Differential Diagnosis of Skeletal Injuries

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What are all the possible causes of a pathological condition and which one is the most likely cause?

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Contents

Accuracy in the skeletal diagnosis of injuries around the time of an individual's death relies on the integration of as many lines of evidence as possible. Data from a variety of sources should be used in combination—the anthropologist's examination of the skeletal tissues, microscopic analysis of the affected bone surfaces, radiographic data, the assessment of the individual's clothing, the evaluation of the physical evidence of weaponry, etc. After all the evidence is considered, deduction is used to classify each injury category, identify the mechanism of the injury, and determine the most likely cause of death.

The objectives of this chapter are to demonstrate the techniques for reconstructing fragmented skeletal remains and outline the methodology for identifying skeletal trauma. First, fractures resulting from possible injuries are differentiated from normal skeletal variation and nontraumatic skeletal pathology. Second, a brief overview of fracture classification and mechanisms of injury provide a framework for interpreting trauma data. Third, the timing of fractures is established to differentiate antemortem injuries, perimortem

* Ortner 2003, 4.

trauma, and postmortem modification or taphonomic processes. Fourth, supporting evidence for trauma identification from radiographic data and clothing analysis are presented. Additionally, the characteristics of burned bone and features used to differentiate peri- from postmortem burning and microscopic techniques for interpreting fracture evidence are discussed. (Refer to case study 2.1.)

Reconstructing Skeletal Fractures to Identify Trauma

A postmortem examination of skeletal remains begins with radiography or fluoroscopy,* followed by detailed examination of each bone and associated clothing, to ensure that all evidence, even the smallest skeletal fragments, are recovered. The skeletal remains are washed and laid out in anatomical order. Adherent tissues are removed either through washing or boiling. The anthropologist then reconstructs fractured bones so that the fracture type, pattern, and overall distribution of wounds are evident. Adhesive material is used to bind fractured skeletal remains.† The strongest and easiest adhesives to use are "instant adhesives" or commercial grade cyanoacrylates composed of methyl methacrylate, which are activated with a catalyst or accelerator. This type of adhesive is instantly binding and creates a very strong bond that allows reconstructed skeletal elements to be handled, photographed, and if necessary, radiographed without the need of external support structures. In our experience, this type of glue often remains bonded even after reconstructed skeletal elements are placed in body bags, transported, and later reexamined.

Skeletal reconstructions of fractured remains, depends on the amount and type of fracturing, subsequent warping or deformation due to burial, or other postmortem damage. Experience has shown that creating two units, the face and vault, and then uniting the two segments create an accurate and stable reconstruction. When reconstructing fragmented cranial remains, each bone is put together as completely as possible before uniting different structures to one another. Once each bone is reconstructed, then aspects of the vault should be articulated, beginning with the left and right parietals. The occipital should then be added to the parietals followed in order by the frontal, temporals, and sphenoid. We recommend reconstructing the facial bones by first attaching the nasals and zygomatics to the maxilla. Depending on the location and nature of the fractures, it is sometimes necessary to first attach the zygomatics to the frontal and temporal bones and then add the maxilla. Approaching the cranium anatomically as two units, the vault and the face, and uniting them with the sphenoid create an accurate and strong reconstruction. Figures 2.1–2.2 depicts a cranial reconstruction following a gunshot wound to the skull. Extreme fragmentation is consistent with high-velocity trauma, particularly when multiple injuries are present. Through the reconstruction, the fracture patterns are elucidated and enough information about the injuries is available to accurately interpret the mechanism and number of injuries.

* Although scanning the remains with an x-ray machine or a fluoroscope is recommended, it is not always possible in cases where such equipment is not available. Close examination of remains and clothing will recover metal fragments and is recommended (Baraybar and Gasior 2006).

† It is recommended that samples for DNA or histology are taken prior to the use of adhesives or any chemical agent for processing. The protocol described here for skeletal reconstruction is based on practical experience; varying contexts may require modification to laboratory methods. It may not always be possible to reconstruct skeletal remains due to deformation from burial or incomplete recovery (Refer to Steadman et al. 2006 for discussion of lab methods.)

Figure 2.1 Fractured cranial remains are washed and laid out in anatomical order. Two circular entry wounds are present on the right parietal. The first cervical vertebra is fractured and the left maxilla exhibits a circular defect indicating additional injuries. Extreme fragmentation is consistent with high-velocity trauma. (Printed with permission from International Criminal Tribunal for the former Yugoslavia.)

Figure 2.2a Reconstruction begins with each bone individually. Bones of the vault are joined followed by the face. Fragments are joined posteriorly to anteriorly. The lateral fragments are then added to the vault and face. Pictured here is Edixon Quinones, OMPF (ICTY).

Figure 2.2b The vault is reconstructed and the smaller fragments are added to the vault (ICTY).

Figure 2.2c "Hot glue" adhesive material is used to reconstruct fractured elements together (ICTY).

Figure 2.2d The base of the skull is reconstructed once the calotte is in place. (Printed with permission from International Criminal Tribunal for the former Yugoslavia.)

Reconstruction of the mandible and most postcranial elements tends to be simpler than that of the cranium, although extreme damage in the form of crushing and comminuted fractures may shatter structures, such as areas of spongy bone in the distal femur or lower vertebra. Fractures through thick areas of trabecular bone from crushing mechanisms may be more difficult to reconstruct. Nevertheless, attention to the outer cortex of the remaining bone will often reveal typical wound characteristics that allow the mechanism of the injury to be estimated.

The largest fragments should be reconstructed first, followed by smaller sections of bone added to the primary or larger piece. To begin, investigators work through the fragments, uniting segments into units and then combining the units together. These units may then be combined to whatever extent possible and added to the bone from which it fractured. Figure 2.3 illustrates the reconstruction of a comminuted fracture to the femoral shaft fragmented by a gunshot wound in an autopsy case.

Successful reconstructions are dependent on expert knowledge of osteology and the ability to recognize and position small fragments of bone. Of equal importance is good

Figure 2.3a The projectile penetrated from the lateral aspect of the left thigh and exited through its medial wall, creating a keyhole defect on the anterior wall of the proximal one-third of the femoral shaft. Trajectory of the bullet demonstrates piercing of the femoral artery. (Reprinted with permission from Baraybar, J.P. and Gasior, M. 2006. Forensic anthropology and the determination of the most probable cause of death: an example from Bosnia and Herzegovina. *J Forensic Sci* 51(1): 103–108.)

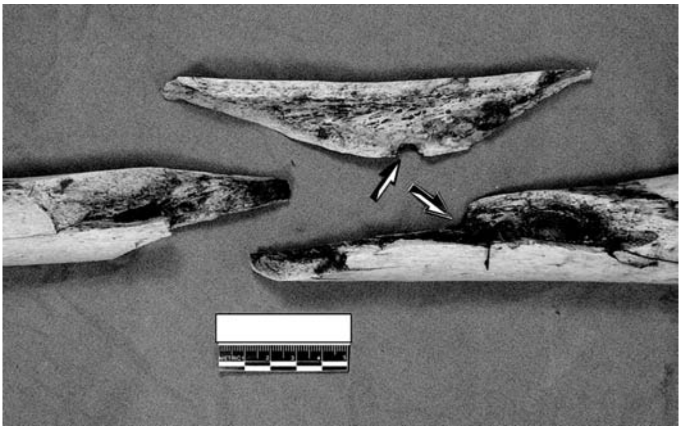


Figure 2.3b Comminute femoral shaft before reconstruction. (Reprinted with permission from Baraybar, J.P. and Gasior, M. 2006. Forensic anthropology and the determination of the most probable cause of death: an example from Bosnia and Herzegovina. *J Forensic Sci* 51(1): 103–108.)

archaeological recovery of all fragments. Therefore, careful excavation and assessment of clothing is crucial, as small fragments may be embedded in clothing or become disarticulated following decomposition of the soft tissues. The type of weaponry or blasting material used to create the injury may also compromise the recovery of fragments. Bone and tissue may be expelled at the time of injury or pass through the body as secondary projectiles and therefore not even be present at the time of burial. The use of *secondary burials*, in which graves are dug up and moved to new and different sites also results in a loss of materials as bone becomes exposed and small fragments disarticulated. Ultimately, complete recovery of all skeletal elements depends on the context and archaeological excavation of the grave. Despite great efforts in some cases to hide burials (Schmitt 2001; Skinner et al. 2001), skeletal fragments resulting from gunfire wounds to the head have been recovered from multiple sites and rearticulated in the laboratory.

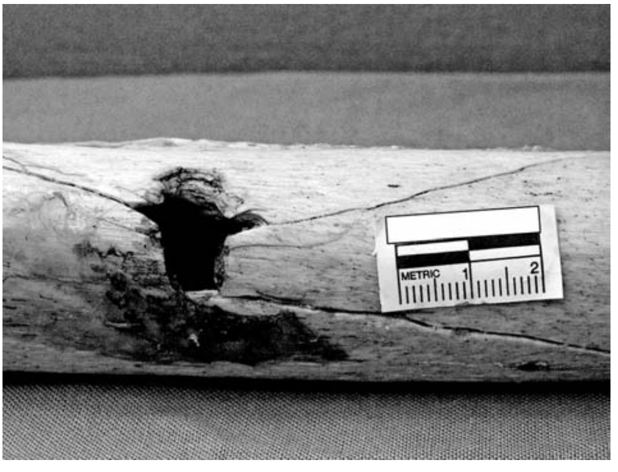


Figure 2.3c Reconstruction of a femur exhibiting a through-and-through single gunshot to the left thigh with high-velocity ammunition, 7.62 × 39 mm. (Reprinted with permission from Baraybar, J.P. and Gasior, M. 2006. Forensic anthropology and the determination of the most probable cause of death: an example from Bosnia and Herzegovina. *J Forensic Sci* 51(1): 103–108.)

Skeletal Reconstruction: A Practical Example of Associating Remains from Multiple Sites

This example demonstrates how skeletal materials from multiple locations were reconstructed based on skeletal morphology and later confirmed through DNA testing (Figures 2.4–2.8). In July 1998, the Kosovo Liberation Army (UÇK, Ushtria Clirimatre e Kosovoës) detained 85 Kosovo-Serb civilians in the vicinity of the Orahovac/Rahovec village. After the subsequent release of 45 of the victims, approximately 40 males were still unaccounted for (HRW 1998).

In October 2004, the police undertook an investigation into a case of 16 unidentified bodies that had been exhumed and autopsied by the ICTY in 1999. The remains were reburied on the eastern side of the Peja/Pec cemetery. These bodies, apparently due to their condition, could not be identified at the time of the autopsies. According to the information from various human rights organizations in Kosovo, seven other corpses were found in different locations in the Peja/Pec region between 2000 and 2001 and were brought to the morgue of Peja/Pec hospital. Following autopsies, they were also buried in the Peja/Pec cemetery. It was not clear at the time whether the remains were associated, due to their incompleteness. In November 2004, one of the graves in Peja/Pec cemetery, marked with a wooden marker but without an inscription, was exhumed and given a site code. This grave contained eleven plastic bags and body bags containing multiple skeletal remains.

In April 2001, the Regional Investigation Unit responded to three separate calls about the existence of bones, allegedly human, found by people searching in a cave between the Volljak/Volujak and Sverska villages, in the Kline/Klina municipality of Kosovo. The police were given a number of bones and pieces of clothing, allegedly exposed by rainwater and light excavation. The skeletal remains were transported to the Rahovec/Orahovac mortuary where they were kept. A brief examination of the remains concluded that more than one individual was represented and that it was possible further remains were still to be found at the location from which they were originally collected.

The Volljak/Volujak site consists of a large crater (20 × 10 m), at the bottom of which is the entrance of a cave that spans more than 245 m. The depth of the crater is approximately 25 m

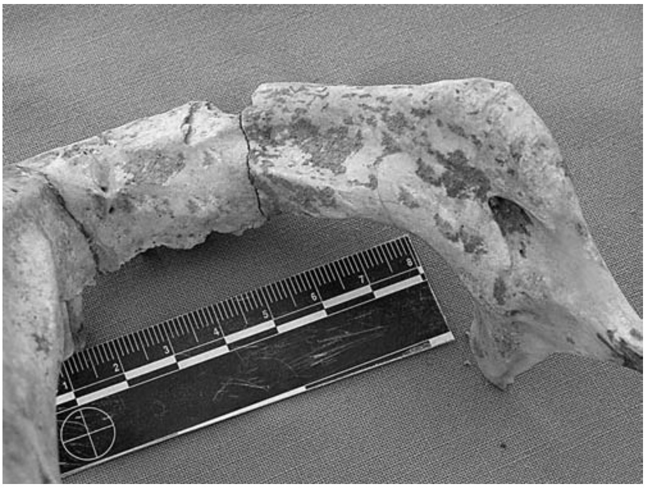


Figure 2.4 Two reassociated fragments of mandible found in different locations: a cave (left ramus) and in buried in a cemetery (symphysis) (Alain Wittmann).

