cremains was of 1840 g and male mean weight was of 2893 g. Therefore, the Portuguese samples were approximately 300 g heavier than those two samples.

Still in the United States, Bass and Jantz (2004) obtained a mean weight of 2350 g for 155 females with a mean age of 70.7 year-old. Also, an average weight of 3379 g for 151 males with a mean age of 62.8 years-old was obtained on this sample from the Tennessee. The results from Van Deest et al (2011) presented similar mean weights on another Californian sample from Chico. The mean weight was of 2238.3 g for females (n = 363) and of 3233 g for males (n = 365). The mean age-at-death of the females was of 76.1 years-old and of 71.4 years-old for the males.

Another study was carried out in Thailand which found an average mean weight of 2120 g for 55 females with a mean age of 73.3 years-old and of 2680 g for 55 males with a mean age of 63.5 years-old (Chirachariyavej et al, 2006). All the remains were weighed including both the bones and the < 2 mm fraction. The female skeletal weight on the Thailand population was thus quite similar to the one from the Portuguese sample. In contrast, males from the latter were 300 g heavier.

Given all the researches regarding the weight of cremains, it becomes clear that a considerable variation has been reported until now. Three major factors have been recurrently pointed out to explain this variation in previous studies – sex, age and regional differences (McKinley, 1993; Warren and Maples, 1997; Bass and Jantz, 2002; Van Deest et al, 2011; May, 2011). Significant sexual dimorphism concerning skeletal weight was indeed found for these studies regardless of age differences being considered or not. The analysis carried out on the Portuguese sample was no exception. In this case, sexual dimorphism was more prominent for the oldest age group as was demonstrated by the effect sizes regarding the testing of differences on the cremains weight excluding the 2 mm fraction. The magnitude of the difference for the >70 years-old age group was larger than for the younger group.

An important effect of age on the skeletal weight of burned remains has been previously documented by several researchers (Malinowski and Porawski, 1969; McKinley, 1993; Bass and Jantz, 2004; Chirachariyavej et al, 2006; May, 2011; Van Deest et al, 2011). For the Portuguese sample, the remains of older females were significantly lighter than the remains of younger females but the same result was not detected on the male sample. This contrasts with the results from Bass and Jantz (2004) and from May (2011) that found a statistically significant decline on cremains weight in both females and males. For the first research, the loss of weight on females was twice as much as the weight loss observed on males. The contrasting result could be related to the old age of the Portuguese sample which did not allow for the compilation of younger age groups. Such procedure could have eventually led to different results.

McKinley (1993) suggested that the decrease in female weight could be related to increased bone loss during cremation. The present research indeed confirmed that female weight of cremains was significantly smaller for older females. This fact is mainly related to the antemortem loss of bone mineral density in older women (Lindsay et al, 1992; Riggs et al, 2004) and was documented on other researches regarding unburned skeletal weights (Silva et al, 2009). An eventual increased bone loss related to the cremation process was not specifically investigated by this research on a Portuguese sample. However, it is possible that the lesser resilience to fragmentation of the older age group would have resulted on relatively larger < 2 mm fractions thus suggesting that old aged females experience more bone loss. However, the mean weight of the < 2 mm fraction was not significantly different between both female age groups therefore suggesting a contrasting scenario. Nonetheless, this result is not completely reliable because the < 2 mm fraction includes other kinds of remains besides bone – charred wood from the coffin and clay residues loosened from the cremator.

Regional differences have been suggested as accountable for the variation regarding the weight of cremains. Bass and Jantz (2004) refer the obesity rate as a possible explanation for the different results obtained for the Tennessee (23.0%), Florida (18.2%) and Californian states (19.5%). May (2011) also refers to higher reported levels of obesity and body weight for Tennessee in comparison with the other states. However, this factor alone is not able to explain the very dissimilar values reported for the two Californian samples. In addition, the similar values reported for the Tennessee and the Chico Californian sample do not fit into the hypothesis regarding the regional differences. Table 4.4.1 shows that the Thai have the lowest mean body mass index (BMI) and mean stature. It also indicates that these parameters are lower for the Portuguese population in comparison to the British and American populations (Padez, 2003, 2007; McDowell et al, 2008; Seubsman and Sleigh, 2009; Health Survey for England, 2009; World Health Organization). It should be noticed that the values presented for the stature of the Thai and the Portuguese males refer to young military recruits while the values presented for the British and Americans refer to samples drawn from the entire population. The regional differences hypothesis could for instance explain the contrasting results presented between the Portuguese and American samples – < 2 mm fraction included. However, it does not help explaining the heavier cremains of the Portuguese sample when compared to the British sample, although we must bear in mind that the latter is small in size so results may not be sufficiently representative of the entire population. Given this scenario, although regional differences most likely have an effect on the weight of cremains, other factors probably contribute for the explanation of differential burned skeletal weights. Differences regarding the approaches used for the weighing of the remains, the age composition of the samples or the kind of containers in which the cadavers were cremated are probably also related to the contrasting results regarding burned skeletal weights.

Table 4.4.1: Mean body mass index (BMI) and mean stature for the Portuguese, American and British populations.

