Annex C

Anthropology Report
Dr. Julie Ann Roberts
16 December 2013
Anthropology Report

Report of Julie Ann ROBERTS BA (Hons), MSc, PhD

Occupation Forensic Anthropologist and Archaeologist at Cellmark Forensic Services
Unit B1, Buckshaw Link, Ordnance Rd, Chorley, Lancashire, PR7 7EL

Dated the 7th day of January 2014

Signature………………………………………………………………………………

Laboratory Reference Number: CFS/917413/13
Customer Reference: Mortonhall Crematorium Investigation

Contents of Report

1. Qualifications and Experience 2
2. Background and Introduction 3
3. Request 4
4. Scope and Purpose 5
5. Technical Note 5
6. Skeletal Development in the Foetus and Infant 6
7. The Cremation of Human Remains 13
8. The Cremation Process: Survival of Foetal and Infant Remains 15
9. Conclusions 24
1. Qualifications and Experience

I have been employed as Scientific Lead and Team Leader for the Anthropology, Archaeology and Ecology Department at Cellmark Forensic Services since September 2010. I hold a Doctoral degree (PhD) in the subject of Forensic Anthropology from the University of Glasgow, a Master of Science degree (MSc) in Osteology, Palaeopathology and Funerary Archaeology from the University of Sheffield, and a Bachelor of Arts degree (BA Hons) in Archaeology and Ancient History from the University of Manchester.

I have worked as a Biological Anthropologist and Archaeologist for approximately 19 years and I have approximately 15 years forensic casework experience, specialising in the excavation and examination of decomposed, burnt, fragmented and commingled human remains from scenes of crime. I specialise in the analysis of fragmented, burnt and commingled bone and I have undertaken research on the taphonomy of burnt human bone, and the colour changes and fracture patterns which occur as bone is burnt. I researched and examined Bronze-Age cremation burials at Glasgow University for approximately eight years and have published extensively on this subject in archaeological journals. I have undertaken a wide range of forensic casework relating to burnt human remains which includes the recovery, examination and reconstruction of burnt, fragmented and commingled remains from fatal fires in houses, cars, aircrafts and military vehicles. I have also recovered, examined and reconstructed burnt fragmented bone from victims of war crimes, terrorist incidents, individual and multiple homicides in the UK where bodies have been burnt in attempts to dispose of evidence. I have examined burnt adult and juvenile bone from archaeological and forensic contexts and have also been required to distinguish between burnt human and non human bone from fatal fires and large bonfires. I have produced numerous witness statements relating to burnt and fragmented remains and given evidence in court and at inquest on my anthropological examinations of burnt remains.

I am registered with the College of Policing and National Crime Academy as an Expert Advisor in Forensic Anthropology and Archaeology and I am a member of the Home Office Forensic Provision Expert Panel advising UK DVI on Forensic Anthropology. I am a member of the Forensic Science Society, the British Association of Biological Anthropologists and Osteoarchaeologists, the British Association for Forensic Anthropology and the British Association of Human Identification. I am a lecturer and board examiner for the Diploma in Forensic Human Identification, run by the Faculty of Forensic Law and Medicine, Royal College of Physicians.
2. Background and Introduction

This report relates to findings from the Rosendale Investigation initiated on 10\textsuperscript{th} of December 2012 by Mike Rosendale, Head of Schools and Community Services, on behalf of City of Edinburgh Council. It was set up in response to questions raised by SANDS Lothians, a local stillbirth and neonatal death charity (Bruce, 2013, 2). The concerns related to the cremation of babies (foetuses, neonates and infants) at Mortonhall Crematorium and practices surrounding the recovery of their ashes. These concerns were prompted by the response to an enquiry made to the Bereavement Services Manager at Mortonhall about the cremation of a child 26 years ago. The parent had been informed at that time that no ashes had been recovered, but examination of the records kept at Mortonhall indicated that ashes had been interred in the Crematorium’s Garden of Remembrance. The subsequent media coverage led to a large number of enquiries from bereaved parents seeking to establish whether ashes had been recovered from the cremation of their babies. The findings of the investigation can be found in a document dated 15\textsuperscript{th} January 2013 (Bruce, 2013).

Fundamental to this anthropology report are apparent discrepancies in the information given to bereaved parents which relate to the survivability of foetal and neonatal remains following cremation. The Mortonhall Investigation found current national guidelines issued by The Institute of Cemetery and Crematorium Management (ICCM) indicated that parents “...should be informed that there might not be any ashes resulting from the cremation” (Bruce, 2013, Appendix 1: 2). They also identified that the Federation of Burial and Crematorium Authorities (FBCA) guidelines were in agreement with this, emphasising parents must be informed that “when a baby is cremated there are sometimes no ashes recovered. This depends on the length of the gestation period, with the likelihood of recovery of ashes increasing with the length of gestation” (\textit{ibid}).

Both of the above statements make it clear that parents should be informed of the potential for no ashes to be recovered (or that there might not be any ashes\textsuperscript{1}), but it is also implicit in the same guidelines that the reverse could be true, i.e. there could be survival of ashes depending on the gestation period of the baby. With this in mind, the following observation is particularly

\textsuperscript{1} The term “ashes” used in this context requires clarification as does the difference between there being no ashes and no ashes being recovered. See Sections 7.1 and 8.1
significant: “Information provided to bereaved parents by NHS Lothian in May 2012 indicated that “there will be no retrievable cremated remains of your baby following cremation at Mortonhall Crematorium” (ibid: 3). This statement is very definite regarding the survival and recovery of ashes from this particular Crematorium and it includes no caveat relating to the age of the foetus as provided by the FBCA. There is further conflicting information relating to the crematorium:

“At Mortonhall, prior to May 2011, parents and carers were advised that the recovery of ashes could not be guaranteed. However, the paper based records in use before 2001 generally indicate that recovered ashes were interred in the Garden of Remembrance. Computer based records introduced in 2001 and still in use indicated that there were generally no ashes” (ibid).