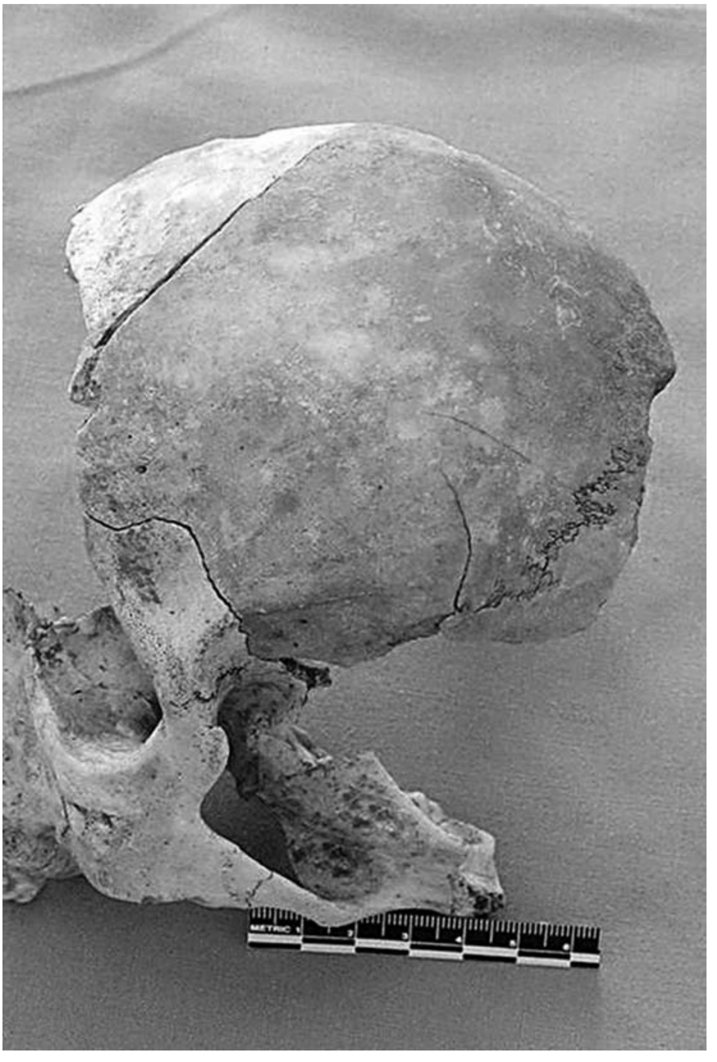


Figure 2.5 Reassociated fragments. The left side of the face of this individual was found in the cave, whereas a fragment of the frontal bone was found in the cemetery (Alain Wittmann).

and is part of a geological formation characterized by volcanic rock. A narrow ravine connects the cave complex to a nearby plain from which floodwaters and melting snow follow their course into the cave. The cave is characterized by a succession of chambers of different sizes; in general terms, the entrance is tall and wide and becomes narrower as it progresses. The surface of the cave is irregular, ascending and descending in different sections, with a total of 13.7 m from the entrance of the cave down to its end, vertically.

Human remains, shell cases, clothing, and other items such as car keys were found on the ground surface, both outside and inside the cave. The excavation and reconnaissance of items began in the interior of the cave from the sections farthest from the entrance. Some of the sectors had areas with water that had to be pumped out. In certain areas, a ladder was installed to reach the bottom of the underground reservoirs into which the remains had washed.

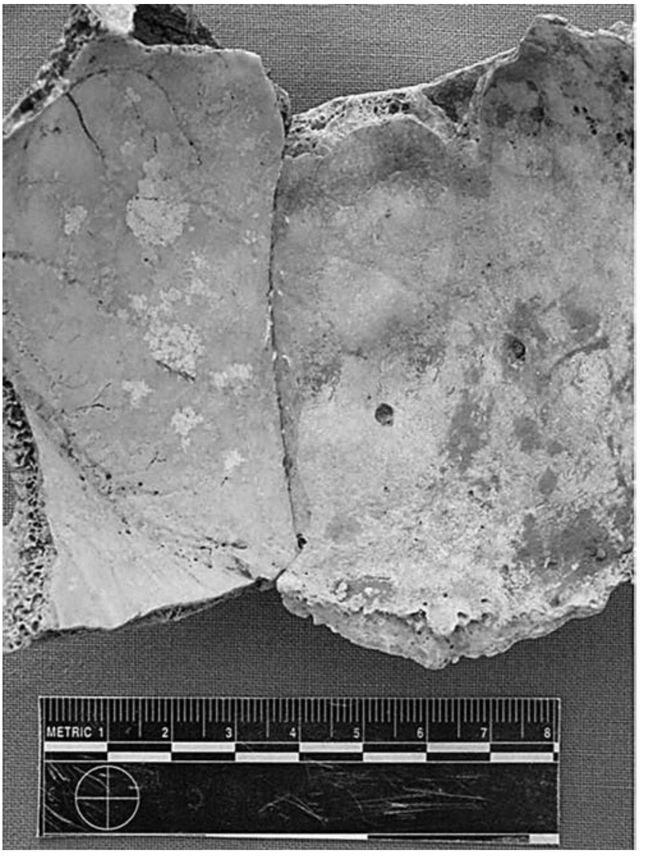


Figure 2.6 Reassociated fragments. Two fragments of frontal bone found in different locations (cave and cemetery) (Alain Wittmann).

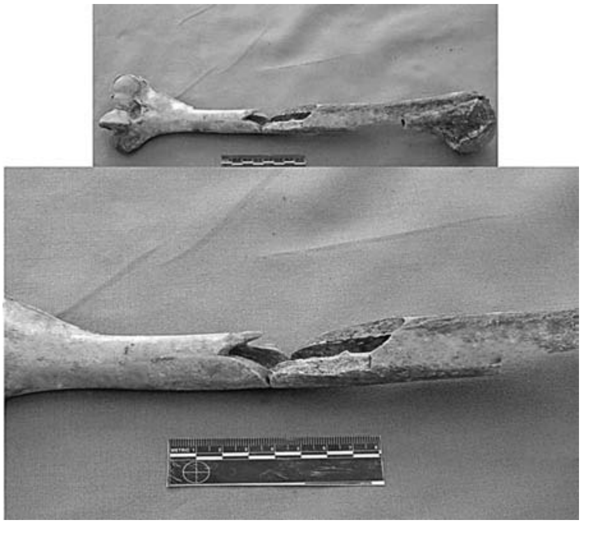


Figure 2.7 Reassociated fragments. Right humerus; each half was found in a different location (cave and cemetery) (Alain Wittmann).

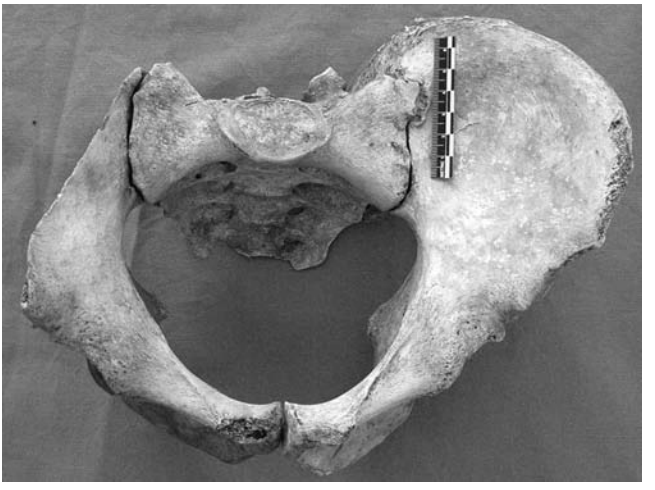


Figure 2.8 Reassociated fragments. Complete articulation of sacrum (found in the cemetery) and pelvic bones (found in the cave) (Alain Wittmann).

Surface searches inside the cave recovered human remains that were commingled and disarticulated, as well as shell casings. Outside the cave, the remnants of a pyre were found. The pyre had been prepared by filling the rocky bottom of the ravine with clay and rocks and by placing some wood branches over it, measuring 4.10 × 1.30 m. In addition, shell casings, coins, burned clothing, a "plate and screws," commingled burned bones, and ashes were also found. The pyre contained the remains of two almost complete skeletons mixed with fragments of a rubber tire. The search at the top of the hill, overlooking the pyre was carried out using a metal detector. Shell casings, one live round, and bullets representing four different calibers of ammunition were recovered. A field experiment was performed to evaluate the possibility that the bodies could have been at the top of the hill and fallen into the cave. Through this, it was observed that the bodies could have fallen in close proximity to the area where the pyre was found.

Shortly after commencing the exhumation of the cave, an ID card was found on the site. Additionally, three DNA results linked bone samples from the cemetery to the bones found years before and to the name on the ID card. In addition to DNA tests, further empirical links were established between the remains recovered from the cemetery and those found in the cave, including physical reassociation of body parts burried in the bags in the cemetery and the cave. These two lines of evidence demonstrated that the remains buried in the cemetery originated from the cave. Therefore, after combining the bones found in the cemetery with those in the cave, a minimal number of 28 (n = 28) individuals were established.

The Anthroposcopic Examination of Skeletal Injuries

The marriage of anthropology and pathology in forensic investigations blends different areas of expertise that may provide a very detailed and comprehensive reconstruction of what events occurred and at the same time, highlights differences in the methodology or terminology of the various disciplines. This book relies on several standard texts for definitions of anatomical, medical, and anthropological terms and methodology (Spitz 1993; Ortner and Putschar 1981; Buikstra and Ubelaker 1994; Ortner 2003).

The classification of skeletal wounds begins with a description of the location, type, and number of fractures or abnormal changes for bone, as well as for the specific aspects of each bone affected. The overall distribution of fractures throughout a particular region or the entire skeleton is examined. An estimation of the number of injuries present is possible based on the pattern or distribution of wounds and intersecting fractures. If more than one injury is noted, then these same lines of data will enable the investigator to sequence the injuries. Consequently, the first question an investigator must ask is whether the observation is normal; if it is determined to be abnormal, the methodological approach should include a differential diagnosis (Table 2.1). Consideration should be given to all lines of data, including radiography and examination of weaponry, if available or associated, so that a possible diagnosis is deduced and the most probable cause and manner of death may be interpreted.

In cases where there is one injury, several bones or different aspects of the skeleton may be affected. For example, a single gunshot wound to the skull may enter anteriorly through the frontal bone and exit the skull posteriorly through the occipital bone. In this scenario, different areas of the skull are affected with multiple fracture lines. Determination of a single gunshot wound is evident after documenting the type and location of each fracture, then analyzing the overall distribution of fractures in relation to one another. It is also common to have different regions of the body affected by a single gunshot wound. For example, in a study of terrorist-related gunfire and blast injuries, Peleg et al. (2004) report that the majority of trauma was from blast injuries and that the ratio of wounds (gunfire:blast) was

Table 2.1 Differential Diagnosis of Skeletal Trauma

1. Inventory all affected bones.
2. List the location of specific affected areas on bone, including the side/region/aspect.
3. Provide a description of:
   - The number and types of fractures or defects
   - The presence of any abnormal bone shape, growth, or loss
   - The severity, state, and distribution of abnormal bone changes
4. Documentation of any radiographic evidence (fractures or weaponry).
5. Analysis of clothing (defects, tears, burning, or weaponry).
6. Estimation of the timing of fractures based on:
   - Presence of bone reaction (remodeling)
   - Color of fractured edges
   - Shape of defect or cut mark
   - Size of affected area, defect, or cut mark
   - Appearance of tissue bending
   - Location of affected area
   - Number of fractures or cut marks
7. Classification of skeletal pathology by disease category (i.e., infectious, nutritional) and the specific mechanism (i.e., periostitis versus osteomylitis or scurvy versus anemia).
8. Estimation of the mechanism of injury, class of weapon, distance of fire or blast, and victim's position relevant to the direction of the force in relation to the point of impact.

the following: gunfire injuries had a higher number of open wounds (63:53) and fractures (42:31) but fewer cases with multiregions of the body affected (47:62).

Ruling Out Normal Skeletal Variation and Skeletal Pathology

A differential diagnosis requires a careful description of each defect, lesion, fracture, or abnormally shaped bone, which is then compared with the characteristics defined for each possible known condition (Ortner and Putschar 1981; Buikstra and Ubelaker 1994; Goodman 1993). The investigator must have a clear understanding of the range of variation normally likely to occur. This includes knowledge of normal skeletal variation due to epigenetic traits, such as accessory foramina or vessels in bone and vertebral fractures, or skeletal nonunion such as spondylosis, cleft neural arches, or spina bifida. Many examples of skeletal epigenetic traits may be confused with traumatic injuries, even to experienced practitioners. Therefore, a clear understanding and evaluation of normal skeletal variation is necessary to avoid the misdiagnosis of variation verses inflicted trauma or skeletal disease.