	Portuguese		American		British		Thailand	
	BMI	Stature	BMI	Stature	BMI	Stature	BMI	Stature
Females	26.8	-	30.8	162.2 (n = 4857)	27.9	161.5 (n = 2135)	24.1	-
Males	26.9	172.1 (n = 42584)	30.0	176.3 (n = 4482)	28.1	175.4 (n = 2077)	23.1	169.2 n = 1000)

The effect of the intensity of combustion on the cremains weight was not completely understood on the Portuguese sample. Although duration of combustion was apparently a significant factor when interacting with other variables such as sex and age, the exact nature of that effect was not determined due to the small size of the sample. Nonetheless, it became clear that its effect was not as powerful as those other factors suggesting that the final weight of cremains was not significantly affected by the length of the cremation. In addition, the maximum temperature reached by the cremator had no significant effect on the weight of cremains as well. However, the effect of temperature was probably concealed by the composition of the Portuguese sample because 98.3% of the cadavers have been burned at temperatures ranging from 800 to 1050º C. Therefore, a comparison with cadavers burned at lower temperatures was not carried out. This could have led to different outcomes. If nothing else, the results at least demonstrated that bone weight was not significantly affected by temperature beyond the 800º C marker. This corroborates the results from Mayne Correia (1997) and Thompson (2004) indicating major weight loss during the decomposition stage at temperatures lower than 800º C.

It is important to note that the cremains weight of skeletons were significantly lighter than the cremains weight of cadavers for both sexes. Apparently, population differences were not present between the samples of cadavers and skeletons because both were composed of Portuguese contemporary individuals. Although only the female cremains weight was negatively correlated to age on the present research, other researches (Bass and Jantz, 2004; May, 2011) found the same pattern for both sexes. In theory, an older skeleton sample could thus lead to heavier weight in comparison to a younger cadaver sample but no such scenario was found. The mean age-at-death for skeletons was of 72.7 years-old (n = 44). This was similar to the mean age-at-death obtained for the sample of cadavers (mean = 71.2; n = 51), so age composition of the sample was apparently unrelated to the mean weight differences regarding both samples.

Another explanation for the contrasting weight of the cremains of cadavers and skeletons can be related to differential fragmentation. Hypothetically, a more severe fragmentation of skeletons could have led to relatively larger < 2 mm fractions thus explaining their significantly lighter skeletal weights. However, these fractions represented only 17.5% of the total weight of skeletons while the same represented 21.9% of the total weight of cadavers. These values are quite close to the mean percentage of 19.4% (n = 15) obtained by McKinley (1993). Therefore, fragmentation also does not seem to explain these results.

Soft tissues provide for some protection against fire and heat (Pope and Smith, 2004), so a direct comparison between cadavers and skeletons is inevitably biased. The explanation for the smaller weight obtained for the skeletons may be related with the protection that soft tissues confer to bones. If the intensity of combustion has a real effect on weight, the bones from fleshed cadavers are less vulnerable to heat than skeletons during the earlier stages of the cremation and therefore possibly experience less weight loss. In fact, a similar effect may have been present for heat-induced shrinkage. As was seen for the osteometric sexual dimorphism, the size of skeletons was systematically smaller than the size of cadavers despite these differences not being significant. Although plausible, this explanation is merely speculative given that none of the data directly supports it.

The analysis of burned skeletal weights brings one main benefit to bioanthropological research. Weight is an analytical data that is not affected by heat-induced fragmentation. Therefore, it has an advantage over other procedures based on the number or on the size of bone fragments which are sometimes used to report skeletal fragmentation or bone representation. However, the use of the weight of cremains to estimate some parameters such as sex or such as the minimum number of individuals is not straightforward and should be addressed with special caution. Only the crossing of bone weight data with other kind of data – such as osteobiographic information – can strengthen any inference based on burned skeletal weights. Human behaviour regarding the processing of burned remains can interfere severely with the weight of cremains. For instance, the funerary behaviour of archaeological populations was not uniform. The depositional modalities of the remains could be very diverse – sometimes guaranteeing the extensive burial of the remains and some other times neglecting a major fraction of them. As a result, the correct estimation of the minimum number of individuals present in a given assemblage is certainly the stepping stone from which any other kind of estimations based on skeletal weight can be achieved. This is so both for the archaeological and forensic arenas.

4.4.3. Skeletal Representation

Given that the results indicated a significant sexual dimorphism according to the weight of cremains, it was not surprising to find a similar result for the analysis according to bone category on both samples of cadavers and skeletons. However, their relative representation on the remains was not significantly different between females and males for about half of the bone categories. Therefore, although males were heavier, these differences tended to fade away or to become less substantial when the absolute weights were turned into percentages. Nonetheless, the proportions of female post-cranial bone categories were generally smaller while the skull had a larger representation for females than for males on the sample of cadavers. As for skeletons, the females presented larger relative representations of the skull, the vertebral column and the os coxae.

When the representation of main skeletal regions was considered, sexual differences were found for all regions but the trunk on the sample of cadavers and for the cranium and lower limbs on the sample of skeletons. Following the results for the skull, the cranium was the only region significantly more represented in females than in males. In addition, results indicated that, as expected, the proportion of each skeletal region improved with the increase of the RAI. Although the same occurred for the cranial region, the improvement was not as substantial thus suggesting that the successful identification of cranial fragments was less dependent of fragmentation. In addition, when the mean proportions were tested against the results obtained on unburned skeletons by Silva et al (2009), less significant differences were found for the cranial region than for all other regions. This also suggested that the anatomical identification of cranial fragments and respective representation on the skeletal weight were not as affected by fragmentation as were the trunk and the limbs.