It is not at all clear from the above information whether foetal and infant remains did survive cremation and / or the recovery process at Mortonhall and if they did, where the remains were interred and what information the parents were given. Clarification of all these issues is not within the scope of this report which addresses only certain aspects of the investigation. The key findings from the preliminary investigation which are of direct relevance to the expert anthropology report relate to the survival of foetal and infant remains during and after the cremation process, working practices surrounding the type of cremator used and recovery of ashes from the cremators.

3. Request
In January 2013, I was approached by Dr Marjorie Turner, Consultant Forensic Pathologist at the University of Glasgow, on behalf of the Right Hon Dame Elish Angiolini, DBE QC, in relation my expertise in the analysis of cremated remains. Dr Turner asked if I would be able to provide assistance to Dame Elish who is leading an independent inquiry into the cremation of babies at Mortonhall Crematorium. I agreed that I would be able to assist and there followed a series of telephone conversations between myself, Dame Elish and Claire Soper, a member of the Mortonhall Investigation Team.

On the 17th October 2013, together with David Hartshorne, Commercial Director at Cellmark Forensic Services, I met with Dame Elish and Claire Soper at the Principal’s House, St Hughes
College, Oxford. During the meeting it was identified that the expert opinion of an anthropologist could assist the investigation by providing accurate information on the following:

- The development and ossification of the human foetal and neonatal skeleton
- How the human body (bones and soft tissue) are modified by the cremation process
- The gestation period at which the foetal skeleton is able to survive the heat it is exposed to during cremation
- Factors which affect the survival of the skeleton post-cremation
- How the type of cremator used and the methods of recovery of remains from it would affect the survivability of the bones

4. Scope and Purpose of Report

In order to address the areas outlined above it was agreed that the anthropology expert report would contain an assessment and review of the following.

1. Skeletal development in the foetus and infant
2. The cremation process, how it affects the body and the skeleton
3. The survivability of foetal and infant remains during and after cremation
4. The relationship between the survival and recovery of remains and the methods used to cremate them and retrieve them from the cremator
5. The accuracy of current advice provided by funeral directors and / or crematoria staff

Point 4 would take into consideration information provided by the combustion expert Dr Clive Chamberlain and a review of photographic images of cremated foetal remains from the private crematoria at Warriston and Seafield in Edinburgh.

5. Technical Note

5.1 Appendices and archive

A diagram of a neonatal skeleton is provided for reference purposes in Appendix One, a glossary of terminology used in the report is provided in Appendix Two, a list of sources of metric data for foetal and infant remains is provided in Appendix Three, and a bibliography of texts referred to in this report can be found in Appendix Four. A full record of the work undertaken within the laboratory in relation to this work has been retained in the archive at
Cellmark Forensic Services, Chorley, and this can be made available on request providing sufficient notice is given.

5.2 Terminology relating to foetal age
It should be noted that there is a difference between gestational and conceptional or fetal age. Gestational age refers to the length of pregnancy after the first day of the last menstrual period (LMP) and is usually expressed in weeks and days. Conceptional age is the true fetal age and refers to the length of pregnancy from the time of conception (Mongelli, 2012). Fertilisation can not occur till ovulation has occurred approximately 14 days after the first day of the menstrual period. As such conceptional age is always approximately two weeks behind gestational age (ibid). Gestational age is more frequently used because the actual day of conception is often unknown, whereas the LMP can usually be determined. For further terminology relating to foetal and infant age see Appendix Two.

5.3 Comparative Data and Related Research
A great deal of the literature relating to cremated bone is based on experimental research using archaeological human remains or modern animal remains. This information covers a range of topics and is easily accessible. However, primarily for ethical reasons, there is has been little research involving modern cremated human adult remains and even less focusing on foetal and infant remains. Because of this there is hardly any scientific data available for reference purposes when it comes to providing an evidence based opinion on the survival of foetal remains during and after cremation. When considering the survivability of foetal remains during and after the cremation, the limited reference data must therefore be supplemented by knowledge of skeletal development, how cremation affects the body, visual examination of relevant images from modern crematoria and familiarity with findings from research on non-human and ancient human remains.

6. Skeletal Development in the Foetus and Infant

6.1 Development and ossification of the foetal and infant skeleton
Bone develops from the primitive mesenchymal tissue of the embryo in a process called ossification. There are two types of ossification; intramembranous and endochondral (Scheuer and Black, 2000: 21-24). The essential difference between the two is the presence or absence of a cartilaginous phase.
In intramembranous ossification there is direct mineralisation of a highly vascular connective tissue membrane. Some of the mesenchymal cells differentiate into osteoblasts at primary ossification centres and they secrete new bone matrix which calcifies. This occurs in some of the flat bones of the skull, the facial bones, the mandible and the clavicle (Scheuer and Black, 2000: 21-22; Gray, 1977: 1168).

In endochondral ossification a cartilage template composed mainly of collagen is first formed out of the tissue membrane. Osteoblasts sitting just beneath the outer membrane of the cartilage deposit bone around the outside of the cartilage shaft, this membrane develops into the periosteum and produces compact bone. At the centre of the cartilage model, the cartilage is removed by chondrocytes, there is infiltration of blood vessels and mineralisation occurs forming the cancellous bone. Osteoclasts which are active on the inner surface of the bone work in apposition to the osteoblasts, removing and remodelling bone so that it can increase in diameter (Scheuer and Black, 2000: 24; White and Folkens, 2005: 46). Bones formed by endochondral ossification include the limb bones, the vertebrae, the ribs and the basi-cranium \textit{(ibid, Sanders, 2009)}.

Two types of bone are formed during intramembranous and endochondral ossification; compact and cancellous (also known as cortical and trabecular respectively). Compact bone is composed of parallel columns along the long axis of the bone and it forms the shaft or cortex (outer surface) of the bone. Cancellous bone is arranged in a lattice structure orientated along the lines of stress and it provides structural strength within the bone. Cancellous bone is laid along fibres of the mesenchyme and compact bone is laid beneath the periosteum (Biswas and Iqbal, 1998: 57).