Table 2.2 provides a summary list of commonly observed epigenetic or congenital traits observed throughout the skeleton (complied from Barnes 1994). This is only a partial list of the traits exhibiting variation or congenital anomalies, but it does provide a summary of the traits typically observed during osteological analysis that may be easily confused with wounds resulting from inflicted trauma. Variants can be grouped into categories:

Table 2.2 Common Epigenetic or Congenital Traits of the Skeleton that May be Confused with Skeletal Trauma

Congenital Disorders	Skeletal Region Commonly Affected
Transitional vertebra	Occipitalization of cervical (C1)
	Thoracization of cervical (C7)
	Lumbarization of thoracic (T12)
	Lumbarized first sacral (S1)
	Sacralized fifth lumbar (L5)
	Lumbar-sacral undetermined
	Fused coccyx
Bone fusion	Multiple vertebrae
	Sternum/manubrium/xiphoid process
	Sternum/ribs/costal cartilage
	Ilium/sacrum
	Tibia/fibula
	Hand or toe phalanges
	Carpals or tarsals
Bone nonunion	Sternal body segments
	Bifurcated neural arches
	Acromion process unfused (*Os acrominale*)
	Spina bifida/occulta
Abnormal shape	Hemivertebra
	Talus *Os trigonon*
	Abnormally small nasal bones
Accessory foramina	Septal apature (humerus)
	Sternal foramen (sternal body)

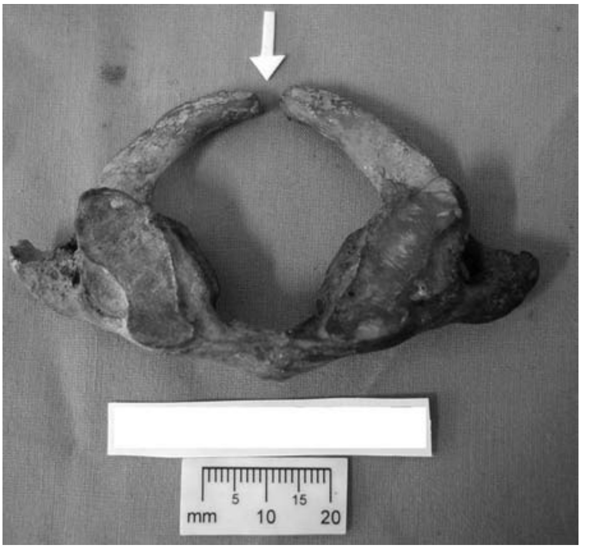


Figure 2.9 First cervical vertebra, superior view. Posterior cleft neural arch, congenital defect. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

(1) transitional vertebra, (2) abnormal but nontraumatic bone fusions, (3) abnormal but nontraumatic nonunion of skeletal segments, (4) abnormally shaped bones, and (5) accessory foramina. Barnes (1994) provides a detailed and comprehensive text for identifying epigenetic traits and a thorough review of their etiology and frequency. Figures 2.9–2.16 illustrate examples of normal skeletal variation.

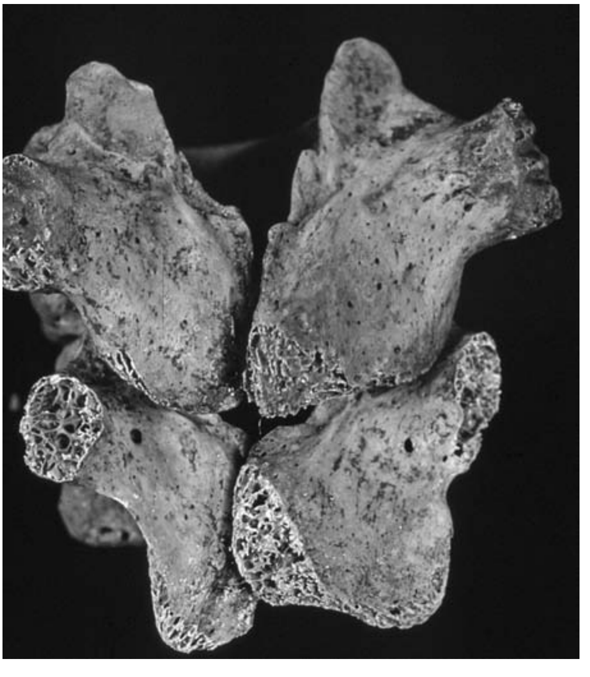


Figure 2.10 Adult thoracic vertebrae, posterior view. Bifurcated neural arches, congenital defect (Courtesy of Jane Beck).

Figure 2.11a Adult fourth and fifth lumbar vertebrae, posterior view. Neural arches never fused to vertebral bodies. Complete spondylolysis. Common congenital defect. Note the smooth, rounded edges of the laminae visible along the top border of the inferior articular facets (Courtesy of Jane Beck).

Although not all disease processes manifest in the skeleton, there are a large number of skeletal indicators of malnutrition, growth disruptions, physiological stress, infectious disease, and antemortem wounds that commonly result from neglect and poverty associated with human rights (HHRR) abuse and armed conflict. The health consequences associated

Figure 2.11b Adult sacrum, posterior view. Complete spina bifida. Nonunion of the sacral neural arches, segments 1–5. Congenital defect (Courtesy of Jane Beck).

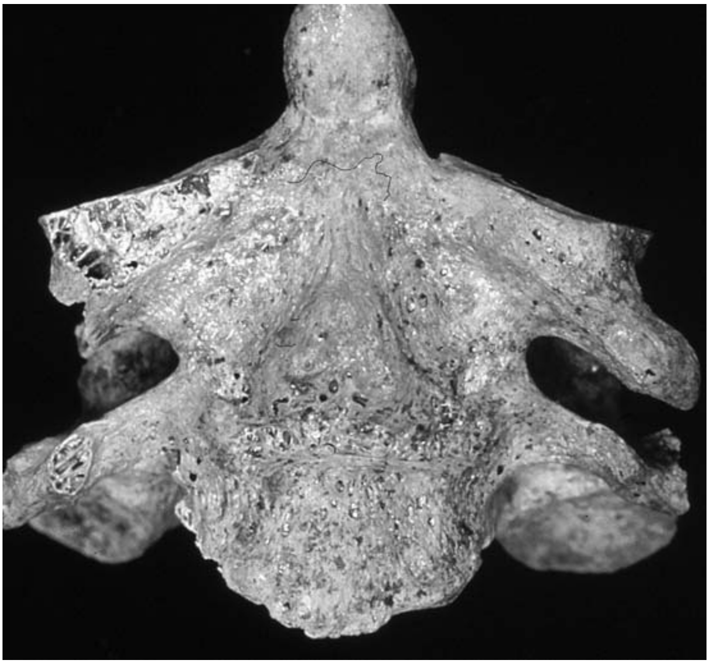


Figure 2.12 Adult cervical (C) vertebrae, anterior view. Vertebral bodies of C2 and C3 congenitally fused (Type II, Klippel-Feil syndrome) (Courtesy of Jane Beck).

with armed conflict are well documented. Some examples include inadequate nutrition, a lack of or denial of medicine and medical intervention, poor sanitation, debilitating injuries, and increased prevalence of infectious diseases (Levy and Sidel 1997; Henderson and Biellik 1983; Garfield and Neugot 1991; Toole et al. 1993; Weinberg and Simmonds 1995; Zaidi et al. 1995; Goldson 1996; Salama et al. 1999; Spiegel and Salama 2000; Murray et al. 2002; Van Herp et al. 2003; Holdstock 2004; Morley 1994; Taipale et al. 2002). In an editorial to the *Medicine Conflict and Survival*, Holdstock wrote (2004, 291):

> Estimates of war-related deaths and illness among civilians are even less precise; when does the death of a malnourished child become war-related? In Iraq, the combined effect of infrastructure damage from the 1991 Gulf War and subsequent sanctions may have caused the premature death of half a million children. The contributing disruption of health care in Iraq today will add many more to the total and is surely a consequence of war.

People may be intentionally or unintentionally affected as access to supplies or aid may be lacking due to embargoes, roadblocks, or the destruction of social infrastructure. The Human Security Report (2005, 7) states:

> The biggest death tolls do not come from the actual fighting, however, but from war-exacerbated disease and malnutrition. These "indirect" deaths can account for as much as 90% of the total war-related death toll. Currently, there are insufficient data to make even rough estimations of global or regional "indirect" death toll trends.

Basic human securities may be intentionally compromised as a form of control or with the intention to commit genocide. Thereby, basic human securities may be manipulated and

Figure 2.13 Adult manubrium and sternal body, anterior view. Nonfusion of segments. Segment 1 is not fused to the second and third segments. Note that the left and right sides of the distal segment did not fuse. Further, the presence of a sternal aperture (foramen) is present in the distal segment of the sternal body. These traits are congenital anomalies of the skeleton (Courtesy of Jane Beck).

used as *weapons* against civilian populations. According to the Human Security Report (2005, 7), "disease and hunger result in more deaths than trauma from actual war wounds, with a ratio of indirect to direct as high as 10:1." The particular health consequences resulting from war atrocities and armed conflict will further depend on whether people were detained prior to death and the overall context and duration of the situation.

Observable skeletal pathology should be systematically documented through postmortem examinations not only to enable differential diagnosis of perimortem trauma related

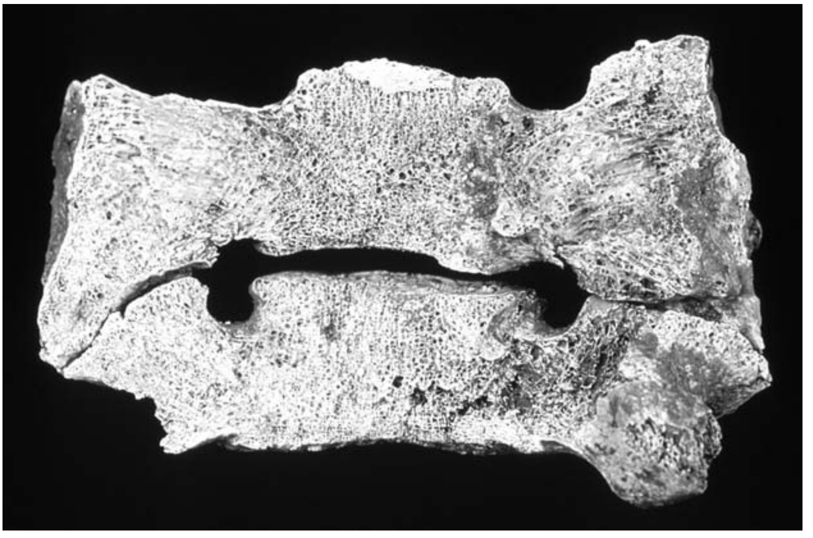


Figure 2.14 Adult individual. First (S1) and second sacral (S2) elements congenitally never fused (vertebral shifting, lumbarization of S1). Postmortem damage also present in the anterior surface. (Courtesy of Jane Beck.)

Figure 2.15 Adult pelvis, superior view. Fusion of the left sacroiliac joint. Right sacroiliac joint has accessory facets, where the two bones articulate, posterior to the articular surface (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY]).

Figure 2.16 Superior view of the adult cranium. Congenital bilateral parietal thinning (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY]).

to the individual's death but also as a matter of historical record, to provide possible evidence of maltreatment, to obtain information that may assist with victim identification, and to understand wounding patterns that may be altered by age or disease (Buchsbaum and Caruso 1969; Evans 1973; Schmidt 1979; Morse 1983; Berryman and Symes 1998; Catanese and Gilmore 2002; Hart 2005). Schmidt (1979, 103) wrote: "Experience shows that with advancing age the resistance of adults against deformation shrinks. Even a fall on flat ground may cause a series of rib fractures in an old person. Experiment confirms that, whole body or single rib alike, the difference in breaking strength with differences in age are considerable."

The paleopathological literature is full of similar examples from archaeological populations throughout the world where diseases manifest in bone without the benefit of modern medical intervention. The examples discussed here are a few of the more common conditions we have encountered. For comprehensive texts on skeletal pathology, readers are referred to Steinbock (1976), Brothwell (1981), Ortner and Putschar (1981), Aufderheide and Rodriguez-Martin (1998), Roberts and Manchester (1995), Ortner (2003), and Mann and Hunt (2005). Forensic anthropologists in the United States are often trained as bioarchaeologists and skeletal biologists and may have extensive experience working with archaeological populations whose skeletal pathologies may resemble populations today, if victims have not had access to modern health care, antibiotics or other medicine, or adequate nutrition.

Similarly, the diagnosis of *battered child syndrome* based on fracture patterns and other evidence of neglect or maltreatment also has implications for ill-treatment or torture cases in HHRR investigations (Rae 1969; Betz and Leibhardt 1994; Reynolds 1998; Cheung 1999; Brogdon and Vogel 2003a; Altun et al. 2004; Cattaneo et al. 2006). For example, skeletal manifestations of battered child syndrome can include nutritional deficiencies and infectious diseases (Rae 1969, Krogman and Iscan 1986). Issues of malnutrition and starvation raised in several of these examples highlight an important point about skeletal evidence of nutritional deficiencies, which may cause a variety of skeletal or dental reactions (Figures 2.17 and 2.18). For example:

- Vitamin D deficiency may result in rickets, osteomalacia, or marked bowing of the tibia.