The contrasting cranial representation between both sexes has been found previously for unburned skeletons (Silva et al, 2009). Although the absolute weights of each skeleton were not reported for each sex, the results from Silva et al (2009) – turned into percentages – allow concluding that the relative cranial proportion of females was larger than males (Table 4.4.2). We do not know if this difference was statistically significant but it should be so because sexual differences were statistically significant for all bone categories according to Silva et al (2009). The reverse scenario was seen for the remaining skeletal regions. In both samples, the trunk had similar representation in both females and males and a substantial difference between both sexes was present for the upper limbs. As for the lower limbs, the difference was larger for the burned samples than for the unburned sample. Given this comparison, the larger representation of the female cranium was apparently not related to the cremation process. In contrast, it is apparently inherent to our species and it is still detected on burned skeletal remains.

The anatomical identification of bone fragments was demonstrated to be more successful for the cranium than for other skeletal regions. Two results led to this conclusion. First, the variation in cranial representation according to RAI was not as large as for the trunk and the limbs. The percentage of these was much more positively correlated to the increase of RAI. Another finding was that the cranial representation was much more similar to the observations reported for unburned skeletons (Silva et al, 2009). In fact, no statistically significant difference was found between this and the sample of burned skeletons with a RAI of 55-78%. Therefore, the discrimination of cranial fragments was very comprehensive even if only about 3/5 of the remains were successfully appointed to a skeletal region.

The present work has important implications for archaeology regarding the distribution of the skeletal regions in order to interpret funerary behaviour (Grévin, 1990; Duday et al, 2000; Blaizot and Georjon, 2005; Richier, 2005; Gonçalves, 2007; Gonçalves, 2010). The aim has been to estimate the distribution of each skeletal region on cremains and to compare it with natural anatomical weight proportions. Hypothetically, contrasting proportions would indicate intentional selection of bones from the pyre to be included in the burial of the remains. For instance, a cranial representation of 9% – about 10 points smaller than the mean relative weight obtained by Silva et al (2009) – would suggest that the cranium had been somewhat neglected for burial. Until now, all weight comparisons have been done according to weight references developed from unburned skeletons with special preference for the work of Lowrance and Latimer (1957, In Krogman and Işcan, 1986). These references seem to be relatively suitable for the analysis of cremains presenting extremely good rates of anatomical identification (Richier, 2005). However, it is unlikely that they can be reliably applied to cremation burials presenting poor anatomical identification of bone fragments. In fact, the present research demonstrated that the analysis of cremains based on the weight references provided by Lowrance and Latimer (1957, In Krogman and Işcan, 1986) led to an inflated misclassification of assemblages with poor anatomical identification. In these cases, there was a tendency to classify the skeletal regions as under-represented on several cremains although the sample was composed of the almost complete remains of each individual. In other words, a normal skeletal configuration was known to be present in each tested skeletal assemblage but the un-calibrated method – based on Lowrance and Latimer (1957, In Krogman and Işcan, 1986) – failed to detect it thus confirming that those weight references are inadequate for assemblages with low RAI.

In order to solve that problem, regression equations were created to predict the proportion of the cranium, the trunk and the limbs from the RAI. The principle behind this operation was that more unsuccessful anatomical identification of bone fragments lead to smaller proportions of the skeletal regions. As a result, it was demonstrated that the equation of linear regression predicted the expected percentage of each skeletal region with a significant degree of accuracy. Therefore, it has potential for the interpretation of archaeological assemblages of cremains. At the very least, it was more reliable than the skeletal proportions calculated from unburned skeletons (Lowrance and Latimer, 1957, In Krogman and Işcan, 1986; Silva et al, 2009). This is so because it is better adjusted to deal with extreme fragmentation by calibrating itself according to the rate of anatomically identified bone fragments. This calibrated method allows for two approaches based on intervals according to the standard deviation. The results suggested that the ±1SD approach is only reliable to find tendencies regarding over- and under-representation of skeletal regions. The ±2SD is more conservative and thus more reliable to detect strongly atypical burials. Nonetheless, even a clear atypical distribution of skeletal regions does not constitute an absolute evidence of intentional behaviour. Any explanation linking this to a given skeletal configuration will be necessarily speculative.

It is important to note that some problems can be associated to the new calibrated method. For instance, the analysis of the cremains was not comprehensive due to time constraints. Therefore, the sample did not report values for RAI above 78% which could impair its prediction power on cases with extremely good anatomical identification of bone fragments. To tackle this problem, the results from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) and Silva et al (2009) were included to the sample from which the linear regressions were calculated so that the full skeletal proportions of non fragmentary skeletons could also act on the prediction power of the equation.