The bone has to grow lengthways as well as in diameter and in the long bone this is achieved by means of a growth plate at the end of the shaft of the bone. New bone is deposited between the growth plate, also known as the epiphyseal plate, and the end of the diaphysis (the shaft) which is termed the metaphysis. (White and Folkens, 2005: 46). Once the baby is born, secondary sites of ossification develop within the cartilaginous epiphyses which are separated from the metaphysis by the growth plate. Controlled by hormones and genes and influenced by other factors such as health and nutritional status, bone growth continues at the metaphysis until such a time that it has reached its predetermined size. Cells at the growth plate then stop dividing and the primary and secondary sites of ossification (the main part of the bone and the epiphysis) fuse together in a process called epiphyseal fusion or closure (Biswas and Iqbal,
1998: 59; White and Folkens, 2005: 47). Epiphyses will ossify and fuse at different ages in different bones from early infancy through to the age of up to 25 – 29 years when the medial end of the clavicle finishes development (Scheuer and Black, 2000).

On a molecular level, bone tissue is a composite of organic and inorganic material, protein and mineral. The protein is collagen which constitutes about 90% of the bones organic content. The mineral component is hydroxyapatite, a form of calcium phosphate. Crystals of this mineral impregnate the collagen matrix to form a weave of protein and minerals. The mineral component gives the bone its hardness and rigidity, whilst the protein component is rubber-like and flexible (White and Folkens, 1991: 19). The composition of bone is highly relevant when considering the effects of cremation on bone and expectations regarding its survival of the process.

Scheuer and Black cite the clavicle as being probably the first bone in the human body to show evidence of bone development in the sixth week of foetal life (2000: 23). In a study of ossification of the limb bones in 728 foetuses ranging in age from 8 to 26 weeks, Bagnall et al. found that primary ossification centres showed at approximately 9 weeks of conceptional age (Bagnall et al., 1982). They also observed that there was a predictable order to this ossification whereby the centre of the humerus appeared first followed by the femur, radius and ulna which appeared simultaneously, the tibia and then lastly the fibula (ibid).

The rate of growth differs between the upper and lower limb bones. In early development the upper limb bones are longer than the lower limb bones due to their earlier ossification and faster growth rates (Sanders, 2009: 6). From 19 weeks gestation until birth, however the lower limb bones grow faster than the upper limb bones and the reverse becomes true (ibid). Studies have shown that there are also differences between the growth rates of bones on the right and left sides of the body in utero, with growth of the humerus, tibia and fibula being favoured on the left side and growth of the femur being favoured on the right (Bagnall et al., 1982). In terms of recognition of skeletal elements, Scheuer and Black (2000) note that by 12-13 weeks gestation bones such as the femur are distinct enough for identification (Sanders, 2009). This is also illustrated by the data in Table One.

In terms of weight of the skeleton, this increases with age during the foetal period and continues to increase after birth at approximately the same rate until the early teens (Trotter and Hixon, 1974). The greatest proportionate contribution to total skeleton in the foetus is the skull (ibid).
Table One summarises the maximum lengths of some of the bones which are easily identifiable in the foetus and infant. References for individual sources are given in Appendix Three. The majority of the data is derived from a collection used by Fazekas and Kosa (1978) which comprised 138 spontaneously aborted white European foetuses. The measurements were taken from dry bone as opposed to ultrasound scans, and age is given in weeks. This age was taken from maternal history and it is not specified whether this means weeks in conceptional age or weeks in gestational age. A commentary by Schutkowski (1987) on the collection (which he used for his research into sex determination of foetal skeletons) refers to their age in lunar months which equates to gestational age (Black, 2000:6).
Table One: Measurements of unburnt foetal and infant bones

<table>
<thead>
<tr>
<th>Age</th>
<th>Maximum Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occipital*</td>
</tr>
<tr>
<td>Weeks</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2.7</td>
</tr>
<tr>
<td>14</td>
<td>4.0</td>
</tr>
<tr>
<td>16</td>
<td>5.9</td>
</tr>
<tr>
<td>18</td>
<td>7.7</td>
</tr>
<tr>
<td>20</td>
<td>9.5</td>
</tr>
<tr>
<td>22</td>
<td>10.6</td>
</tr>
<tr>
<td>24</td>
<td>11.8</td>
</tr>
<tr>
<td>26</td>
<td>13.1</td>
</tr>
<tr>
<td>28</td>
<td>14.1</td>
</tr>
<tr>
<td>30</td>
<td>14.7</td>
</tr>
<tr>
<td>32</td>
<td>17.0</td>
</tr>
<tr>
<td>34</td>
<td>19.3</td>
</tr>
<tr>
<td>36</td>
<td>20.8</td>
</tr>
<tr>
<td>38</td>
<td>23.4</td>
</tr>
<tr>
<td>40</td>
<td>26.5</td>
</tr>
<tr>
<td>Perinatal</td>
<td>65.2</td>
</tr>
<tr>
<td>Months</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>(0-6m)</td>
</tr>
<tr>
<td>9</td>
<td>(0-6m)</td>
</tr>
<tr>
<td>12</td>
<td>(7-12m)</td>
</tr>
<tr>
<td></td>
<td>54.1</td>
</tr>
</tbody>
</table>

*Cranial bone, pars lateralis

**6th Rib chosen as a typical rib
6.2 Factors affecting development and maturation of the skeleton

Rates of increase in the size and maturity of bones differ between the sexes and this is evident before birth. There is also a difference in the timing of ossification of bones and mineralisation of teeth (Scheuer and Black, 2000:4). In their research Bagnall et al. (1982) observed that the female foetus is in advance of the male in terms of skeletal maturation after 21 weeks. After birth skeletal maturity continues to be more advanced in girls than boys but bone mineral density is significantly less in girls than boys, the latter having a higher mineral density and larger long bones (Scheuer and Black, 2000: 4)

Sanders (2009) summarised a number of studies which focused on femoral lengths of neonates and foetuses of different ancestries. In one study (n=450), it was found that the femur length of Indian neonates was significantly longer than that of Malaysian and Chinese neonates (Lim et al., 2000 in Sanders, 2009: 18). In another study which took femoral measurements by ultrasound from 39 Asian, 31 black, and 100 white foetuses of 15 to 20 weeks gestation, it was found that the femur lengths of the Asians were shorter than expected and those of black fetuses were longer than expected. (Ship, 2001 in Sanders, 2009: 18).