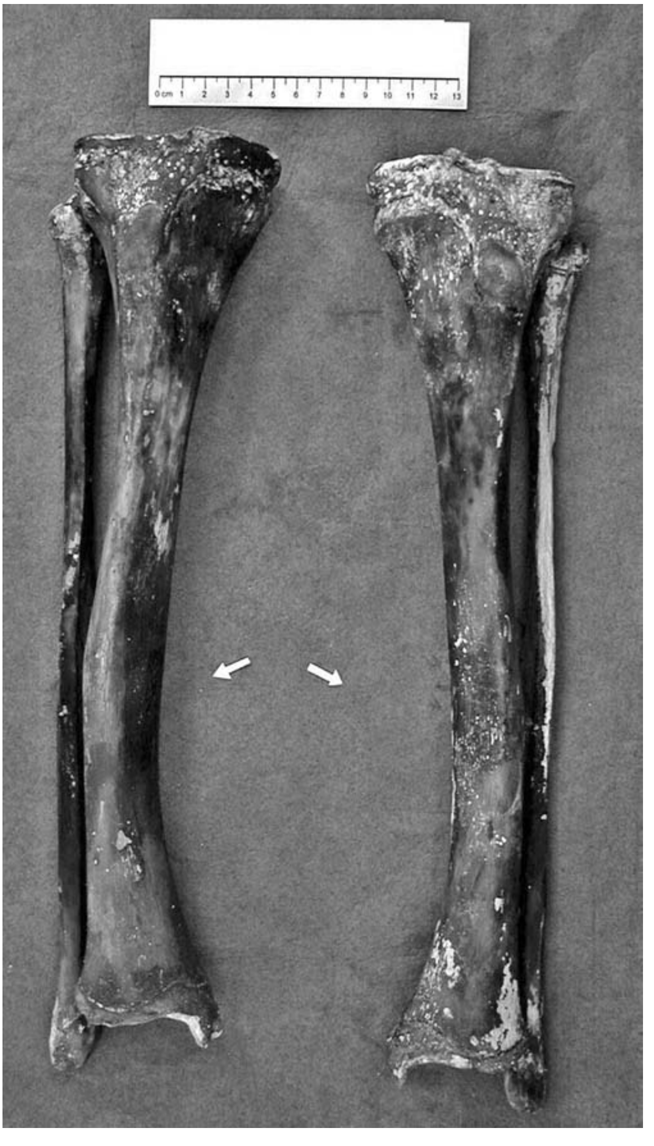


Figure 2.17 Bilateral tibiae and fibulae exhibit bowing, likely resulting from childhood nutritional deficiency, possibly rickets. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

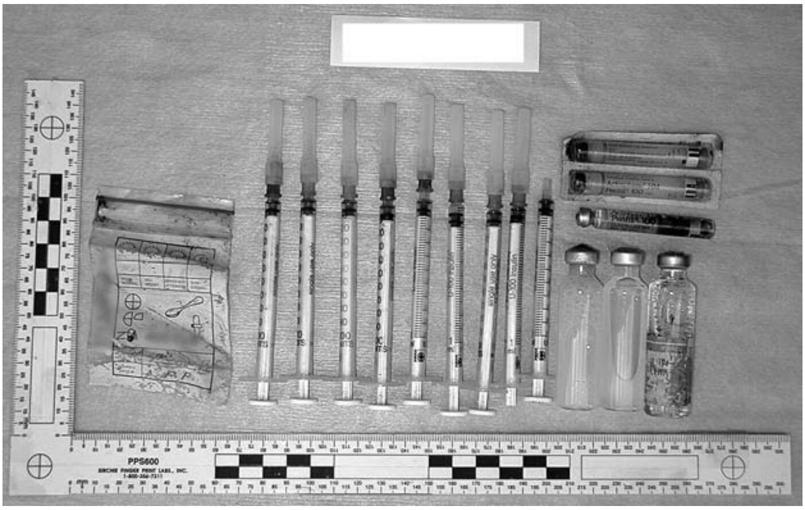


Figure 2.18 Insulin bottles and the hypodermic needles. These objects were recovered from the pockets of a victim exhumed from a mass grave. The presence of insulin is suggestive of the victim having had diabetes. The victim died of a gunshot wound following detainment. (Printed with permission from International Criminal Tribunal for the former Yugoslavia.)

- Vitamin C deficiency may be evident skeletally in the form of scurvy, including skeletal lesions, cribra orbitalia, ectocranial porosis, and lytic lesions of the sphenoid, zygomatic, maxillary, and temporal bones.
- Malnutrition and starvation may result in severe osteoporosis, delayed skeletal development, or abnormal growth.
- Various forms of physical skeletal evidence may be indicative of neglect or abuse. This may illuminate patterns of human insecurities among populations in crisis.

Figures 2.19 and 2.20 depict severe dental disease, abscesses, and large caries in an individual excavated on a mass grave in Bosnia-Herzegovina (BiH). From the extent of pathology (n = 11 abscesses), there was no dental treatment. This raises an important issue for human identification, because even in cases in which antemortem dental or health records may be available, victims who are detained or are in a conflict area for a long period of time may develop new pathological conditions, or preexisting conditions may worsen to a point at which the postmortem record will be sufficiently different from the antemortem record. Table 2.3 lists commonly observed dental conditions. Understanding dental variation and pathology can be important for interpreting injuries (Salis et al. 1987; Pollak and Wieser 1988).

Generalized infections affecting bone are very evident in the form of abnormal bone growth or loss, skeletal disruptions to growth, Harris lines, enamel defects or hypoplasias, and skeletal asymmetries. Generally, infectious processes in bone may be classified as either periostitis or osteomyelitis. Many infectious agents affect skeletal tissue, some of which are easily distributed by the morphological characteristics present. Some examples include streptococcicosis, mastoiditis, osteomyelitis, sinusitis, peritonitis, smallpox, tuberculosis, treponematosis, and syphilis. Infections to bone commonly are the result of streptococci and may be associated with an injury such as a fracture.

Figure 2.19 Dental hypoplasia in the form of linear bands. Indicative of nutritional stress, possibly associated with infectious disease during early childhood. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.20 Right lateral view of craniofacial region and mandible, adult skull. Large caries present in second mandibular molar (M_2). Multiple abscesses of varying sizes (n = 11) present throughout maxillary and mandibular alveolar processes. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Table 2.3 List of Dental Abnormalities

Condition	Etiology
Enamel hypo/hyperplasia	Malnutrition, infectious disease, antibiotics
Caries	Infectious disease
Maxillary and mandibular abscess	Infectious
Antemortem tooth loss	Infectious, age related, traumatic, therapeutic
Congenitally absent or unerupted tooth	Congenital
Periodontal disease	Infectious disease
Fractures	Accidental or inflicted trauma, age related

Figures 2.21–2.23 depict various examples of osteomyelitis with severe abnormal bone growth, the formation of bone remodeling with cloaca.* The left tibia with ankylosed fibula in Figure 2.21 is a case of acute osteomyelitis. The remains of this adult male individual were recovered from a grave in Croatia. Note that the two elements are almost entirely encased in abnormal bone. The mode of infection may be hematogenous, or direct to the bone following a traumatic injury. Figures 2.24 and 2.25 also illustrate examples of infectious disease manifest skeletally.

In addition to nutritional and infectious disease processes affecting skeletal tissue, various forms of neoplastic disorders are evident, quite commonly. Lytic lesions such as those depicted in the adult ilium and ribs (Figure 2.26) are extensive circular, smooth-walled defects resulting from a neoplasm.

Figure 2.21 Adult left tibia with ankylosed fibula, anterior view. Both bones exhibit acute osteomyelitis. The two elements are almost entirely encased in abnormal bone. Mode of infection may be either hematogenous or direct infection of the bone, following a traumatic injury. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

* The examples in the pathology section have been observed for modern populations in conflict areas. The figures primarily come from these cases but in several incidents were supplemented by museum examples, when a photograph was not available for illustration (refer to figure descriptions).

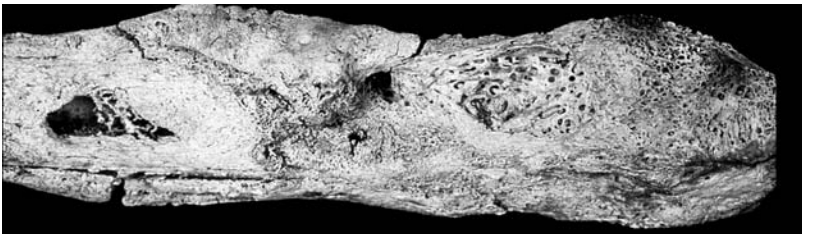


Figure 2.22 The shaft of a lone bone presented with extensive bony growth, cloaca on the left aspect. Severe osteomyelitis, indicative of bone infection, likely resulting from a traumatic injury (Courtesy of Jane Beck).

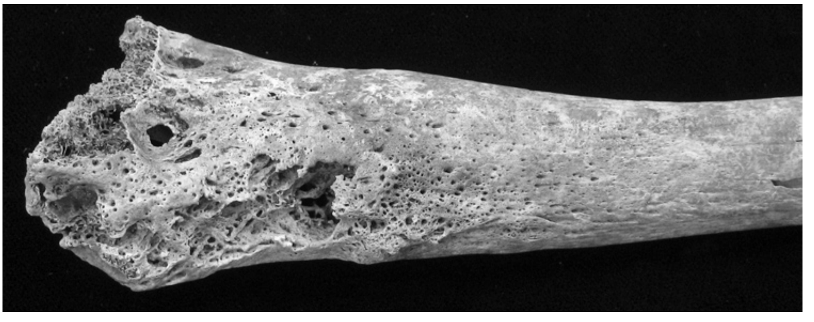


Figure 2.23 Juvenile, right humerus, anterior/distal view. Infectious bone remodeling with cloaca. Postmortem damage is also present along later margin (Rafael Guerra, USF).

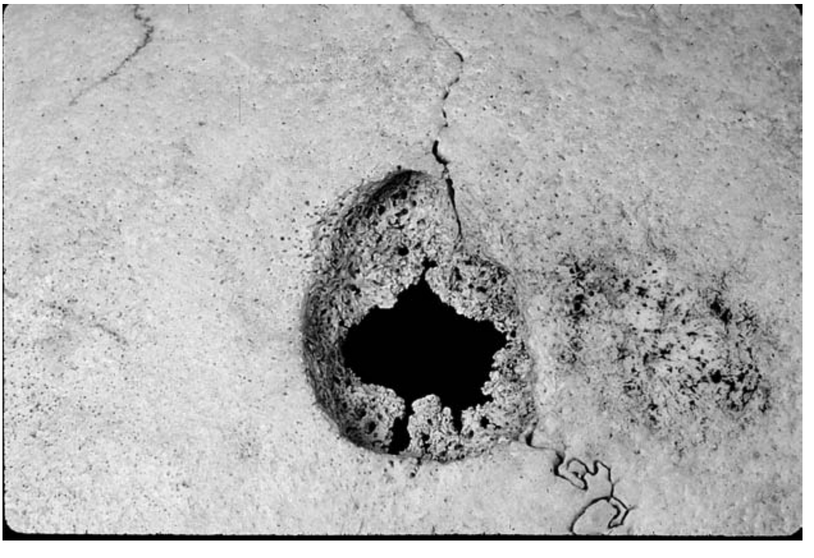


Figure 2.24 Close-up view. Lytic lesion on the cranial vault; note the diplöe is exposed around the circumference of the irregularly shaped defect. Adult. Infectious lesion. Not to be confused with external beveling of a GSW. Lesion is circumscribed with smooth edges. Margins along inner table are irregular. To the right of the defect on the ectocranial surface is abnormal bone loss, caries sicca. Lesions consistent with syphilis (Courtesy of Jane Beck).

Figure 2.25 Superior view of the cranial vault showing extensive lesions. Defects perforate the cranial vault. Extensive porosity is present. Skeletal evidence is consistent with infectious disease, most likely syphilis (Courtesy of Jane Beck).

Classification of Fractures and Mechanisms of Injury

In part, the biomechanical properties of bone account for variation in wound morphology observed for all mechanisms of trauma. Extrapolating the cause or manner of death from skeletal injuries requires interpretation of the mechanism of injury based on the available evidence. The production of fractures depends on the strain rate which is the rate at which deformation in response to force is applied (refer to Gurdjian *et al.* 1950, Evans 1973, Gurdjian 1975, Rogers 1992, Harkess 1984, Nahum and Melvin 1985). The factors guiding boney responses to applied force include the strength, stiffness, elasticity, and composition of the affected tissue as well as the surrounding soft tissues that may provide a barrier or cushion (Rogers 1992, Catanese and Gilmore 2002). Therefore, interpretations of the mechanism of injury from skeletal characteristics must consider the anatomical location and biomechanical properties of the bony tissue affected. Variation in the weapon or mechanism that is applying external force, such as the velocity, weight and distance further influence the skeletal reaction. Refer to the case study at the end of this chapter by Raul and co-workers for a discussion on the application of finite element modeling in forensic medicine.

