CHAPTER 1

History of the Study of Burnt Remains

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Currently, many diverse and complex approaches are available for the analysis of burnt human remains, as documented in chapters of this book. However, these methods have been developed slowly over the last few decades. When the first author entered the field of forensic anthropology in the late 1960s and early 1970s relatively few methods were available. At that time, fragmentary burnt human remains were frequently discarded or ignored, with the sentiment that little information could be gleaned through analysis. That attitude has slowly evolved through recognition that although burning and skeletal fragmentation present limitations to analysis, a great deal can be learned with proper training and thoughtful selection of methods. As in other areas of forensic science, the problems presented by casework stimulated innovative research. That research led to new methods of analysis augmenting the information that can be extracted. This chapter examines the historical development of the casework and experimentation that have fed that intellectual and methodological progress. While the entire literature on this subject is too exhaustive to be presented fully, key publications marking that progress are highlighted.

1.1 Early Developments Prior to 1980

In 1949, Wilton Krogman (1903–1987) initiated experimentation on burnt remains in relation to his study of archaeologically recovered materials (Krogman, 1949). In his examination of burnt human remains recovered from a mound in Ohio, Krogman noted that fragments of specific bones could be recognized, but he became curious about the fracture patterns he observed. His curiosity led him to devise experiments to explain the patterns. Using body parts with intact flesh,

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fresh bone with flesh removed, and dry bone he examined fracture patterns resulting from burning utilizing an acetylene torch and a hickory wood fire. He concluded: "it is possible to completely destroy a human body by the use of fire" (Krogman, 1949:89). Key factors were the source of heat and context, exposure of the remains to maximum heat, and agitation of the calcined remains to promote fragmentation. While his complete destruction comment may have discouraged analysis and was subsequently challenged, his work opened the academic door for further research on burnt remains.

Five years later, Baby (1954) published similar research, also stimulated by study of archaeological samples from Ohio. Although offering few methodological details, he reported a "recent test" (Baby, 1954:4) suggesting a difference between dry bones exposed to fire and those exposed with flesh still present. The dry bones presented superficial checking, fine longitudinal striae, deep longitudinal fractures, splintering, and lack of warping. In contrast, those burned with flesh still presented displayed deep checking, diagonal transverse fracturing, and warping. These observations were reinforced by Binford (1963). Wells (1960) followed up this research with observations from modern cremations, noting fragmentation, "tubular curling" (p. 33) and the difficulty of estimating age and sex. In 1963, Gejvall also observed modern cremations and conducted experiments of reburning ancient, cremated bone, noting the resulting attributes of color, fragment size, and issues of determining the minimum number of individuals present.

Research by Van Vark (1970, 1974, 1975) provided more detail on burning effects on human bone. Controlled experiments revealed no shrinkage of bone at temperatures below 700°C. Progressive shrinkage was found at temperatures between 700°C and 900°C, with no further shrinkage at higher temperatures. With mandible samples, he found maximum shrinkage of 16.42%. He also noted that macroscopically, bone became progressively more brittle when exposed to temperatures up to 700°C and assumed a white color at higher temperatures. Microscopic features were less clear between temperatures of 400°C and 700°C, with loss of recognizable structure above 800°C. In similar experiments, Dokládal (1971) reported little shrinkage with the cranium and variation between 5% and 12% with other bones.

Richards (1977) furthered these temperature related experiments and noted the general sequence of soft tissue destruction and bone exposure with temperatures of 680°C and above. This work highlighted that soft tissue protects bone exposure to fire. In such cases, bone exposure and burning effects appear gradually as soft tissue is reduced. For this reason, the skeletal effects of fire exposure can vary with different bones of the body and even within individual bones. Also in 1977, Herrmann elaborated on microscopic changes, noting that above temperatures of 700–800°C bones display loss of organic matter, shrinkage, and fusion of bone mineral crystals. Then in 1978, Dunlop noted that color changes can also be affected by contact with metal, suggesting a correlation of pink color with copper, green with iron, and yellow with zinc.

T.D. Stewart's (1979) classic text, *Essentials of Forensic Anthropology: Especially as Developed in the United States*, summarized much of the research reported above, emphasizing how bones burned in the flesh could be distinguished from those burned as dry bone. He also noted that careful observation of patterns on different bones could reveal the position of the body during burning. This section of the text offered a guide not only for the analysis of forensic cases involving fire but also archaeological discoveries (e.g. Ubelaker, 1997).

1.2 Post-1980 Advanced Experimentation and Casework

In 1981, Thurman and Willmore devised an experiment involving burning of four human humeri with flesh present and four that were fresh but with flesh removed. Those with flesh revealed warping, serrated margins of fracture sites, transverse fractures, and diagonal cracking. The defleshed bone displayed minimal warping and fractures with parallel-sided margins.