In a research project which examined the weight, density and percentage ash weight of bones from foetuses through to elderly adults (see Section 8.1), Trotter and Hixon (1974) found that the unburnt bones of Negroid foetuses were on average heavier than those of the Caucasoid foetuses and the bones of the males were generally heavier than those of the females. These differences were not statistically significant, but there were significant differences between the lengths of the Negroid and Caucasoid long bones, the former being longer than the latter in four types of long bone tested. (ibid).

Factors such as maternal health and nutrition, disease and environmental pollution can all affect the growth and development of the skeleton in utero and in infancy (Scheuer and Black, 2000: 5). Indeed, Lobo and Zhaurova (2008:) stated that “It is difficult to overemphasize the importance of prenatal environment to a developing fetus ”. They were speaking with reference to birth defects in particular but they did include skeletal malformations in these, for example, the increased risk of cleft lip and/or palate, stillbirths and low birth weights associated with smoking during pregnancy. It is worth bearing in mind when looking at unburnt and burnt foetal skeletal remains that the pregnancy may have ended in spontaneous abortion or stillbirth because the baby was not developing normally. As such the bones may be smaller and perhaps not as well developed as they would be in a healthy foetus of the same gestation.
6.3 Dental development

Although teeth are not part of the skeleton it is important to mention their development in this context as they are capable of surviving the temperatures attained during the cremation process, particularly when they are unerupted and protected by the jaw.

The onset of tooth formation starts with the first deciduous incisor between 14 and 16 weeks after fertilization (15 and 17 weeks gestation). This is followed 2 weeks later by the second incisor and then a week after that the canine starts to form. Deciduous first molars are initiated around 15 weeks after fertilisation and second molars 3-4 weeks after that when the foetus is in its 18th -19th week of life (Hillson, 2002: 121).

In the anterior teeth (the incisors and canine), dentine and enamel is deposited from one central point in the middle of the incisal edge. In the molars, each cusp will develop as a separate cone initially but ridges then spread out from their sides and they eventually join up to form a complete crown. The mineralised occlusal cap of the deciduous first molar is usually complete at birth, but it can be very thin and susceptible to damage. The occlusal cap of the second deciduous molar is not usually complete at 36-38 weeks although the cusps are joined by ridges (ibid: 122).

The first permanent molar also starts forming in utero around 28-32 weeks after fertilization with the lower molars starting to develop slightly earlier than the upper. The other permanent teeth do not start to develop until after birth. The permanent incisors (with the exception of the upper 2nd incisors) are initiated at around 3-4 months followed by the canine approximately one month later. The upper 2nd incisors appear around the end of the first year and the premolars and 2nd molars start to develop in the 2nd and 3rd years (ibid: 125).

Numerous charts and tables providing detailed information relating to crown and root development in the deciduous and permanent teeth have been compiled (Schour and Massler, 1940; Moorrees et al., 1963, in Ubelaker, 1989; Lunt and Law, 1974 in Hillson, 2002; Moorrees et. al. (1963) modified by Smith, 1991, in Scheuer and Black, 2000)

As with skeletal development, girls are in advance of boys, with various studies finding a difference of as much as a year (Hillson, 2002: 125). The difference between the sexes is greater in black girls and boys (double that seen in whites) and black children achieved each stage of dental development on average 5% earlier than white children (ibid).
7. The Cremation of Human Remains
The discussion below focuses solely on the changes which the human body undergoes when it is cremated. It is outwith my sphere of expertise to comment on the technical aspects of the cremation process, for example how the cremator works and various legislation surrounding the cremation process. Expert opinion on this can be found in the specialist statement of Dr Clive T Chamberlain, produced for this investigation and made available to me for reference.

7.1 “Ashes” versus “Cremated Remains”
Before entering into a discussion of the cremation process and its effects on the human body it is useful to consider the terms “ashes” and “cremated remains” The two often appear to be interchangeable in the literature although it could be debated that there are subtle differences between them. It could be assumed that the cremated remains of an individual comprise only the calcined bones which remain following complete combustion (see Section 7.2). However, unless these are all carefully separated out from any extraneous material it is possible that the remains might include other burnt artefacts such as clothing, personal items and a percentage of the coffin (see also report of Dr Clive T Chamberlain).

The term “ash” is defined by The Oxford Compact English Dictionary (OCED) as “the powdery residue left after the burning of any substance” (1996: 52) and the plural “ashes” is defined as “the remains of a human body after it has been cremated” (ibid). If that definition is accepted, then “ashes” are the just the surviving calcined bones of the individual who was cremated and they do not include any other material that was burnt at the same time.

The above discussion has implications for the information given to the parents of babies who were cremated at Mortonhall. For example, it seems highly unlikely that even if a foetus was of a very young gestational age there would be no cremated remains left, if the coffin and personal effects were included in that definition. Skeletal development has already been summarised in Section 6 where it was identified that the process of ossification begins as early as the 6th foetal week of life and individual bones are recognisable at 12 to 13 weeks. The section that follows will include an examination of the stage at which foetal remains are capable of surviving the cremation process and becoming “ashes” which could potentially be returned to grieving parents.
7.2 What happens to the body when it is cremated?

When the body is subjected to extreme heat it will undergo a number of predictable changes; the skin will harden and split, the subcutaneous fat and muscle will burn, there will be dehydration and oxidation of the organic component of the body (including the organic component of bone) and eventually, at temperatures in excess of around 1000 °C, there will be re-crystallisation of the mineral component of the bone (Holden et al., 1995; DeHaan and Nurbakhsh, 2001; McKinley, 1994; Shipman et al., 1984).

As bone is heated, proteins will undergo a process of denaturation. The water that is found in the organic component of bone is removed at between 300 and 500 °C (Harsanyi, 1993 in Fairgrieve, 2010: 138). At temperatures above 700 °C the water contained within the mineral component of bone is also lost and Calcium Oxide (CaO) is formed. It has been suggested that the formation of CaO is linked to skeletal maturity (ibid).

It is important to note that once complete combustion of the organic component of the bone has occurred, the amount of DNA present is much reduced if not lost completely. Standard DNA analysis techniques (eg. STR analysis of nuclear DNA or mitochondrial DNA analysis) used to obtain DNA profiles from unburnt or charred remains have had very limited success when applied to calcined bone, therefore positive identification of the deceased following complete cremation is generally not possible (McDonald, pers. comm.)