Yield has a specific meaning in mechanics referring to an applied stress point past which the material will not return to its original dimensions. A material in its 'elastic range' is flexible and will return to its original dimension. Depending on the force applied, the elasticity allows for some yield in the bone. A slow load will make the bone yield into the elastic phase, deforming it before failing, whereas higher force mechanisms will result in a fracture (Gorman 1981). Generally, compression or torsion results in a dislocation rather than a fracture, unless shearing or bending is also applied, which occurs more commonly

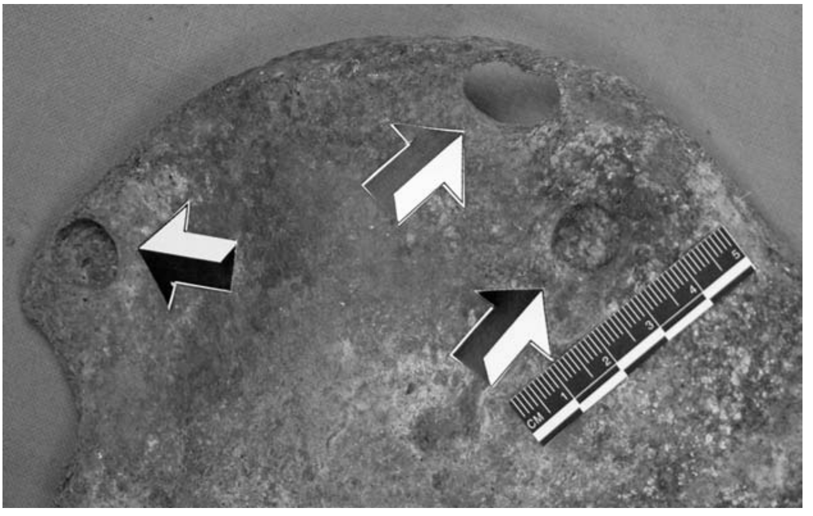


Figure 2.26a Circular, lytic lesions on the right ilium. Three of the four defects do not perforate the bone. Note the symmetrical, round, smooth edges of the defects. These lesions are the result of osteomyeoloma (Alain Wittmann).

(Gorman 1981). Several comprehensive texts and published case studies provide information on the biomechanics of tissue response to abnormal stress and recommendations for differentiating mechanisms of injuries or classes of weapons based on fractures (for example, refer to Lefort 1901, Gurdjian *et al.* 1950, Moritz 1954, Gorman 1981, Ortner and

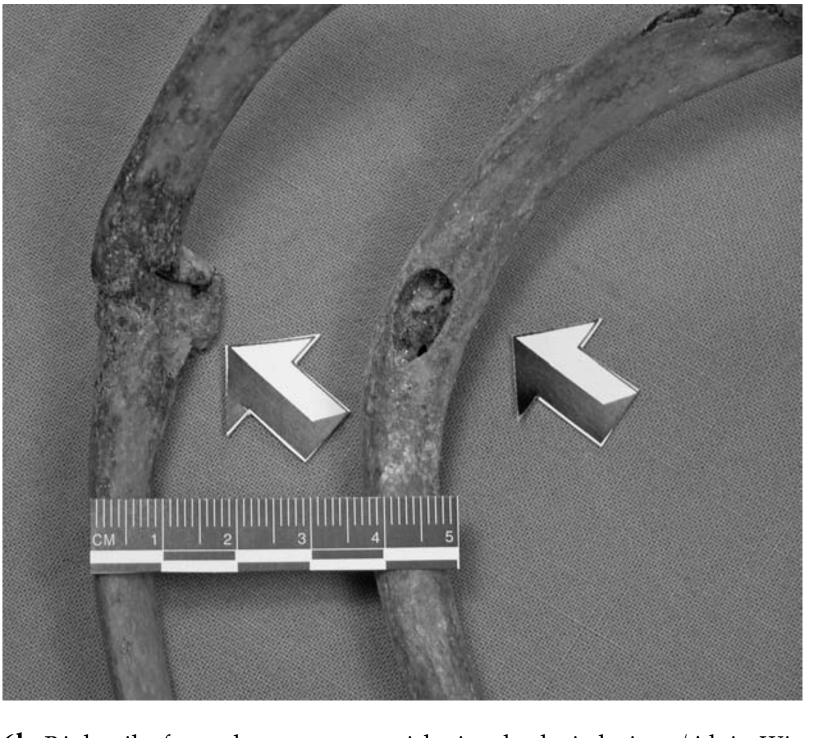


Figure 2.26b Right ribs from the same case with circular lytic lesions (Alain Wittmann).

Putschar 1981, Rogers 1992, Berryman *et al.* 1995, Ross 1996, Lovell 1997, Berryman and Haun 1998, Berryman and Symes 1998, Quatrehomme and Ĭscan 1998, Galloway 1999, Cowin 2001, Browner 2003, Ortner 2003, Byers 2005, Hart 2005).

There are several classification systems for skeletal fractures (Figures 2.27–2.34). Generally, fractures are characterized as *simple* or *multi-fragmented* and further classified by geometric properties (i.e. spiral or linear), the position or location of the fracture, the completeness of the break and the orientation of the fracture relative on the bone. A break that is complete and separates the bone tissue into two pieces is called a *simple fracture*. A break that is complete but results in three or more bone fragments is a *multi-fragment* or *comminuted fracture*. In contrast, a break that does not completely separate is called an *infarction*. Radiating fractures typically originate from the point of stress and extend as force dissipates though bone. Linear fractures may also occur peripheral to the point of impact, extending away from the force, but not actually originating from that point (Gurdjian *et. al.* 1950, Gurdjian 1975, Berryman and Symes 1998) – though this finding is debated by some. *Linear fractures* run parallel to the axis of the bone, whereas *transverse fractures* runs across this axis. *Concentric* or "*hoop*" *fractures* occur circumferentially around the point of impact. *Radiating* and *concentric* fractures are common in high stress

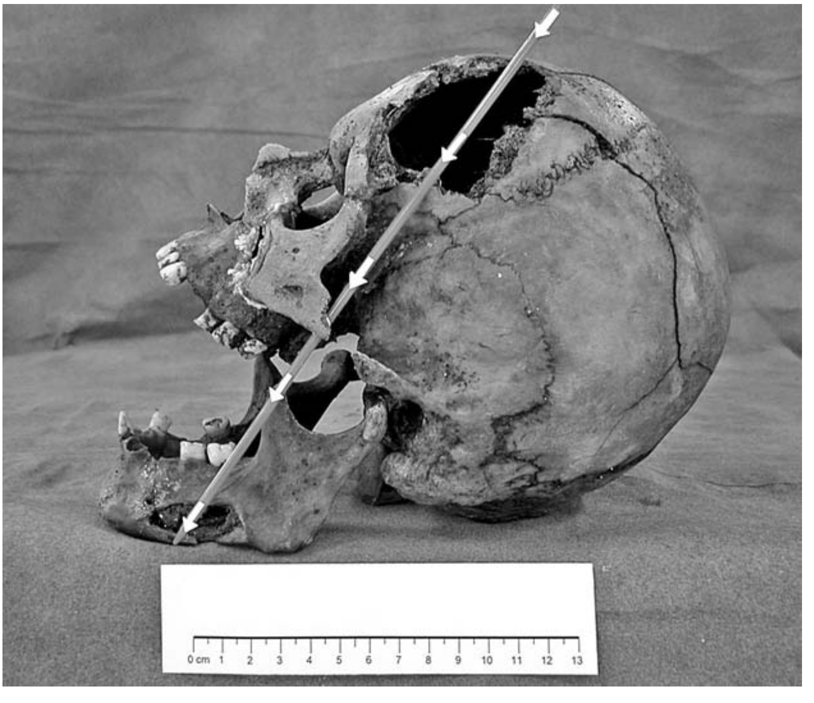


Figure 2.27 Multiple regions of the skull and mandible are fractured resulting from a single gunshot wound from a high-velocity rifle. The shot enters the skull at the top of the forehead (anterior frontal bone), creates a gutter wound as it runs along the frontal bone on the left side, enters into the left cheek (posterior to the zygomatic), and impacts the left mandible, creating a single gutter defect. Radiating fractures from the left frontal to parietal bones, along the left maxilla, and left zygomatic arch are present. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

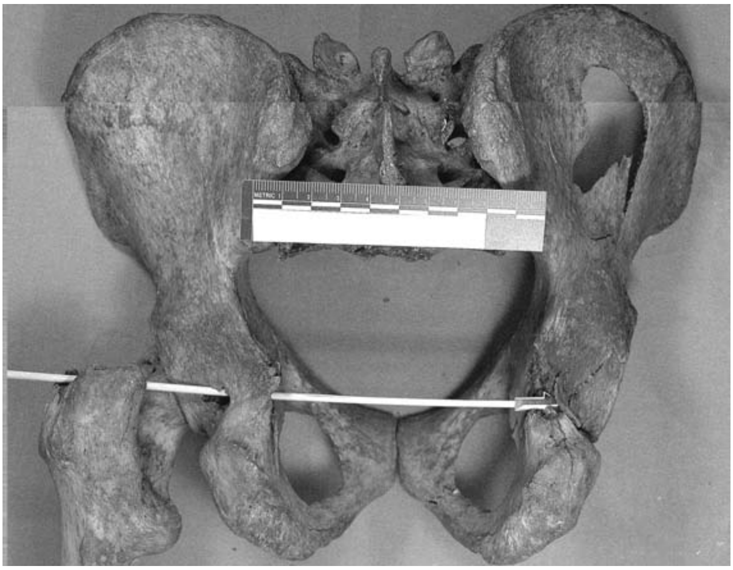


Figure 2.28 Multiple regions of the body are affected by a single gunshot wound, a left to right shot from a high velocity rifle. The projectile enters through the left hip (greater trochanter of the femur) and passes through the left femur. The projectile enters the left ishium, passes through the pelvic region, and enters the right ishium where it becomes embedded in bone (Alain Wittmann).

Figure 2.29 Pectoral girdle demonstrating multiple fractures of the left clavicle, sternal body, left scapula, and left proximal humerus. This is an example of a single GSW from an AK-47. The projectile entered from behind the left shoulder with a downward trajectory, and exited through the chest. The humerus, scapula, and rib exhibit beveled defects consistent with back-to-front shot. Note the clavicle was struck left to right and fractured on the acromial end and distal 1/3 shaft. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

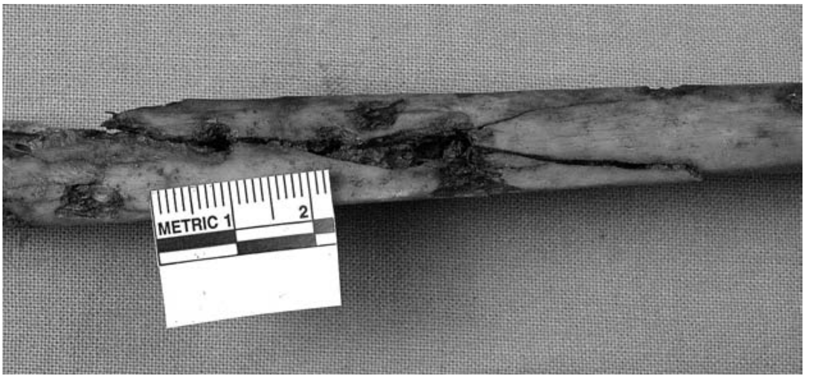


Figure 2.30 Reconstructed comminuted fractures resulting from a shotgun injury to the left tibia, adult (Alain Wittmann).

trauma (Harkess *et al.* 1984, Symes *et al.* 1991), although concentric fractures can occur without radiating fractures (Gurdjian 1975).

Fractures result when abnormal stress is placed against the bone and is characterized by its direction and focus (Ortner and Puschar 1981). The *direction of force* includes tension, compression, torsion, bending, or shearing, and, typically, force is applied from several directions in combination. *Focus* refers to the size of the surface area affected on impact and is categorized as narrow or wide. To some degree, the mechanism of injury may be categorized by its focus and the load of the force, specifically the amount of energy that is displaced from the weapon to the soft and bony tissues.

Figure 2.31 (See color insert following page 38) Single gunfire wound with a shotgun at close range to thoracic vertebrae, front-to-back shot. Vertebral bodies fractured and almost completely destroyed. Fractures extend from T5 to T8. The point of impact was on T6. T7 exhibits slightly less damage than T6, yet a significant portion of the body is destroyed. Note that T5 and T8 exhibit fractures that split the body into two or more fragments. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.32 Anterior view, adult remains. Incomplete radiating fractures of the right radius and ulna as a result of single gunfire injury (Alain Wittmann).

Blunt force injuries usually have a wide focus, whereas projectile and deeply penetrating wounds have a narrow focus. Shrapnel injuries from explosions or blasting mechanisms are characterized by narrow-focus projectile wounds dispersed over a wide region of the body. The range of the explosion, location of blast, and the type of explosive device and materials used in the construction of the device will vary the dispersion of wounds in blasting injuries and the degree to which fracturing results from the blast wave. Blunt force injuries, compared to gunfire injuries, result from slow load force. However, actually within each mechanizing category, there is a range of slow/low to fast/high load. Fackler (1994), in regard to gunfire injuries, points out that wounding ballistics is not a matter of velocity, but of the bullet–tissue interaction, and the amount of tissue disruption is due to the fragmentation of projectiles and number of injuries.

Fractures may be further characterized by their anatomical location. Skull fractures tend to be depressed, radiating, linear, comminuted, blowout, or basilar. Fractures to long bones are differentiated into intra- and extra-articular aspects according to Lovell (1997); refer to Table 2.4. Intra-articular fractures involve the joint and the metaphysis. These may

Figure 2.33 Left inferior view of adult 1st metatarsal with embedded projectile. Incomplete fracture with a projectile embedded along the medial surface. The projectile is a full metal jacketed bullet that was fired from an AK-47. The projectile likely stopped when passing through the bone when it hit the floor. Bullet tip points superior. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

be linear, comminuted, or impacted (Lovell 1997). Extra-articular fractures occur along the shafts of long bones or nonarticulating surfaces of *flat* and *irregular* bones and are classified as linear, comminuted, or segmental (Lovell 1997). Linear fractures may be further subdivided to include information about the direction of force, such as transverse, oblique, or spiral fractures. Comminuted fractures, characterized by multiple fragments, are also referred to as *butterfly* fractures.