As stated previously, no inter- and intra-observer error has been estimated regarding the anatomical identification of the cremains so the replicability and repeatability of this procedure is unknown for now. The regression equations were obviously based on the author’s own skills regarding the anatomical identification of bone fragments which have been more successful for the cranium, followed by the trunk, then by the upper limbs and finally by the lower limbs. However, this may differ from researcher to researcher. Although unlikely, it is possible that some researchers are more at ease at identifying burned trunk fragments than burned cranial fragments. This may interfere with the prediction power of the linear regression but the variation regarding the anatomical identification is probably not very substantial and should be mitigated by the standard deviation. Nonetheless, only the replication of this research may confirm if the differential anatomical identification of bone fragments obtained on this research was typical or not.

Table 4.4.2: Relative proportions of each skeletal region for unburned and burned skeletal remains. Results from Silva et al (2009) were adapted from absolute skeletal weights reported in Kg.

	Cranium		Trunk		Upper Limbs		Lower Limbs	
	Females	Males	Females	Males	Females	Males	Females	Males
Silva et al (2009)	21.0%	17.7%	16.9%	16.8%	16.2%	18.3%	45.5%	46.3%
Burned Cadavers	13.6%	11.9%	6.1%	6.5%	4.9%	6.4%	15.0%	18.4%
Burned Skeletons	17.7%	14.8%	9.9%	9.5%	6.4%	8.3%	17.5%	20.1%

In some cases, the predicted proportion may be so small that the ±2SD intervals will lead the lower bound to be below zero. In those cases, the use of the ±1SD intervals is recommended when possible and researchers should limit themselves to state that the skeletal representation tends to be atypical. If even then the lower bound happens to be below zero, this alone should be interpreted as a sign of atypical representation.

The development of the calibrated method for the prediction of the proportions of each skeletal region brings several advantages regarding the bioarchaeological analysis of cremation burials. Most importantly, it provides for relative weight references that allow for more reliable analyses of cremains. As a result, it is proposed that it can be systematically used by researchers thus contributing for the standardization of analytical procedures regarding burned skeletal remains which has been a major problem for bioarchaeological research. Although its reliability needs further and independent investigation to be validated, the results obtained on this research demonstrated its better adjustment to the analysis of cremains when compared to the un-calibrated references previously used. Expectantly, the calibrated method will lead not only to the additional investigation of cremation burials in the future but also to the re-examination of contexts already investigated in the past. In some of these cases, the proportions of the skeletal regions were analysed according to un-calibrated weight references. In other cases, such an examination was not even added to the analytical methodology due to the uncertainties regarding this procedure. From now on, it is possible to systematically use the calibrated method to carry out more reliable intra- and inter-sites comparisons.

5. Conclusion

5.1. Review of the Investigation

This research was carried out in a modern crematorium and produced new and precious results regarding the effect of heat on bones and its consequent implication for bioanthropological analysis. The objectives presented in the introduction – and now re-addressed in this section – were successfully attended despite some problems and factors which have influenced the results and can, to some degree, affect the conclusions drawn from them. The analytical approach relied on the mere observation of skeletal remains from contemporary cremations. This approach is very advantageous since it recreates burning events on actual human skeletons which otherwise are difficult or even impractical to carry out. Because of that, research done on modern burned human skeletal remains is actually quite rare nowadays. On the down side, this approach regrettably does not profit from the advantages regarding the implementation of controlled conditions usually provided by any experimental research. However, the latter would not provide for a comprehensive perception of the burning of human skeletal tissue because it would hardly allow for the assemblage of such a large sample as the one used in the present investigation. In addition, the combustion conditions produced by a modern cremator do not fully reproduce those found in archaeological or forensic contexts so the results may not be entirely comparable with both these situations. Despite this, the observation of modern cremations is still the best practical way of understanding the effect of heat on the human body.

Although the total sample of skeletons examined under this study was rather large, fragmentation sometimes led to smaller samples to be available for a number of observations. Unfortunately, this affected the significance of some results. Even so, this research was based on some of the largest samples ever assembled so the knowledge obtained from it constitutes a precious contribution for the still barely explored field of burned bone. The teachings provided by this investigation bring new prospects concerning the interpretation of the post-mortem processing of human remains, the biological profiling of unknown burned individuals and the funerary behaviour and practice of archaeological populations. All of these issues thus contribute for the refinement of the analytical and interpretative skills of bioanthropologists which have been and continue to be recurrently challenged while investigating burned skeletal remains because of the extreme fragmentation and the misleading heat-induced alterations that can be found in this kind of material.

On a first stage, the potential of heat-induced warping and thumbnail fracturing for the determination of the pre-cremation condition of the remains – fleshed versus dry bones – was investigated. This objective was achieved by accounting the prevalence of these features on a sample of cadavers and a sample of skeletons. In fact, it was demonstrated that their occurrence was much more frequent for the former than for the latter and may thus be helpful, although not indisputable, indicators of the pre-cremation state of the remains. Therefore, the results obtained on this topic are quite relevant for the interpretation of the post-mortem processing of human remains. It now becomes clear that some of the assumptions made previously about the pre-cremation condition of the remains based on heat-induced features are not straightforward and require some reviewing.

Another objective of this thesis was to determine the impact of heat-induced dimensional changes on skeletal sexual dimorphism and on the potential of osteometric sex determination. This was investigated in calcined bones that – theoretically – presented substantial amounts of dimensional changes. Nonetheless, the results showed that sexual dimorphism was still significant enough to allow for reliable osteometric sex determination and that this could be achieved through three distinct methods, although with rather different accuracies. The prospects resulting from this specific investigation are extremely important for the assessment of the biological profile of unknown individuals.