Experimentation with burnt remains advanced in 1984 with the Shipman *et al.* (1984) study of mandible and astragalus samples from 60 sheep and goats. The bones were exposed to temperatures ranging from 185°C to 940°C, documenting color change, microscopic alterations, and shrinkage, as well as data from X-ray diffraction. The study further documented color changes and growth in the crystal size of hydroxyapatite. They also noted the importance of the difference between bone temperature and that of the heating device/source.

Also in 1984, Bradtmiller and Buikstra (1984) experimentally examined the effects of burning on human bone microstructure. Using a small electric oven, they exposed bone samples with and without flesh to temperatures up to 600°C for 30 minutes. They found that even at 600°C histological features were still visible. With increasing temperatures, the histological structures osteons increased in size, with a slight impact on age estimation using these structures.

Heglar (1984) emphasized the importance of a team approach to the recovery, analysis, and interpretation of burnt remains and the value of anthropological involvement. These themes also have been stressed subsequently by Bass (1984), Owsley (1993), McKinley and Roberts (1993), Owsley *et al.* (1995), Ubelaker *et al.* (1995), Ubelaker (1999), and Blau and Briggs (2011). Of course, the forensic pathologist also plays an important role (Shkrum and Johnston, 1992; Nelson and Winston, 2006). The matter of recovery of burnt human remains is further discussed in the following chapters of this volume: Pope (Chapter 2), Klales *et al.* (Chapter 3), Berketa and Higgins (Chapter 4).

Chandler (1987) published experimental results of the effects of burning on teeth. This study involved examination of the effect of increasing heat exposure to measurements of roots of mandibular premolars. The following percentages of shrinkage with increasing temperatures were found: 0.88% at 440°C, 1.52% at 525°C, 2.36% at 675°C, 16.9% at 800°C, and 14.0% at 940°C. They also detected variable crown destruction and some root curling. In an electron microscopy study of 60 human premolars and third molars, Wilson and Massey (1987) were able to recognize enamel and dentin structure up to 1000°C, but these tissues changed into a "globular form" with exposure over 800°C, for three hours. Duffy *et al.* (1991) later demonstrated the value of human pulp tissue for sex diagnosis after heat exposure. They also called attention to the key difference between overall fire temperature and that within the tooth. This research was built on more recently when Sandholzer *et al.* (2013) analyzed volumetric tooth shrinkage using high-resolution micro-CT scans, and found shrinkage to range from 4.78% at 400°C to 32.53% at 1000°C.

Recognizing that bone shrinkage following burning varied not only with temperature but also the type of bone, Holland (1989) reported experiments on eight cadavers burned at temperatures up to 500°C. Average shrinkage of the cranial base was less than 2%, indicating that this area of skeletal anatomy was still useful for identification after burning at that temperature. Cavazzuti *et al.* (2019) later reported that despite shrinkage, careful selection of measurements can be useful in estimating sex. Most recently, a systematic study by Rodrigues *et al.* (2021), who experimentally burned human bones at temperatures ranging from 450°C to 1050°C with exposure times of between 75 to 257 minutes, found that the scoring of morphological features for sex determination was already affected at low burning temperatures, whereas metric methodologies were more severely affected at higher burn intensities, but fairly reliable at low to medium intensity burns.

By the end of the 1980s, experience with burnt bodies led Eckert *et al.* (1988) to suggest a protocol for case management. They detailed an approach for inventory, construction of a biological profile, and recognition of variation in thermal effects. Glassman and Crow (1996) later suggested a standardized model for describing burn injuries in human remains. Quinn *et al.* (2014) noted the importance and complexity of related terminology. A revised scoring methodology for describing burnt human remains was described by Williams (Chapter 5).

1.3 The 1990s: New Methods and Case Applications

The 1990s ushered in examination of the use of DNA for identification in burn victims. Sajantila *et al.* (1991) reported successful DNA typing after amplification in ten charred bodies. Tsuchimochi *et al.* (2002) presented a technique for successful extraction of DNA from dental pulp, allowing sex determination from incinerated teeth. The possibilities and challenges of conducting DNA analyses from burnt remains are further elaborated in Zapico (Chapter 12).

With the temporal increase in commercial cremations, legal issues, usually relating to commingling, called for analysis. Murray and Rose (1993) presented an early case study, calling attention to the value of such factors as total weight of cremains, inclusions, container materials, and retention of medical and dental evidence.