Tension occurs from pulling on a bone and usually results in dislocations (Byers 2005). Vogel (2003a) reports examples of "positional torture" in which victims were hung from their knees while their wrists and ankles were bound or suspended by their fingers. "Positional" injuries, likely result in joint dislocation, particularly to the shoulder

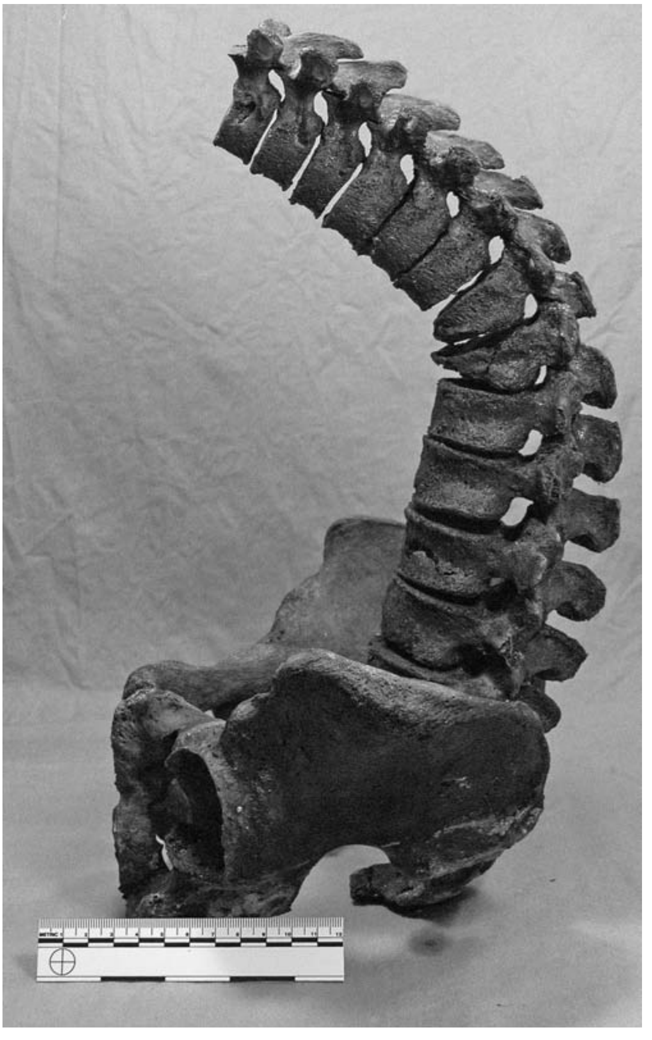


Figure 2.34 Vertebral column and pelvis, left lateral view. Severe anterior compression fracture of 11th and 12th thoracic vertebra with spinal kyphosis (Alain Wittmann).

Table 2.4 General Bone and Fracture Classification

Bone Class	Examples of Skeletal Elements	Classification of Fractures Commonly Observed
Flat	Cranial vault, scapula, ilium, ribs	• Depressed, radiating, linear, comminuted, blowout, basilar
Long/Short	Humerus, radius, ulna, femur, tibia, fibula, metacarpals, metatarsals	• Extra-articular: linear, comminuted, segmental • Intra-articular: linear, comminuted, impacted
Irregular	Sacrum, vertebrae, facial bones	• Extra-articular: linear, comminuted, segmental, radiating, linear, comminuted, depressed, crushing

Figure 2.35 Right femur, anterior view. *Miositis ossificans traumatica*. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

(Vogel 2003a, 131). For example, reported cases of torture from Africa and Latin America include injuries resulting from joints that were bent and rotated to maximum flexion that produced pressure lesions and atrophy (Vogel 2003a). Figure 2.35 depicts an example of *myositis ossificans traumatica*.

Compression forces result from pushing on bone. Blunt force trauma from compression results in crushing injuries, depressed fractures, and penetrating defects with or without radiating fractures, Projectile injuries are also a form of crushing injury and variably result in radiating fractures or penetrating defects of various shapes, depending in part on the shape of the projectile, the angle of entry, and the amount of force.

Overall, the anatomical structure and composition of the particular bone due to the biomechanical properties of bone (i.e., strength, elastic modulus, hardness, and conductivity) will affect the type and pattern of fracture that results. Gorman (1981) notes that trabecular bone crisscrosses for maximum strength to allow for normal loading of body weight and physical activities, such as walking or running. As many researchers have discussed, bone is generally more resistant to compressive forces than to tension; therefore, failure usually occurs first on the side of tension (Gorman 1981, 1981b, 1981c; Harkess et al. 1984; Berryman and Symes 1998). According to Berryman and Symes (1998), bone fractures first on the side of tension, which is on the external table in blunt force mechanisms when the force does not perforate the bone and on the internal table in gunfire or shrapnel injuries when the projectile does perforate the bone. Hart (2005) differentiated injury mechanisms by the location of beveling and illustrated significant differences that can be used to predict the mechanism of injury by isolated fragments.

In most cases of compression injuries, force is also applied through bending or shearing (Gorman 1981a). Vogel (2003b) reports on compression fractures to hands and feet in cases of torture. In these examples, force is applied to the sole's of feet or to the fingers and hands. Other common examples of crushing injuries or *depressed fractures,* result from blunt trauma to the head and ribs (Fenton et al. 2003). Shearing force is essentially a bending force that is applied when the bone is immobilized. However, this type of injury often occurs in deeply penetrating or sharp force injuries. Torsion occurs as a result of twisting bone and is often seen in cases of beatings and torture that use some type of a weapon to strike the victim.

Ortner and Putschar (1981) report that fractures resulting from bending forces are the most ubiquitous but that they rarely occur without other types of force also applied. Force applied to bone will cause the bone to bend until it reaches maximum threshold, at which point it will fail and fracture. Byers (2005, 285) points out that bending force rarely results in linear fractures at either the point of impact or on the opposite side of tension. Rather, injuries resulting from bending force typically occur in cross section as the force is applied at a 90° angle. This may result in a *butterfly* fracture in which the fracture lines extend away from the point of impact and create a triangular wedge of bone (Figure 2.36). This is frequently observed in cases of blunt force and projectile injuries to the long bones or ribs.

Detailed descriptions of the location and geometric properties of skeletal fractures provide the necessary information from which interpretations may be drawn about the mechanizing force. The mechanisms most relevant to skeletal trauma in cases of HHRR abuses, extrajudicial executions, and armed conflict include blasting and gunfire injuries, deeply penetrating wounds or sharp force trauma, and blunt force injuries. Numerous mechanizing forces occur in blasting injuries, producing crushing blunt force trauma, acceleration/

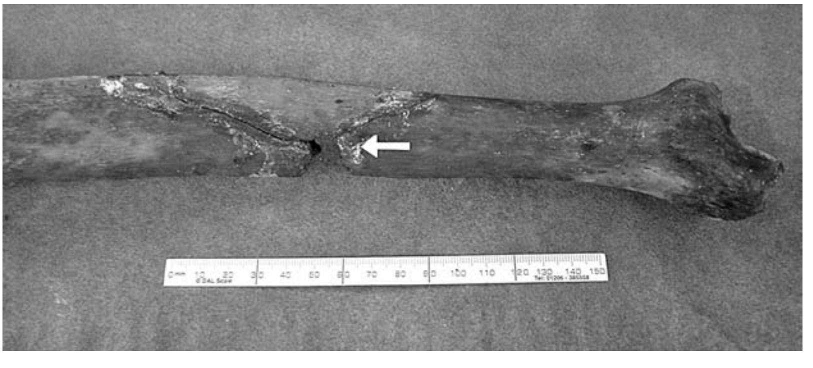


Figure 2.36 Gunshot wound to the left tibia, right to left. Circular defect indicates where the projectile entered the bone is evident. Note two fractures radiating from the defect to the anterior margin, creating a butterfly fracture. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

deceleration wounds, and penetrating shrapnel injuries. Blunt force trauma occurs when a victim is struck with an object, thrown in a blast, and may be associated with gunfire, torture, or explosive injuries. Sharp force trauma includes penetrating wounds that cut, chop, or stab with a sharp edge that slices or cuts tissues. Chopping wounds from axes or machetes are associated also with blunt force trauma as high-energy blows from such heavy objects are swung at a victim, both cutting and crushing tissues. Gunfire wounds are penetrating wounds that crush tissues. Both shrapnel/blasting and gunfire injuries produce projectile trauma. However, they can be differentially diagnosed based on characteristics of skeletal wounds, the distribution of injuries to the skeleton, and fracture patterns.

Generally, projectile injuries result in penetrating or grazing defects, complete, linear, radiating, and multifragmented fractures that displace bone fragments. By nature, they create patterned wounds reflecting the diameter or cross section of a bullet and impart a lot of force to tissues in a relatively narrow area. Shrapnel behaves similarly to gunfire projectiles in that it creates penetrating defects. However, shrapnel generally produces irregular-shaped defects (reflecting irregularly shaped metal fragments), is commonly embedded in bone, and rarely perforates the body. In contrast, blunt force injuries have a wide impact site with compression, shearing, and bending forces applied, resulting in either simple or comminuted fractures. In addition to projectile trauma, blasting mechanisms also produce a multitude of these forces from the blast wave that results in traumatic amputations of body parts or skeletal fractures. Sharp force injuries from knives have a narrow focus, whereas chopping instruments may have a wide focus.

The Microscopic Examination of Skeletal Tissue

The microscopic examination of skeletal tissues is a useful tool for distinguishing ante-, peri-, or postmortem changes in bone (Shipman 1981). It is also a useful tool for timing antemortem healing among fractures that occurred prior to death (Feik et al. 1997; Islam et al. 2000; Glencross and Stuart-Macadam 2000; Walsh-Haney 1999). Due to the specialized equipment and training needed for histological analysis, as well as time and financial constraints coupled with the high volume of cases, it has rarely been applied in the contexts of HHRR investigations, with a few notable exceptions (refer to Case Study 5.3 in Chapter 5). For example, microscopic techniques have been used to investigate cases of torture in which individuals were detained, beaten, and later killed. The timing of antemortem fractures in various stages of healing can demonstrate chronic abuse. It is useful for investigators to understand the biomechanical and physiological changes that occur microscopically and will likely manifest more broadly in the future.

The Timing of Fracture Based on Gross Inspection

Victims of HHRR abuses or extrajudicial executions are rarely killed and buried in the same place. More often, efforts are made to hide the crimes committed. Concealment or efforts to hide the cause of death or actual physical remains may take several forms; the body of the deceased may be hidden, graves may be moved or disguised for concealment, and death or autopsy records may be falsified. Victims may be killed in one location, then transported, and buried. Sometimes these graves are dug up and subsequently reburied in *secondary sites* (*The Prosecutor v. Krstic*, IT-98-33-T: 596, p. 212). Through this process, carnivores and rodents may have access to the remains. Burial and excavation tools may also leave marks on bones. Further attempts to hide or destroy evidence include dismemberment, burning, or bombing the remains—sometimes multiple strategies are used in combination. Having been buried in clandestine graves or within known cemetery plots, during the process of legal investigations, the remains are excavated, transported, stored in refrigerated coolers, and autopsied. Therefore, evidence of perimortem injuries, postmortem modification, and taphonomic processes that naturally occur during the decompositional process may all be visible on the remains and must be differentiated. To ascertain that the fracture is perimortem and possibly a contributing factor to the cause of death, the location, size, color, morphology, and number of modifications are documented and carefully interpreted. These variables have been widely documented in the bioarchaeological and paleoanthropological literature (Behrensmeyer and Hill 1980; Shipman 1981; Willey and Snyder 1989; Micozzi 1991). The timing of antemortem (before death) fractures, perimortem (at or around the time of death) trauma, and postmortem modifications (occurring after death) is discernable.

It is important to point out that the timing of these injuries is standard in anthropology but may vary slightly from pathology, where antemortem and perimortem categories may be combined or used interchangeably. Anthropologists refer to antemortem as a classification for events that occurred prior to and apart from the death event itself. Injuries related in time with the death, are classified as perimortem.

Antemortem Fractures

Antemortem injuries are easily distinguished because of evidence of healing (bone remodeling) such as abnormal bone growth, callus formation, abnormal bone shape, necrotic tissue, or characteristics associated with an infection (Ortner and Putschar 1981). By 1 to 3 weeks after the injury, the edges of the break become rounded (Sauer 1998) as the two elements reunite. After approximately 6 weeks, a bony callus begins to form (Sauer 1998). New (woven) bone growth is structurally different in form and may be best described as *disorganized*. Brickley (2005) demonstrated that rib fractures healing at the time of death were an important tool for demonstrating the history in child abuse cases. Over a long period of time, evidence of the break may only be visible radiologically if sclerotic bone is formed. A similar approach has been taken to document patterns of abuse and torture. Figures 2.37–2.42 illustrate examples of antemortem factures in various stages of healing.

Figure 2.37a Right clavicle (inferior view). Healed antemortem fracture with partial non-union in midshaft in the shape of a circular defect, giving the impression of a foramen (ICTY).