The third main objective was to assess the potential of skeletal weights and skeletal proportions for bioanthropological and bioarchaeological analyses. Reference weights for the Portuguese population were documented in function of each sex as well as of skeletal proportions. Regression coefficients based on the rate of anatomically identified bone fragments were then calculated in order to determine the expected proportion of each skeletal region according to the relative amount of anatomically identified bone fragments. The regression equations were tested on both modern and archaeological samples and the results strongly indicated that they are quite valid for the interpretation of funerary behaviour and practice.

In summary, the teachings obtained under this research are quite innovative and contribute for more enlightened upcoming investigations regarding burned skeletal remains.

5.2. Implications for Analytical Protocols

The new insights provided by this research lead to subsequent recommendations for attaining more reliable bioanthropological courses of action. In the case regarding the use of heat-induced features as indicators of the pre-cremation condition of remains, the results corroborate and thus confirm some previous investigations that pointed out to their inherent ambiguity (Buikstra and Swegle, 1989; Spennemann and Colley, 1989; Whyte, 2001; Gonçalves et al, 2011b). Ideally, the determination of the pre-cremation condition of human remains should not be carried out from the recording of the presence of heat-induced warping and thumbnail fracturing alone, but also be observant of other evidences such as the representation of skeletal elements – being either relatively complete or relatively incomplete – and the presence or absence of clothing-related objects or other evidences for the whole presence of the skeleton. These clues can suggest whether or not the skeleton was already disarticulated when submitted to cremation. Although such procedure is also relevant for archaeological contexts, this is especially so for forensic cases in which the circumstances of death and the post-mortem handling of the remains are of the utmost importance.

As for the sex determination, many authors stated that osteometry had a limited potential on burned skeletal remains (Dokladal, 1962; Strzalko and Piontek, 1974; Rosing, 1977; Holck, 1986; Thompson, 2002 and 2004; Fairgrieve, 2008). Although this is still somewhat true, this investigation demonstrated that sex can nonetheless be estimated on calcined bones with reasonable accuracy thus following the findings of previous researches (Gejvall, 1969; VanVark, 1975; Schutkowski, 1983; Schutkowski and Herrmann, 1983; Holland, 1989; Van Vark et al, 1996). Morphological features should be preferentially used for sex determination, but fragmentation often impedes this approach which relies on multivariate analysis. Therefore, the combination of morphological and osteometric methods is very likely to be required when dealing with cremains.

Although some of the osteometric standards – regarding cut-off points and regression coefficients – here provided were tested on small samples, the results strongly point to their validation. Therefore, its application is at least practicable on burned skeletal remains from contemporary individuals of Portuguese ancestry. Logistic regression is especially useful because it allows for the reporting of the probability of an assessment being correct by simply using a logit transformation table. On the other hand, the adoption of correction factors in order to calibrate standard references developed on unburned skeletons may be of some use on calcined bones although the testing revealed differential success among the standard measurements that were monitored. On this subject, the 10% correction factor proposed by Buikstra and Swegle (1989) appears to be quite suitable for typically white calcined bones. In theory, this conclusion can be extrapolated to all human populations besides the Portuguese – as long as standard metric references for unburned skeletons are indeed available – because heat-induced dimensional changes are most probably not population-specific. Those references must be up to date because, for what it has been observed on this research, slight secular trends interfere substantially with correct sex classification. Of course, this issue is more complicatedly addressed on archaeological populations for which specific metric references are usually not developed. Also, the use of correction factors on pre-calcined bones was not tested and therefore no sustained recommendations involving osteometric techniques can be proposed. Although the results pointed to a mean 4% shrinkage, the dynamics regarding the heat-induced dimensional changes in pre-calcined bones is more variable than this figure alone demonstrates since both reduction and increase in size were detected.

Skeletal weight should always be recorded on cremains and may often be the only workable data in very fragmentary material. This parameter may allow for some insights especially regarding the number of individuals represented on a given assemblage, the completeness of the remains, the degree of anatomical identification and the proportions of each skeletal region. The estimation of the minimum number of individuals using skeletal weights is a rather problematic issue because their range of variation is quite large and cremains are often found absent of some of their components. Nonetheless, weight can be suggestive of the presence of more than one individual when the assemblage is unusually heavy. This is probably the single almost fully reliable inference that can be made regarding the minimum number of individuals by using the weight of cremains. Of course, the more conventional methods of estimation of the minimum number of individuals – bone repetition along with age, sex and pathological inconsistencies – should be preferentially used but these may well be fruitless when dealing with cremains.

As for the sex determination, this is as problematic as for the latter issue and due to the same reasons. Although the difference between females and males is statistically significant, the range of variation and the eventual incomplete presence of the skeleton strongly jeopardize such inference. In addition, age-related differences also interfere with that assessment. As a result, only quite heavy cremains from a single individual can be attributed to a male with some certainty but even this is not straightforward. When available, other evidences from the osteological inspection should therefore give support to such estimation.