Exposure to extreme heat will cause visible changes to bone and, at sufficiently high temperatures, alteration of its microstructure. In laboratory conditions it has been proven that the colour of bone changes progressively and predictably as it is heated. These colour changes range from pale yellow, through to red /brown, black, blue, grey and finally white, when all the organic matter has combusted and the bone is calcined (Shipman et al, 1984; Holck, 1986; Holden et al., 1995).

Studies at both macroscopic and microscopic levels generally agree that under conditions of extreme heat bone shrinks, splits and cracks. There is a wide variation in the degree of shrinkage reported in different studies, with figures ranging from 2 to 25% reduction from the original fresh bone (Nelson, 1992). In the experimentally controlled cases reviewed by Nelson the amount of shrinkage was found to be at the lower end of that range averaging between 3 and 5% (ibid). A study which closely mimicked conditions in a modern crematorium involved the cremation of one half of each of five cadavers in a gas oven with a temperature range of 600 to
1000 C°. From measurements taken on the preserved unburned half compared to the cremated half in the same individual the researcher established shrinkage rates of between 5 to 12% (Dokladal, 1971 in Correia, 1997: 227). With regard to the cremation of juveniles, research has shown that the bones of neonates and infants contract by an average of 10% (Uytterschaut, 1993). In one study it was found that the decrease in bone volume which occurs during cremation was greater in neonates and infants than adults where the percentage reduction never exceeded 13% (Herrmann, 1977 in Uytterschaut, 1993).

Numerous studies have been undertaken examining the fractures which occur as a result of thermal damage to bone (Goncalves et al., 2011; Schmidt and Symes, 2008; Bontrager and Nawrocki, 2008; Buikstra and Swegle, 1989). The majority of experimental studies have shown that burning fleshy bone, as in a modern cremation, typically produces characteristic curved, transverse, thumbnail, and step fractures, deep longitudinal fractures and warping of the bone (Ubelaker, 1989; Bontrager and Nawrocki, 2008; Buikstra and Swegle, 1989). These fractures are easily distinguishable from the fractures caused by mechanical damage following cremation, although they can actually pre-dispose the bone to this type of damage. Some examples of heat induced fractures can be seen on the foetal bones in Images 3, 4 and 6 Section 8.1.

In terms of bone and tooth survival, cancellous bone will shrink but generally retain its shape, whereas compact bone will shatter into small pieces, un-erupted teeth and roots survive while the exposed crowns break apart (Mayne Corriea, 1997:278). The survival of bones and teeth is well documented in archaeological cremation burials of up to c. 4000 years old, even where the remains are calcined, completely mineralised and brittle (Hillson, 2009; McKinley, 1994, 1996; Downes and McGregor, 1995; Roberts, 1995, 1998, 2001; McSweeney, 1995). It has also been proven through archaeological and modern crematoria studies that certain bones are more likely to survive than others and in summary, the denser bones and those well embedded in muscle tissue are found to be most resilient (Mayne Corriea, 1997:278).

8. The Cremation Process: Survival of Foetal and Infant Remains

8.1 The survival of foetal and infant bones during and after cremation

Where ossification has not begun or is in its very early stages, the cartilage or connective tissue prototype for the bone can be lost entirely in the cremation process as all the organic matter in the body is combusted. Once the bone has started to ossify, however, it will undergo broadly
the same changes as adult bone during the cremation processes. That said, there are some differences to take into consideration which relate to the development and maturity of the bone. It has already been noted that neonatal and infant bone loses more volume than adult bone when burnt and some studies found there was a greater degree of shrinkage in foetal bone. Fairgrieve (2010: 138) stated that neonatal bones will burn “more completely” than adult bones and less mineral residue will be left following cremation. This is due to a lack of Calcium Oxide (CaO) in the bones of young individuals as the intermolecular cross-links between the collagen chains have not yet developed (ibid):

It is true for adults that bone mineral density and the weight of cremated bone is affected by age, sex, stature, diet, activity and even geographical location (Van Deest et al., 2011). It follows that some of these criteria would also apply to foetal, neonatal and infant skeletons with more emphasis on the maternal environment (see Section 6.2). Some foetuses and neonates may be smaller than usual or have delayed development for their gestational age and therefore there bones may be more susceptible to damage from the heat and post-cremation mechanical damage.

In terms of gross anatomy, foetal and infant bones are thinner, smaller, less robust and lighter than adult bones therefore they will combust more quickly and at lower temperatures. It has been noted that for an adult the whole cremation process takes on average 90 minutes at a temperature of 1000 C° or more, whilst cremation of an infant or foetus can be completed in 40 to 60 minutes at temperatures of 700 C° (Dunlop, 2004). In the same paper, Dunlop noted that foetal skeletal remains (he does not state gestation period) could be “discerned quite clearly” following cremation at Hull Crematorium (ibid). This is discussed further in Section 8.2.

Direct evidence that foetal remains can survive the cremation process and that skeletal elements are recognisable from as early as 17 weeks gestation (15 conceptual weeks), was obtained from two private crematoria, Seafield and Warriston, currently operating in Edinburgh. There follows an analysis of photographic images from the crematoria (Images 1 to 6 below) provided by Claire Soper from the Mortonhall Inquiry team. They comprise three photographs from Seafield showing the cremated bones of foetuses aged 17 weeks gestation, 20 weeks gestation and full term, and three photographs from Warriston showing the cremated bones of foetuses aged 19 weeks gestation, 22 weeks gestation and full term. Following each image there is a list of the bones which are identifiable in that picture.
**Image 18/1: Seafield, 17 Weeks Gestation (15 foetal weeks)**

This image has been removed from the Report due to its sensitive nature. It is available to view in Production 18 in the folder of photographs held by City of Edinburgh Council. This is Production 18/1.

Bones identifiable on the image include the femur, humerus, mandible, ilium (pelvic bone), the *pars lateralis* and possibly *basilaris* of the occipital bone (skull), radius, ulna, clavicle and a minimum number of 12 ribs. It is likely that the fibula is also present but it is difficult to distinguish clearly.