Figure 2.37b Right lateral adult skull. Healed SFT to right zygoma, defect still evident. Note round smooth edges of defects (ICTY).

Figure 2.38 Right rib, anterior view, exhibiting callus with woven bone resulting from antemortem fracture. The rib was in the active process of healing at the time of death (Alain Wittmann).

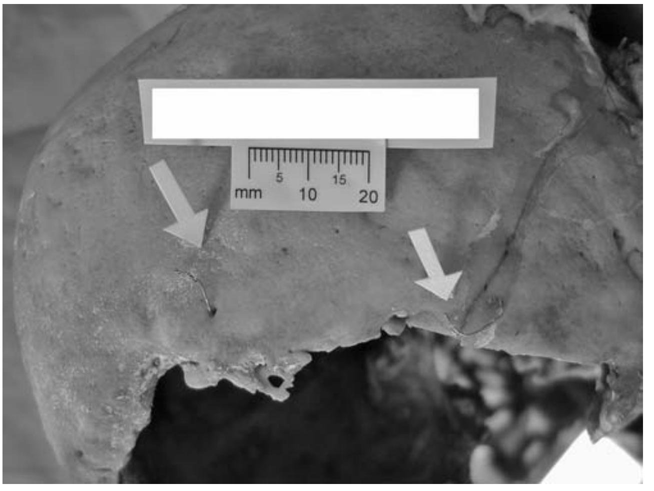


Figure 2.39 Evidence of craniotomy with healed bone tissue. Note the edges of the cranial fracture are smooth and blunt or rounded. There is also evidence of surgical wire present, indicating old injury with previous medical intervention. The individual died of a gunshot wound to the skull that resulted in extensive fracturing of the facial bones and mandible. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Peri- versus Postmortem Fractures

Perimortem fractures, in contrast to antemortem injuries, exhibit no evidence of healing. Further, perimortem fractures, unlike postmortem fractures, occurred while the bone was wet and encased in muscle, periostium, skin, and other soft tissues. Therefore, the skeletal remains exhibit characteristics unique to the timing of these injuries, including uneven

Figure 2.40a Evidence of craniotomy with remodeled bone tissue. Note the edges of the cranial fracture are smooth and blunt or rounded. Also, perimortem lateral through and through GSW, to the skull evident in the temporal region (ICTY).

Figure 2.40b Numerous small, circular defects in cranial vault are present, as indicated by arrows. These defects were created as part of surgical intervention and healed with extensive bone remodeling (ICTY).

edges that may also be irregular, hoop fractures (the bone may be bent or warped), radiating or concentric fracture lines, and an angled or jagged fracture edge (Maples 1986; Sauer 1998). Figures 2.43–2.48 illustrate examples of postmortem damage.

Distinguishing peri- and postmortem fractures may be the most challenging but also extremely important for accurately reconstructing the circumstances around and after death. Postmortem fractures occur during or following the decomposition process and,

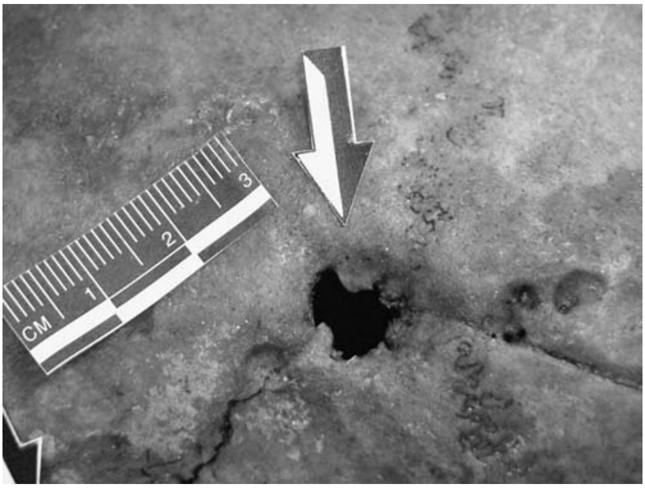


Figure 2.40c Lateral view of the cranium with trephination. Note the edges of the circular defect have a slight margin. The fractures between the defects were part of the surgical intervention. The bones show clear signs of healing. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.41 Radiography can be useful to correctly diagnose and document antemortem trauma. Healed fracture of left pubic bone with sclerotic bone is indicative of old fracture. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.42 Radiographic image. Two screws used to set antemortem fracture to the tibia and fibula. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.43a Postmortem skull fractures resulting from burial compression (ICTY).

Figure 2.43b Postmortem skull fractures, close-up view. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.44a Right lateral mandibular fragment, adult. Breakage postmortem (Rafael Guerra, USF).

therefore, may occur before the bone has become dry. The time for it to dry varies, depending on the burial environment. Generally, when bone is dry, fractures tend to have straight and sharp edges with no evidence of bending (Villa and Mahieu 1991; Ubelaker and Adams 1995). The broken surface may differ in color from the rest of the bone, and there will be an absence of fractures, such as radiating fractures.

Puskas and Rummey (2003) illustrate how postmortem scavenger marks may be distinguished from perimortem gunfire injuries. In cases in which heavy equipment, such as

Figure 2.44b Left lateral mandibular fragment from a second adult individual. Breakage also occurred postmortem (Rafael Guerra, USF).

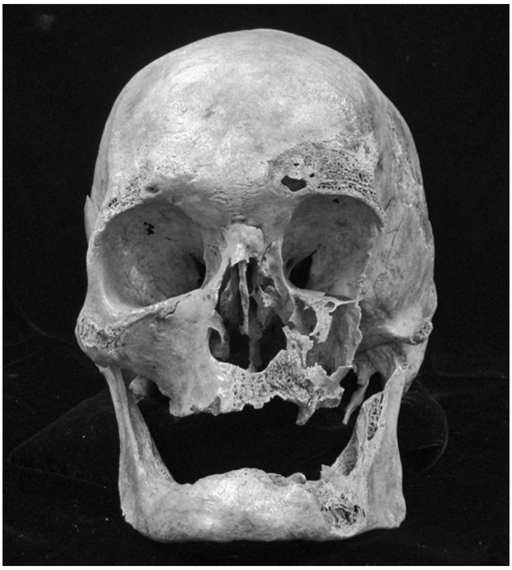


Figure 2.45 Adult male skull. Frontal bone, maxilla and mandible exhibit postmortem damage. The fractures are associated and appear linear, likely the result of excavator or shovel damage. When the fractures are aligned, notice that the mandible is not in anatomical order. Commonly following decomposition, the mandible will disarticulate from the cranium. This misalignment is also indicative of damage occurring postmortem (Rafael Guerra, USF).

Figure 2.46 Postmortem fracture of the right shoulder. The clavicle, scapula, and humerus exhibit characteristics consistent with damage from heavy equipment. Remains recovered from a secondary mass grave. Note the straight, transverse cut across the shaft of the humerus and the linear cut across multiple bones. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

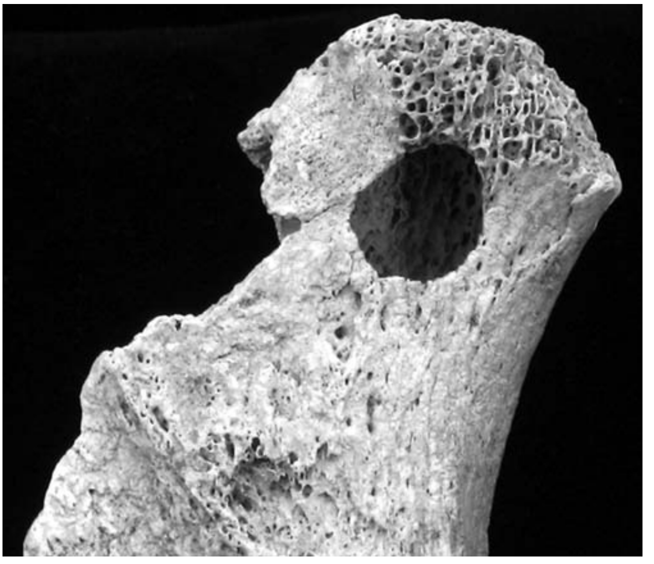
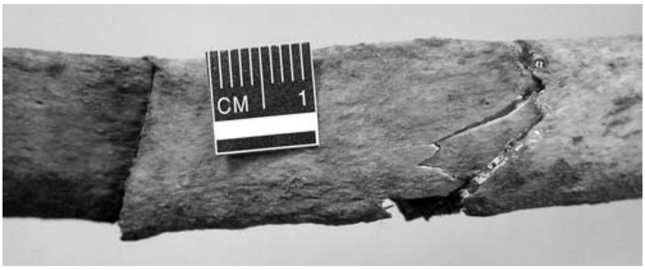


Figure 2.47 Adult right femur, anterior view. Postmortem damage, likely excavator damage. Outer cortex of bone poorly preserved, taphonomic change due to weathering (Rafael Guerra, USF).

bulldozers and backhoes, were used to create or move graves, bilateral transverse fractures of long bones and crushing fractures to other skeletal elements have been observed (Baraybar and Gasior 2006; Tuller and Djuric 2006). Transverse fractures resulted in the loss of limbs or body parts, often breaking through the shafts of long bones, with only the fragments of the fractured elements recovered in the grave. In these cases, the missing body parts were rarely recovered. The edges of the fractured segments were irregular and occurred primarily as linear fractures in the transverse plane of the shaft. Crushing fractures were also noted in the ribs, vertebrae, and pelvic girdle. The fractured edges exhibited bone spicules and "peeling" of the outer surface of the bone with some plastic deformation to the surrounding tissue. Segments of ribs or cranial remains may also exhibit severe deformation due to warping from ground pressure.

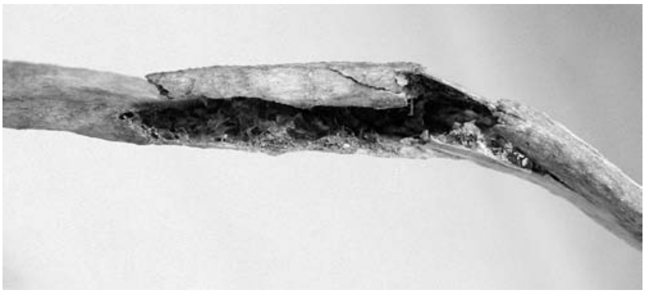
Finally, postmortem fractures tend to be lighter in color than the rest of the bone. Generally, incisions to bone will not cause deformation, but a trowel or other tools used for excavation or burial may cut or deform the bone. Cutting or chopping mechanisms will generally produce striation marks in bone that may have characteristics useful for differentiating postmortem modification from sharp force injuries (Greenfield 1999):

- Metal knives produce either a narrow V-shaped groove with a distinct apex at the bottom or a broader U-shaped groove with a flat bottom.
- Metal knives make more uniform patterns on the bone.
- In general, metal knives produce a clean and more even slicing cut (except for scalloped-edge knives and sawlike blades).

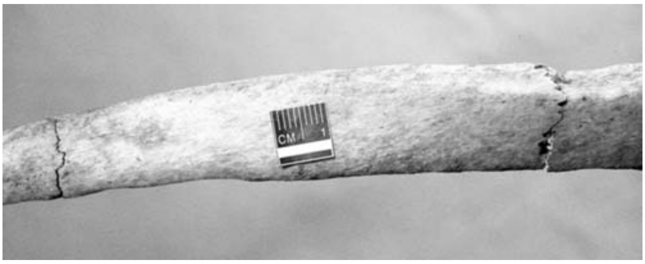


(a)

(b)



(c)



(d)

Figure 2.48(a–d) Adult ribs, various views. Postmortem breakage and fracturing (Alain Wittmann).

For more discussion on how to distinguish perimortem cut marks from postmortem modification (i.e., taphonomic factors or animal damage), refer to Haynes (1983), Willey and Snyder (1989), Berryman et al. (2001), and Symes et al. (2001).

Peri- versus Postmortem Burning

Just as with fractures it is important to distinguish perimortem from postmortem burning. Skeletal evidence of burning is fairly easily recognized, but, interpreting the timing of the burning may be challenging as burned bone has also been observed in cases in which perpetrators attempted to conceal evidence of victims or crimes committed. Burned bone will discolor, fracture in a variety of different ways, crack, and shrink (Mayne 1997). Burning characteristics are influenced by the use of an accelerant, clothing or associated materials burned with the remains and the location of the event in an open or closed space, the temperature of the fire, and time of exposure, as well as the presence of soft tissues (Shipman et al. 1984; Reinhard and Fink 1994; Mayne 1997). Numerous authors (Bradtmiller and Buikstra 1984; de Gruchy and Rogers 2002) have pointed out that understanding the morphological features of burned bone can be vital for differentiating perimortem trauma. Van Vark (1970), in controlled experiments cremating bone, reported:

- There is no bone shrinkage under temperatures of 600°C; however, the bones become more brittle as the temperature increased.
- There was up to 5–10% bone shrinkage at 700°C.
- There was up to 20% bone shrinkage at 800°C. Interestingly, at temperatures of 900–1500°C no more shrinkage occurred.