Analysis of commercial cremations called for more data on the expected weight of cremains. Warren and Maples (1997) answered this call in 1997 with data from 100 individuals who had been commercially cremated. The weights of adult cremains ranged from 876 g to 3784 g. They found that cremains' weight represented an average of 3.5% of body weight in adults, 2.5% in children, and only 1% in fetuses. McKinley (2000) later described the importance of understanding the cremation process and noted that some pathological conditions can be recognized after cremation. Subsequently, Warren *et al.* (1999) described finding evidence of arteriosclerosis in cremated remains. Brooks *et al.* (2006) reported on the use of elemental analysis to distinguish between cremains and other materials, as did Ellingham *et al.* (2018) who discussed the use of SEM-EDX elemental analysis in cases of contested cremains. General recommendations for the analysis of commercial cremations are provided by Fairgrieve (2008) and Schultz *et al.* (2008).

Further advances involved new techniques of analysis and new technology. Grévin *et al.* (1998) emphasized the value of reconstruction to interpret burn cases. Quatrehomme *et al.* (1998) used scanning electron microscopy of maxillary/mandibular fragments to reveal correlations of exposure temperatures with the patterns observed with this instrument.

Although the fragmentation of bone exposed to fire can limit analysis, research indicates that traumatic injury still can be recognized. Herrmann and Bennett (1999) noted that although difficult, traumatic fractures not related to heat can be distinguished from heat-related fractures. Chop marks can be identified after incineration (De Gruchy and Rogers, 2002) as well as other type of trauma (Pope and Smith, 2004).

Interpretation of burn victims calls for understanding of the combustion process. DeHaan and Nurbakhsh (2001) called attention to the important factor of body fat of the victim in promoting combustion. The body itself, especially body fat, provides fuel for the fire, accelerating combustion from temperatures of 700°C upwards (Ellingham *et al.*, 2016). Other key factors include a porous, rigid char that functions as a wick and a sustained external flame. Christensen (2002) added that bone composition also can be a factor, with osteoporotic bone being more susceptible to fragmentation and color change.

By 2004, Thompson was able to define four stages of heat-induced transformation in bone: dehydration, decomposition, inversion, and fusion, and presented revised temperature ranges for these stages. He also identified the key changes known to take place with heat exposure: color change, weight loss, fracture formation, changes in strength, recrystallization, porosity change, and size change. The following year Thompson (2005) reported experimentation on 60 sheep, documenting these changes more thoroughly and noting that bone can involve both shrinkage and expansion.

In 2006, Bush *et al.* (2006) reported that composite resins in teeth can be detected after incineration. These resins can prove valuable to assist in identification efforts, which is further elaborated on in Bush *et al.* (Chapter 9).

Schmidt and Symes (2008) published an edited volume that summarized methods of analysis of burnt remains at that time. The volume presented many useful chapters, including discussion of changes related to both temperature and duration (Beach *et al*., 2008), the impact of environmental conditions (Walker *et al*., 2008), the association of bone color with depositional history (Devlin and Herrmann, 2008), analysis using isotope ratios (Schurr *et al*., 2008), recovery procedures (Schmidt, 2008), bone destruction patterns (Symes *et al*., 2008), and basic principles of fire interpretation (DeHaan, 2008).

In 2009, Piga *et al*. (2009) turned to X-ray diffraction analysis of 57 human bone sections and 12 molar teeth. They found that an increase in heat led to growth of hydroxyapatite crystallites.

Finally, several recent syntheses focusing on burnt remains set the academic stage for the chapters of this book. Ubelaker (2009) provided such a review summarizing 81 published works. Also in 2009, Thompson summarized methodology in burnt human remains, calling attention to his own important research, as well as that of others.

In 2015, Thompson edited a volume with the focus on burnt remains in funerary studies. In Thompson's volume, Garrido-Varas and Intriago-Leiva (2015) related a case from Chile requiring thermal interpretation. Ubelaker (2015) showed how recent research in thermal effects can be used effectively in forensic case interpretation.

Most recently, Cerezo-Román *et al*. (2017) published an edited volume with an archaeological focus. Chapters provide detail on archaeological approaches and analysis (Williams *et al*., 2017).

1.4 Summary and Conclusions

Throughout the history of the analysis of burnt human remains several themes emerge. The problems and questions presented by casework lead to innovative research designs and experimentation. Results of that experimentation and the information gleaned are fed back into analysis protocols and approaches to new casework. Research is advanced by ideas and hypothesis testing, but also by new technology. The simple observational approaches utilized by such early workers as Krogman, Baby, and Stewart are now supplemented by X-ray diffraction, scanning electron microscopy, isotope analysis, and DNA amplification, just to name a few. Key observations are macroscopic in nature, but also include histological, microscopic, and chemical dimensions. Modern interpretation calls for careful recovery, consideration of context, understanding of the burning process, and then selection of the most appropriate methods of analysis from the many available. Terminology is important, but also complex and somewhat variable among different fields and practitioners. The research process continues and evolves with new technology and good ideas. Just a few decades ago, analysists were reluctant to study burnt remains, feeling that little could be learned. Research demonstrates that even fragmented, calcined remains offer a great deal of information. Such remains offer inviting challenges to contemporary forensic scientists.

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