Skeletal weight can also be an approximate indicator of the completeness of the remains and thus point towards their scattering or deficient retrieval. However, in order to make a correct assessment, this should be made only in well defined single cremains. Also, the current available weight references are from adults. Age-at-death must then be assessed before making any inferences and therefore make sure that these concern only adults.

By using the percentage of anatomically identified bone fragments, it is now possible to calculate the expected proportions of each skeletal region and then make a comparison with the observed proportions. This can pinpoint atypical configurations more reliably than by using references from unburned skeletons such as the ones from Lowrance and Latimer (1957, In Krogman and Işcan, 1986) and from Silva et al (2008). However, this has its own problems. Although it is possible for the researcher to consistently identify atypical proportions of skeletal anatomical regions using this method, proving that this is the outcome of genuine and intentional selection of specific parts of the skeleton from the pyre is a completely different matter. Nonetheless, such inference seems to be sustainable if it is based on patterns found at a more wide-ranged level – like for a necropolis or a specific time period – rather than based on a single burial or on a few burials. Therefore, one of the major advantages of the proposed regression equations – besides supplying references that are specific to burned skeletons – is to provide for a replicable methodology which allows for chrono-cultural comparisons.

5.3. Future Prospects

The approach used in this research was quite successful at tackling the issues that were being dealt. The analysis of modern cremations from individuals for which the age and sex was known allowed for the collection of valuable data that otherwise would hardly be obtainable. Nonetheless, it became clear that such an approach also has its own frailties. First of all, it has to submit itself to the requirements that are obviously associated to commercial cremations. This means that the researcher has no control over the parameters of the combustion and that these are adjusted according to the needs of each cremation. Therefore, it can be said that all cremations were somewhat different due to specific durations, temperatures and oxygen intakes besides the evident differences regarding each individual that also influence combustion. As a result, the cremations are not fully comparable with each other. On the bright side, this variation had the advantage to provide for a very comprehensive portrayal of human cremation under variable conditions. Nonetheless, further research should also profit from controlled experimental endeavours on human skeletons in order to complement the results obtained by using the approach taken during this investigation. That raises important ethical questions but experimentation on cadavers is recurrently carried out in order to answer to some research questions from varied scientific fields that otherwise would not be possible to address. The same happens with the effect of heat-induced changes on bioanthropological methods. Although sometimes impractical, there seems to be no better way of having a valid insight into human bone specificities than investigating human bone itself rather than using other species. This approach should thus be followed more frequently in the future.

Regarding the topic of the potential of heat-induced features for the determination of the pre-cremation condition of the remains, this research was not able to investigate the possible effect of collagen preservation on the prevalence of warping and thumbnail fractures. Such investigation must be done experimentally by measuring collagen preservation on bones previous to cremation and then account for its association to the occurrence of those features. This would contribute greatly for the understanding of bone heat-induced changes.

The amount of individuals composing the sample examined for the topic of osteometric sexual dimorphism was relatively small for some of the standard measurements that were monitored during the investigation. The test-samples used for the validation of the recommended cut-off points and logistic regression coefficients were also somewhat small and sometimes unevenly balanced according to sex. Therefore, the enlargement of these samples must be carried out in order to provide for more insightful and reliable information regarding their validation. As for the calibration method by using the correction factor of 10% recommended by Buikstra and Swegle (1989), its testing on other populations beside the Portuguese must be done in order to confirm or dismiss the results obtained in this very same thesis. In addition, other osteometric standards for calcined bones that are specific to other than Portuguese populations must be developed.

As for the skeletal weights, the issue concerning the proportions of the skeletal regions is the more debatable one. The regression coefficients are based on the author’s own skills at anatomically identifying burned bones on a limited amount of time. These may vary from one researcher to another so inter-observer variation must be assessed in order to verify for the robustness of the regression equations. Further research similar to this one may solve this problem and eventually improve the coefficients that were here proposed.

As all other scientific productions, this one does not constitute a final product. Only the additional research can contribute for the refinement of the results and recommendations that were presented. Hopefully, similar works will be published in the following years that may help establishing comparisons with this one and allow for a more insightful understanding of the topics that were dealt in this thesis.

5.4. Final Remarks

Although the research field regarding burned bone had a reluctant start and struggled throughout many decades, it is now becoming an increasingly dynamic and solid area of investigation in biological anthropology. Burned bones constitute a large amount of the human skeletal remains found in both the archaeological and forensic arenas and can not be subject to the disregard and neglect that granted them a marginal role in bioanthropological research for so long. Anthropologists seem to have found refuge on the wrong and often heard notion that “nothing or almost nothing can be done with burned bones” in order to avoid researching this kind of material, despite important work developed in the Past demonstrated just the opposite. Fortunately, such inflexible stand is becoming less frequent and we can certainly expect new and incisive work in this field in the years to come.

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APPENDICES

Table A1: Descriptive and inferential statistics for the absolute mean weights of each bone category according to sex on the sample of cadavers (in grams).