**Image 18/2: Seafield, 20 Weeks Gestation (18 foetal weeks)**

This image has been removed from the Report due to its sensitive nature. It is available to view in Production 18 in the folder of photographs held by City of Edinburgh Council. This is Production 18/2.

Bones identifiable on the image include the right and left mandible closely associated with the developing crown of an anterior tooth, the humerus, femur, tibia, fibula, radius, ulna, ilium, scapula, clavicle and a minimum number of 15 ribs.
Image 3: Seafield, Full Term Stillborn

This image has been removed from the Report due to its sensitive nature. It is available to view in Production 18 in the folder of photographs held by City of Edinburgh Council. This is Production 18/3.

The image above was slightly over-exposed and the remains were partially obscured by a finger making the individual elements slightly harder to recognise despite their larger size. It was possible however to identify the femur, humerus, ilium, scapula, tibia, possibly an ulna, multiple vertebrae (body and neural arch), a minimum number of 12 ribs and multiple phalanges (fingers and toes).

Image 4: Warriston, 19 Weeks Gestation (17 foetal weeks)

This image has been removed from the Report due to its sensitive nature. It is available to view in Production 18 in the folder of photographs held by City of Edinburgh Council. This is Production 18/4.

There is less separation of the bones from associated debris than seen in the images from Seafield but it is still possible to identify the humerus, femur, clavicle, a minimum number of 14 ribs, possibly a scapula and two long bones that could not be assigned to skeletal element.

Image 5: Warriston, 22 Weeks Gestation (20 foetal weeks)
Bones identifiable on the image include the femur, tibia, fibula, ilium, possible humerus, possible mandible and tooth crowns, unidentified long bones and a minimum of 10 ribs.

**Image 6: Warriston, Full Term Stillbirth**

Bones identifiable in the image above include the femur, tibia, ilum, vertebrae (body and neural arch), metatarsal / metacarpals, phalanges (fingers or toes) and a minimum number of 5 ribs.

Table Two, presents the metric data taken from Images 1 to 6 and compares it to the measurements of unburnt foetal bones of around the same age shown in Table One. An assumption has been made that the ages shown in Table One are gestational age (see previous discussion Section 6.1). The original photographs shown above were taken at different scales and so it was not possible to take comparable measurements from them. In order that the bones could be measured more accurately they were reproduced at the same scale using the ruler in Image 5 and the distance between the grooves in the metal trays which appear in all
images. This rescaling is dependent on the distance between the grooves being approximately the same. It should also be emphasised, that in some instances the position of the bones, for e.g. if they were placed at an angle or not lying flat, may have slightly reduced the accuracy of the measurement. Where obvious distortion could be seen, caused either by the cremation process (warping and cracking) or the angle of the photograph or bone, not recordable (nr) was written in the corresponding data field.

Table Two: Comparative measurements of foetal bones from Fazekas and Kosa (1978) reference data, Warriston and Seafield Crematoria. Measurements taken from Images 1 to 6 reproduced at same scale

<table>
<thead>
<tr>
<th>Age (weeks)</th>
<th>Maximum Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clavicle</td>
</tr>
<tr>
<td></td>
<td>FK</td>
</tr>
<tr>
<td>16</td>
<td>16.3</td>
</tr>
<tr>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>19.4</td>
</tr>
<tr>
<td>19</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>22.7</td>
</tr>
<tr>
<td>22</td>
<td>24.5</td>
</tr>
<tr>
<td>24</td>
<td>26.9</td>
</tr>
<tr>
<td>26</td>
<td>28.3</td>
</tr>
<tr>
<td>28</td>
<td>30.3</td>
</tr>
<tr>
<td>30</td>
<td>31.3</td>
</tr>
<tr>
<td>32</td>
<td>36.6</td>
</tr>
<tr>
<td>34</td>
<td>37.1</td>
</tr>
<tr>
<td>36</td>
<td>37.7</td>
</tr>
<tr>
<td>38</td>
<td>42.6</td>
</tr>
<tr>
<td>40</td>
<td>44.1</td>
</tr>
</tbody>
</table>

FK = Fazekas and Kosa, WA = Warriston, SE = Seafield
nr = not recordable due to damage and distortion by cremation or angle of bone/photograph
- = image or bone not present
It can be seen from the table above that the measurements of the unburnt bones in the reference collection and those from Warriston were similar at 18 and 19 weeks. At 20 weeks the reference data and that derived from Seafield were almost exactly the same and that was also the case for Warriston at 22 weeks. A major difference can be seen in the earlier gestational period where the burnt bones from Seafield at 17 weeks were considerably shorter than the unburnt bones at 16 weeks. At Full Term, the reference data and that from Warriston were also broadly comparable, but at Seafield whilst the pelvic measurement was similar to the reference data (although slightly smaller), the humerus and femur were much shorter.

These results have not been statistically analysed and the sample size is small, so on the basis of these findings alone it cannot be determined whether there is a trend for the bones to be shorter than normal at Seafield in the youngest and oldest age categories, or whether the results are anomalous. They could be a true reflection of the pre-cremation smaller size of the foetuses or they could indicate that a greater degree of shrinkage is taking place during cremation. If the latter is true, it has not had a detrimental effect on the preservation of the bones in question, as they appear from the images to be in a very good state of preservation with minimal fracturing caused by thermal or mechanical damage. If the former is true, it could be an indication that the foetus was small for its gestational age. It may even have died in utero some time before the spontaneous abortion or stillbirth occurred.

The above analysis within the context of the Mortonhall Investigation provides direct, visual evidence that multiple individual skeletal elements can be recognised following cremation in individuals as young as 17 weeks. By comparing the metric data to a documented reference collection it can also be seen that in the majority of instances, if cremation is conducted carefully, there is little alteration to the size and shape of the foetal bones (see also Section 8.2).