Bone	Sex	n	Mean	SD	Median	Range	Value	Sig.	Effect Size
Skull	Female	29	234.58	66.31	213.80	236.70	540.0	.015	-.26
	Male	55	280.13	79.03	268.50	416.30			
Mandible	Female	29	9.87	6.67			-4.137	.000	1.00
	Male	55	17.74	9.01					
Vertebral Column	Female	29	77.02	39.85			-3.452	.004	.81
	Male	55	111.59	45.48					
Ribs	Female	29	35.65	19.56			-3.655	.000	.90
	Male	55	56.93	27.91					
Scapulae	Female	29	8.81	5.78	8.40	21.00	417.5	.000	-.39
	Male	55	16.01	10.74	13.10	54.50			
Clavicles	Female	29	5.79	4.20	4.20	16.40	483.0	.003	-.32
	Male	55	10.32	8.59	8.10	50.20			
Humeri	Female	29	41.38	18.74	35.20	66.30	326.0	.000	-.48
	Male	55	75.00	35.55	72.50	160.60			
Radii	Female	29	11.86	7.08	11.70	24.30	343.5	.000	-.47
	Male	55	22.46	11.54	20.60	66.50			
Ulnae	Female	29	15.64	10.41			-3.184	.002	.79
	Male	55	26.08	15.94					
Hand	Female	29	5.23	3.18	4.80	12.80	233.5	.000	-.58
	Male	55	11.25	4.93	10.80	19.90			
Os coxae	Female	29	50.74	29.71	49.50	114.10	423.0	.000	-.38
	Male	55	85.52	43.05	85.10	160.90			
Femora	Female	29	123.90	52.46	101.70	182.20	357.0	.000	-.45
	Male	55	189.27	72.33	178.90	281.50			
Tibiae	Female	29	44.75	23.62	38.90	92.30	208.0	.000	-.61
	Male	55	96.88	40.22	95.40	172.00			
Fibulae	Female	29	12.32	7.86	10.80	26.00	357.5	.000	-.45
	Male	55	23.29	13.15	20.90	68.10			
Foot	Female	29	37.21	17.93			-5.306	.000	1.24
	Male	55	61.00	20.32					

Table A2: Descriptive and inferential statistics for the percentage mean weights of each bone category according to sex on the sample of cadavers (in %).

Bone	Sex	n	Mean	SD	Median	Range	Value	Sig.	Effect Size
Skull	Female	29	13.04	2.66			3.113	.003	-.71
	Male	55	11.15	2.63					
Mandible	Female	29	0.54	0.34	.51	1.43	566.0	.29	
	Male	55	0.71	0.34	.58	1.71			
Vertebral Column	Female	29	4.18	1.95			-.364	.717	
	Male	55	4.32	1.50					
Ribs	Female	29	1.92	0.91	1.89	3.15	666.5	.218	
	Male	55	2.22	0.96	2.15	4.01			
Scapulae	Female	29	0.49	0.29	.44	.98	633.0	.122	
	Male	55	0.63	0.37	.59	1.96			
Clavicles	Female	29	0.33	0.23	.23	.92	664.0	.209	
	Male	55	0.41	0.35	.30	2.25			
Humeri	Female	29	2.29	0.90	2.55	3.53	561.0	.026	-.24
	Male	55	2.99	1.35	2.94	6.06			
Radii	Female	29	0.65	0.37	.62	1.33	547.0	.018	-.26
	Male	55	0.88	0.42	.80	2.35			
Ulnae	Female	29	0.88	0.60	.67	2.36	660.5	.197	
	Male	55	1.05	0.64	.92	3.05			
Hand	Female	29	0.28	0.16			-3.999	.000	.97
	Male	55	0.45	0.19					
Os coxae	Female	29	2.74	1.38			-1.774	.080	
	Male	55	3.31	1.43					
Femora	Female	29	6.83	2.33			-1.147	.255	
	Male	55	7.47	2.45					
Tibiae	Female	29	2.50	1.23	2.41	5.34	378.0	.000	-.44
	Male	55	3.89	1.56	3.94	6.38			
Fibulae	Female	29	0.66	0.35			-2.682	.009	.63
	Male	55	0.91	0.44					
Foot	Female	29	2.04	0.85					
	Male	55	2.45	0.83			-2.136	.036	.49

Table A3: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting cranial representation (cadavers)

Model	β	SE β	Beta	t	Sig.
Constant	5.139	1.610		3.191	.002
Sex	-2.348	.524	-.395	-4.479	.000
Age	.014	.016	.075	.864	.390
RAI	.188	.029	.573	6.526	.000

Table A4: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting the representation of the trunk (cadavers)

Model	β	SE β	Beta	t	Sig.
Constant	2.125	1.379		1.541	.127
Sex	-.174	.449	-.037	-.388	.699
Age	-.026	.014	-.175	-1.888	.063
RAI	.147	.025	.559	5.945	.000

Table A5: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting the representation of the upper limbs (cadavers)

Model	β	SE β	Beta	t	Sig.
Constant	-1.732	1.019		-1.700	.093
Sex	.746	.332	.158	2.250	.027
Age	-.014	.010	-.095	-1.374	.173
RAI	.193	.018	.740	10.576	.000

Table A6: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting the representation of the lower limbs (cadavers)

Model	β	SE β	Beta	t	Sig.
Constant	-5.532	1.500		-3.688	.000
Sex	1.777	.488	.177	3.639	.000
Age	.026	.015	.083	1.739	.086
RAI	.472	.027	.849	17.568	.000

Table A7: Descriptive and inferential statistics for the absolute mean weights of each bone category according to sex on the sample of skeletons (in grams).