Experimental research has been undertaken to quantify the percentage of bone (bone ash or calcined bone) remaining in human skeletons following cremation. Trotter and Hixon (1974) studied skeletons from an early foetal period through to old age. This included 124 male and female foetuses of American Caucasoid and Negroid ancestry, which ranged in age from 16 to 44 weeks gestational age. It was possible to record the ash in even the youngest and lightest skeletons, the lightest being a white male of 16 weeks gestation which weighed 3.4 g pre-cremation. Individual percentage ash weights ranged from 58%, a white female, to 72.3% a white male (Trotter and Hixon, 1974: 13). The mean percentage ash weights showed a slight,
but significant increase with age, but no statistically significant differences were found with regard to sex and ancestry (ibid). Although Trotter and Hixon removed any soft tissue from their subjects before cremation, their results for adults were comparable to the findings in research by Bass and Jantz (2004)\(^2\) conducted on fresh cadavers in modern crematoria. The study by Trotter and Hixon is important because it illustrates that even at 16 weeks gestational age (14 weeks true foetal age) there will be survival of calcined bones or “ashes” following cremation.

8.2. The relationship between methods of cremation survivability of remains and recovery of ashes

It has been demonstrated in Section 8.1 that foetal remains of 16 weeks gestation and older can and do survive complete combustion. It is also apparent from the literature and examination of the images from Seafield and Warriston Crematoria that individual bones are identifiable to skeletal element from this age. If that is the case then other explanations must be sought for the apparent absence of ashes in individuals aged > 16 weeks. It seems that there are only three possible explanations:

1. The ashes have not survived the cremation process due to the way in which they were cremated
2. The ashes have survived cremation but they have been destroyed during the recovery process
3. The ashes have survived the cremation and recovery processes but they have not been recognised as human foetal or infant remains

8.2.1 The ashes have not survived the cremation process due to the way in which they were cremated

Details relating to this can be found in the expert report of Dr Clive T Chamberlain. The aspects of cremation which are most detrimental to foetal and infant remains appear to be the jets of air introduced into the cremation chamber and direct heat in excess of 1000 °C (Dunlop, 2004) from support burners. Whereas the weight of adult bones ensures that they are not carried out of the cremation chamber into the secondary combustion chamber, foetal bones are much lighter and so they may be carried through. Ashes are removed from the cremation chamber so if foetal remains have been blown into the combustion chamber then they will not be retrievable.

\(^2\) Bass and Jantz looked only at individuals older aged older than 17 years
Clearly a less vigorous method of cremation would be of benefit when dealing with foetal remains. Lower temperatures of around 600 to 700 °C are recommended by both Dr Chamberlain and Dr Dunlop, a Medical referee at Hull Crematorium. Dunlop also recommends that “no forced air is turned on” (2004: 341) and that the coffin containing the foetus / young infant is placed in a preheated furnace in a corrugated metal tray with sides. Dr Chamberlain refers to modified practices at Seafield Crematoria and trays such as those described by Dunlop can be seen on Images 1 to 6, this report.

8.2.2 The ashes have survived cremation but they have been destroyed during the recovery process

Recovery of foetal and infant ashes is closely linked to the issue of how the remains are contained during cremation. Clearly there is going to be a better chance of recovering all the small bones if they are kept together in a small metal tray which restricts dispersal during cremation. The other area of concern is how the ashes are removed once the cremation is complete. As previously discussed bones become more brittle and fragile once the organic component has been combusted and therefore they are more susceptible to mechanical damage. Usual practice is for the ashes to be raked out of the cremation chamber once they have cooled down (Bass, 2004; Chamberlain, 2013). This process however, is extremely detrimental to delicate foetal and infant bones which may already be fractured due to thermal damage. Further fragmentation in combination with their already small size, could lead to destruction of the bone altogether or loss amongst any accompanying burnt material. A better means of recovery of foetal and infant remains would be to lift them out on a small tray once it has cooled down and then retrieve the bones by hand.

8.2.3 The ashes have survived the cremation and recovery process but they have not been recognised as human foetal or infant remains

The bony parts of the foetal and neonatal skeleton might not necessarily be recognisable as skeletal remains to the untrained eye or inexperienced member of staff. At eleven weeks before birth there are usually about 800 ossification centres, the bony “pieces” of the skeleton and at birth there are approximately 450 centres (White and Folkens, 2005: 47). Whilst some skeletal elements such as the long bones, cranium and ribs are relatively easy to recognise, others such as the incomplete vertebrae, the tarsal bones and any newly developed epiphyses could be

---

3 This is standard practice at Hull Crematorium
confused with other burnt debris. The younger the foetus is, the more difficult it is to recognise the components of the skeleton. There is therefore, a potential risk that crematoria staff might inspect the contents of the cremation chamber and wrongly conclude that there are no ashes surviving. Clearly the issue here is one of training and awareness.

9. Conclusions

Greater clarity and more detail are required in relation to the guidelines currently issued by the Federation of Burial and Cremation Authorities (FBCA) and many individual Crematoria. Currently when discussing the survival of foetal remains and advice to parents, the focus seems to be on gestational age alone. There are clearly more factors than this involved, the key ones being methods of cremation and recovery of remains.

Another important factor to consider is skeletal maturity. It has been demonstrated that foetal bones do survive the cremation process and they can be identified and recovered from at least 17 weeks gestation. Perhaps then the FBCA and crematoria staff should be working towards an anatomical model, focusing on skeletal maturity in relation to gestational age, rather than gestational age per se and viability or non viability of the foetus, when providing advice to bereaved parents.

Key recommendations include:

- Improved training and awareness in foetal development for crematoria staff.
- The use of specially designed cremators for foetal and infant remains and / or the adaptation of methods used in adult cremators.
- Improved techniques for the recovery of foetal remains.
Appendix One: Diagram of the Neonatal Skeleton

[Diagram of the Neonatal Skeleton]

- Parietal
- Frontal
- Temporal
- Maxilla
- Mandible
- Clavicle
- Cervical vertebrae
- Scapula
- Thoracic vertebrae (articulate with ribs)
- Ulna
- Metacarpals
- Sacrum
- Lumbar vertebrae
- Ilium
- Pubic bone and ischium
- Femur
- Tibia
- Calcaneus
- Talus
- Metatarsals
- Phalanges
Appendix Two: Glossary of Terminology

i) Terminology Relating to Age of Baby  
(Scheuer and Black, 2000, Appendix 1)

*Embryo*: The first 8 weeks of intra-uterine life  
*Foetus*: From week 9 to birth  
*Perinatal*: Around the time of birth, from 24 weeks gestation to 7 post-natal days  
*Neonatal*: From birth to 28 days  
*Infant*: From birth to 1 year  
*Pre-term*: from < 37 weeks (258 days) gestation  
*Full-term*: from 37-42 weeks (259-293 days) gestation  
*Post-term*: > 42 weeks (294 days) gestation  
*Stillbirth*: Infant born after gestational period of 24 weeks who shows no signs of life  

*Gestational age*: The number of days or weeks that have passed since the first day of mothers last menstrual period  
*Conceptional age*: The number of days or weeks that have passed since conception i.e. fertilization of the egg.

ii) General Terminology

*Articulate(s)*: Adjacent to and joins with, eg. The bottom end of the femur articulates with the top end of the tibia to form the knee joint or the base of the skull articulates with the 1st cervical vertebra of the neck.