Bone	Sex	n	Mean	SD	Median	Range	Value	Sig.	Effect Size
Skull	Female	31	233.24	62.49			-2.162	.035	.56
	Male	30	270.35	71.44					
Mandible	Female	31	15.03	8.78			-3.068	.003	.80
	Male	30	23.69	12.94					
Vertebral Column	Female	31	101.13	39.91			-2.366	.021	.61
	Male	30	131.17	57.91					
Ribs	Female	31	43.26	21.31			-2.654	.010	.68
	Male	30	58.60	23.81					
Scapulae	Female	31	15.69	9.70	14.90	39.00	299.5	.017	-.31
	Male	30	22.50	12.15	18.25	51.60			
Clavicles	Female	31	9.05	4.68			-3.376	.001	.88
	Male	30	14.19	7.02					
Humeri	Female	31	34.67	22.48	26.30	77.90	227.0	.001	-.45
	Male	30	63.41	35.26	54.20	154.70			
Radii	Female	31	14.25	9.11	12.70	35.80	223.5	.000	-.54
	Male	30	25.38	13.13	25.55	47.30			
Ulnae	Female	31	13.28	8.13			-3.790	.000	.99
	Male	30	23.25	12.10					
Hand	Female	31	8.00	4.96	6.90	20.50	172.0	.000	-.54
	Male	30	18.89	12.45	16.60	49.70			
Os coxae	Female	31	48.45	28.38	43.80	108.60	361.0	.134	
	Male	30	65.03	40.94	52.40	173.60			
Femora	Female	31	99.15	61.29	82.10	269.60	208.0	.000	-.48
	Male	30	171.17	82.39	159.05	306.30			
Tibiae	Female	31	62.75	45.54	48.90	147.40	318.5	.035	-.27
	Male	30	87.36	46.52	74.10	211.60			
Fibulae	Female	31	9.28	6.45	8.30	25.60	221.5	.000	-.45
	Male	30	17.28	10.44	16.55	49.50			
Foot	Female	31	39.61	20.85	35.50	101.50			
	Male	30	63.96	30.74	60.80	145.60	221.0	.000	-.45

Table A8: Descriptive and inferential statistics for the percentage mean weights of each bone category according to sex on the sample of skeletons (in %).

Bone	Sex	n	Mean	SD	Median	Range	Value	Sig.	Effect Size
Skull	Female	31	16.62	5.51			2.520	.014	-.66
	Male	30	13.66	3.38					
Mandible	Female	31	1.05	.60	1.01	2.20	400.5	.352	
	Male	30	1.18	.59	1.10	2.35			
Vertebral Column	Female	31	6.92	1.90			.810	.421	
	Male	30	6.47	2.45					
Ribs	Female	31	2.88	1.08			-.108	.915	
	Male	30	2.91	.98					
Scapulae	Female	31	1.07	.64	.99	3.23	422.5	.540	
	Male	30	1.11	.49	1.05	2.02			
Clavicles	Female	31	.60	.24			-1.372	.172	
	Male	30	.70	.31					
Humeri	Female	31	2.34	1.33			-2.137	.037	.55
	Male	30	3.12	1.53					
Radii	Female	31	.92	.44	.90	1.55	325.5	.044	-.26
	Male	30	1.27	.65	1.25	2.20			
Ulnae	Female	31	.89	.48			-1.965	.054	
	Male	30	1.17	.60					
Hand	Female	31	.54	.26			-3.739	.000	1.00
	Male	30	.92	.50					
Os coxae	Female	31	3.30	1.79			.304	.762	
	Male	30	3.16	1.65					
Femora	Female	31	6.68	3.51	5.58	14.03	334.0	.059	
	Male	30	8.40	3.46	8.08	11.54			
Tibiae	Female	31	4.06	2.59			-.364	.717	
	Male	30	4.28	1.98					
Fibulae	Female	31	.59	.34			-2.517	.015	.65
	Male	30	.85	.46					
Foot	Female	31	2.64	.99					
	Male	30	3.15	1.26			.334	.081	

Table A9: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting cranial representation (skeletons)

Model	β	SE β	Beta	t	Sig.
Constant	10.347	2.482		4.168	.000
Sex	-3.007	1.106	-.316	-2.719	.009
RAI	.142	.046	.361	3.103	.003

Table A10: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting the representation of the trunk (skeletons)

Model	β	SE β	Beta	t	Sig.
Constant	1.074	1.218		.882	.382
Sex	-.631	.543	-.107	-1.162	.250
RAI	.172	.022	.708	7.663	.000

Table A11: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting the representation of the upper limbs (skeletons)

Model	β	SE β	Beta	t	Sig.
Constant	-3.574	.880		-4.060	.000
Sex	1.673	.392	.286	4.266	.000
RAI	.193	.016	.797	11.882	.000

Table A12: Multiple regression analysis summary for age, sex and rate of anatomically identified bone fragments predicting the representation of the lower limbs (skeletons)

Model	β	SE β	Beta	t	Sig.
Constant	-7.843	2.267		-3.460	.001
Sex	1.965	1.010	.137	1.946	.057
RAI	.493	.042	.827	11.776	.000

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