*Basi-cranium*: The bones of the base of the skull

*Body (of vertebra)*: The main part of the vertebra that constitutes the weight-bearing portion of a vertebra

*Cancellous bone* / *Trabecular bone*: Spongy, porous, lightweight bone with a honeycomb structure, found under compact bone e.g. within vertebra, in the ends of long bones,
filling short bones and sandwiched within flat bones. The spaces in cancellous bone are filled with marrow.

<table>
<thead>
<tr>
<th><strong>Chondrocytes</strong></th>
<th>The only cells within cartilage, they produce and maintain the cartilage matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collagen chains</strong></td>
<td>Chains of the specific amino acids which form collagen</td>
</tr>
<tr>
<td><strong>Collagen</strong></td>
<td>The major protein of the white fibers of connective tissue, cartilage, and bone</td>
</tr>
<tr>
<td><strong>Compact bone/</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cortical bone</strong></td>
<td>Solid, dense bone found in the walls of bone shafts and on external bone surfaces including joint surfaces</td>
</tr>
<tr>
<td><strong>Cranium</strong></td>
<td>Bones of the skull excluding the mandible (lower jaw)</td>
</tr>
<tr>
<td><strong>Deciduous (dentition)</strong></td>
<td>the first set of teeth, (milk teeth)</td>
</tr>
<tr>
<td><strong>Dentine</strong></td>
<td>The calcified tissue beneath the enamel in a tooth</td>
</tr>
<tr>
<td><strong>Diaphysis</strong></td>
<td>Shaft of a long bone</td>
</tr>
<tr>
<td><strong>Enamel</strong></td>
<td>The calcified tissue covering the outer layer of the crown of the tooth (smooth outer layer of the tooth)</td>
</tr>
<tr>
<td><strong>Endochondral</strong></td>
<td>The formation of bone within a cartilage model</td>
</tr>
<tr>
<td><strong>Epiphyseal plate</strong></td>
<td>The area of growing tissue at the end of the metaphysis</td>
</tr>
<tr>
<td><strong>Epiphysis</strong></td>
<td>Ends of long bones</td>
</tr>
<tr>
<td><strong>Foramen magnum</strong></td>
<td>Large hole at the base of the skull through which the brainstem passes and turns into the spinal cord</td>
</tr>
</tbody>
</table>
Hydroxyapatite  The calcium containing constituent of bone and teeth

Ilium  Thin bladelike section of one of the two pelvic bones, the part just above the hip socket

Incisal edge  the cutting edge of an incisor or canine tooth

Intermolecular cross-links  The bonds between molecules

Intramembranous  The formation of bone within a membrane in the absence of a cartilage model

LMP  Last Menstrual Period

Mesenchymal  Referring to the mesenchyme or mesenchymal tissue

Mesenchyme  The meshwork of embryonic connective tissue in the mesoderm (the middle of the three cell layers of the developing embryo) from which are formed the connective tissues of the body (including cartilage and bone) as well as blood and the lymphatic vessels

Metacarpals  Long bones of the hand, between the wrist and the fingers

Metaphysis  The expanded, flared ends of long bones, adjacent to the cartilage growth plate and epiphysis

Metatarsals  Long bones of the mid-foot

Neural arch  (of vertebra)  The part of the vertebra which forms the arch behind the body enclosing the spinal cord in life

Occlusal cap  The structure of enamel and dentine when the crown is complete prior to the formation of the root of the tooth
Ossification centre  The site where bone begins to form in a specific bone or part of bone as a result of the accumulation of osteoblasts in the connective tissue.
- Primary  the first site where bone begins to form in the shaft of a long bone or in the body of an irregular bone
- Secondary  centre of bone formation appearing later than a primary centre, usually in an epiphysis

Ossification  The process of bone formation

Osteoblast  A cell from which bone develops; a bone-forming cell

Osteoclasts  A type of bone cell which resorbs bone during bone remodelling and shaping

Pars basilaris  The base part of a bone, in the occipital bone it is the thick, square projection in front of the foramen magnum

Pars lateralis  The lateral part of a bone, in the occipital bone, the parts which lie either side of the foramen magnum and articulate with the temporal bones

Phalanges  Fingers or toes (see appendix one)

Tarsals  Seven irregular shaped bones which articulate together between the lower leg bones and the metatarsals to form the ankle and posterior foot (calcaneus and talus are shown in appendix one)
Appendix Three: Reference sources, measurements of foetal and infant bones

Foetal measurements

Perinatal measurements
Humerus, white male: Adapted from Trotter and Peterson 1969 in Scheuer and Black (2000: 288)
Femur, white male: Adapted from Trotter and Peterson 1969 in Scheuer and Black (2000: 394)
Tibia, white male: Adapted from Trotter and Peterson 1969 in Scheuer and Black (2000: 415)

1-12 months measurements
Clavicle: Adapted from Scheuer and Black (1996) in Scheuer and Black (2000: 252)
Appendix Four: References


Buikstra, J.E. and Swegle, M. 1989. Bone Modification Due to Burning in *Bone Modification*, 1st Volume


Dunlop, J. M., 2004 Cremation of Body Parts and Foetuses


McKinley, J.I., 1994. Pyre and grave-goods in British cremation burials, have we missed something? *Antiquity* (68) pp 132-4