Illegal attempts to destroy evidence through burning rarely result in the complete destruction of skeletal tissue. Reconstructions of the biological profile (Bass 1984; Thompson 2004) and trauma analysis (Dirkmaat 2001; de Gruchy and Rogers 2002) have been possible following cremation attempts. de Gruchy and Rogers (2002) demonstrated that it was possible to identify knife and chopping wounds that had been burned. They reported that hacking trauma weakened the bony tissue, and therefore areas with trauma were more likely to fragment when burned, but most importantly the burning had little effect on trauma identification as they report that chop and cut marks were easily recognizable following cremation (de Gruchy and Rogers 2002). Further, the volume and weight of cremated remains may be useful in estimating how complete the body of the victim was prior to burning or the number of victims (Murad 1998; Bass and Jantz 2004). In a series of images provided by Elayne Pope based on controlled experimental studies, examples of bone burned peri- and postmortem, including cases with preexisting perimortem trauma are illustrated (Figures 2.49–2.57). Based on color, location of burn patterns, and the morphology of the fractures, peri- and postmortem burning is distinguishable. Further, identification of preexisting fractures may be detected from cremated remains and are discussed in Chapter 6.

Figure 2.49a Adult crania, anterior view. Burn patterns, fleshed head burned to mimic perimortem event (Elayne Pope).

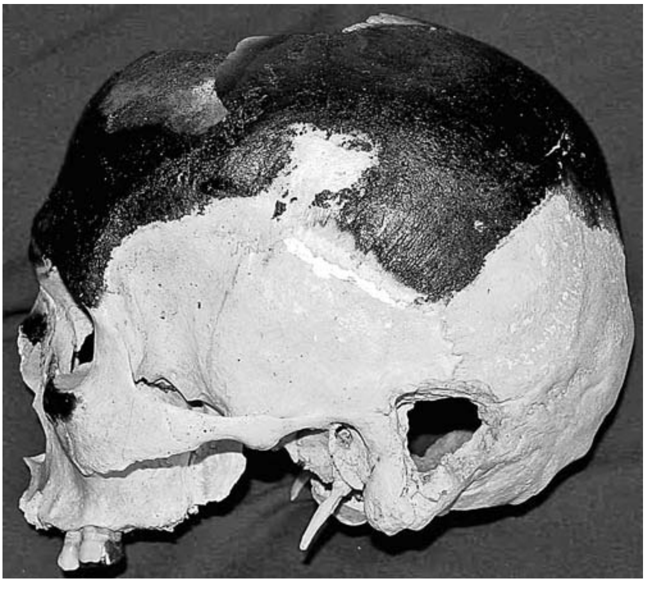


Figure 2.49b Adult crania, left lateral view. Burn patterns, fleshed head (Elayne Pope).

Figure 2.49c Adult crania, posterior view. Burn patterns, fleshed head (Elayne Pope).

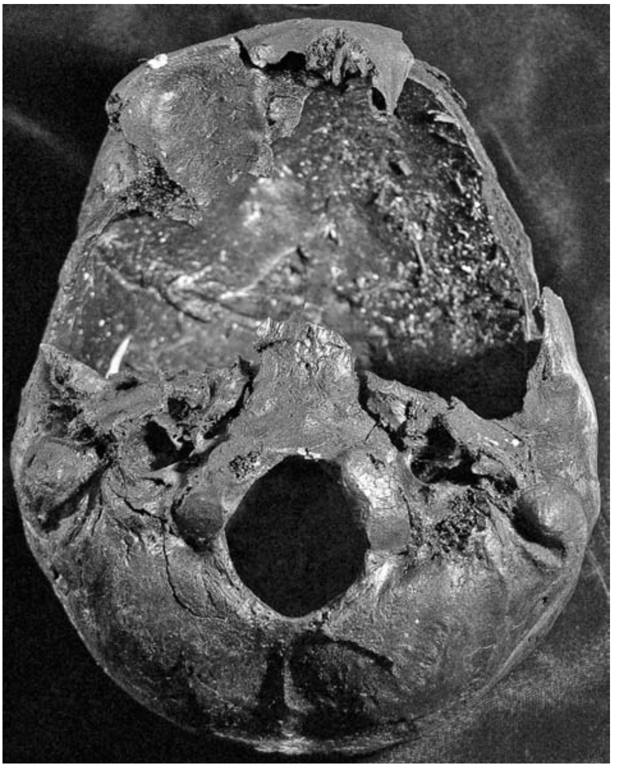


Figure 2.50a Adult crania, basiliar view. Patterns of postmortem burning without flesh present (Elayne Pope).

Figure 2.50b Adult crania, left lateral view (Elayne Pope).

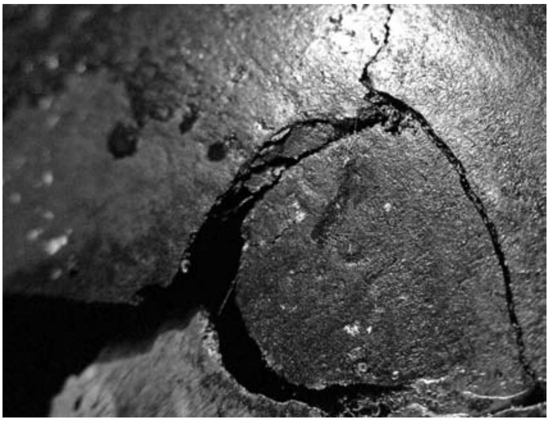


Figure 2.51 Adult crania, right lateral view. Crania burned with pre-burning fracture present (Elayne Pope).

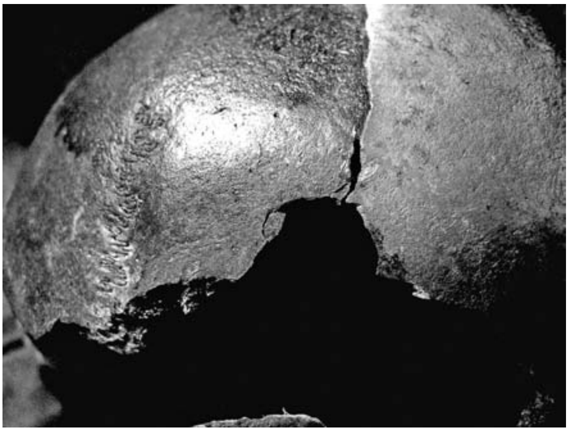


Figure 2.52 Adult crania, right lateral view. Differential coloring of the cranial fragments resulting from preexisting fracture to the skull. Cranial fragments separated during burning resulting in differential color patterns among associated cranial fragments. Color pattern is useful to determine if the fracture was present before burning (Elayne Pope).

Figure 2.53 The color and curved fractures on this bone fragment are indicative of a bone that was fleshed when burned (Elayne Pope).

Figure 2.54 The curved lines indicate the bone was fleshed when burned and the direction of the fire, as tissues pull away from the heat (Elayne Pope).

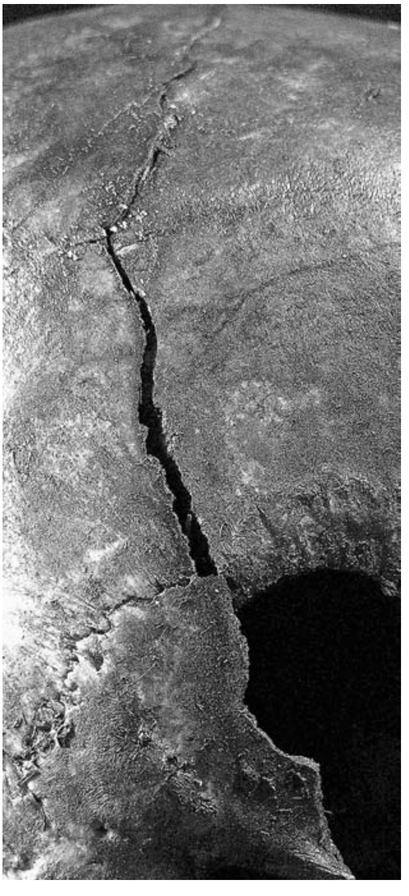


Figure 2.55 Fracture present before the skull was burned. However, the deformation and shrinkage are the results of the fire (Elayne Pope).

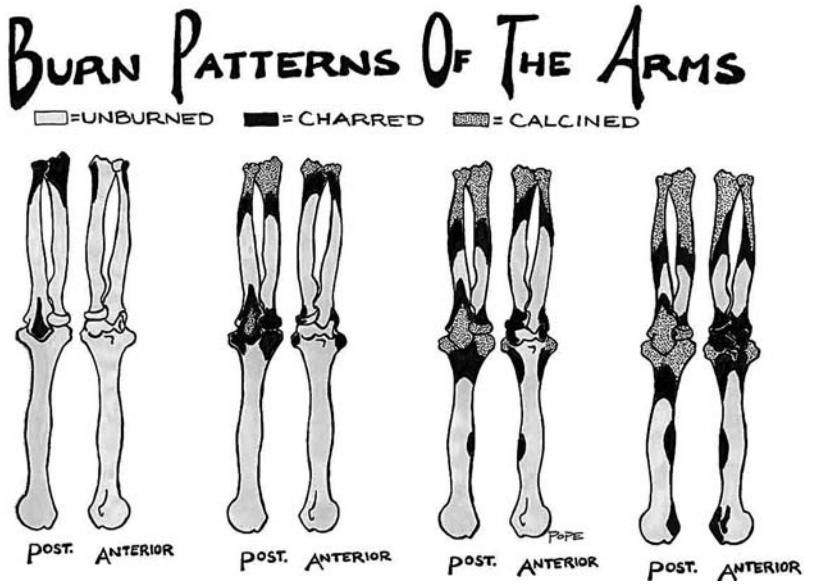


Figure 2.56 Burn patterns of fleshed upper limbs (Elayne Pope).

Diagnosis of Injuries without Evidence of a Defect

A skull may be so extensively fractured that even after reconstruction, it may not be possible to identify a defect or point of impact that clearly allows estimation of the mechanism of injury. So what can be deduced from a fragmented bone without any defects? First, the

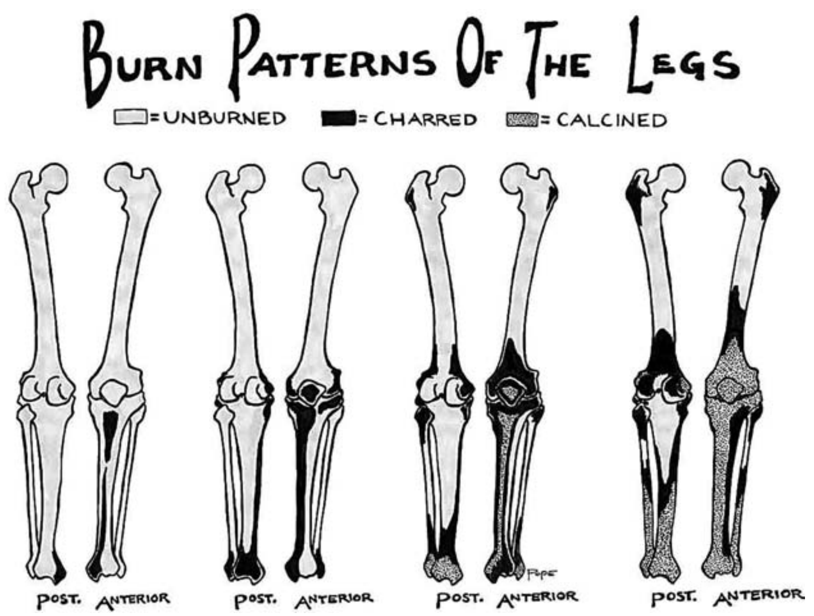


Figure 2.57 Burn patterns of fleshed lower limbs (Elayne Pope).

timing of fractures must be established. In other words, did the fractures occur during the peri- or postmortem interval? Postmortem fracturing of the skull is usually accompanied by plastic deformation of the vault and may or may not have soil staining along the broken edges of bone. Fractures also tend to be isolated or without a clear origin. Postmortem fractures, if not caused during the excavation (in which case they may show patterned injuries with tool markings caused by a pick, shovel, or the "teeth" of a backhoe) may be caused by compression of the head during burial, generally in an anterior–posterior or lateral direction. For example, compression may cause "sinking" of the face into the neurocranium. The facial structures retain their integrity and appear "pushed into" the vault without any possibility to restore them to their original position. Cranial remains may be difficult to reconstruct in these cases because of warping.

Perimortem fractures, without evidence of a ballistic defect may still be consistent with gunfire injuries and indicative of low- or high-velocity forces. Fracturing due to high-velocity forces generally cause extensive comminuted fractures of significant regions of bone; generally, this is associated to multiple generations of radiating and concentric fractures. In the skull, more extensive fracturing occurs at the exit point. In long bones, extensive fracturing will occur at the entry and exit points. In high-velocity cases, radiating fractures sometimes cut across or circumvent areas of buttresses that would not typically break with a low/slow load force. As a general principle, radiating fractures do not show plastic deformation. Comminuted skull fractures can be easily reconstructed with negligible deformation. As explained earlier, however, a fractured skull can be subsequently deformed due to taphonomic factors, such as ground pressure from burial, postmortem.

Second, the type of trauma (i.e., gunfire or blunt force) may be estimated based on fracture patterns, even in the absence of specific defects. For example, on reconstruction of a severely fractured skull, a combination of radiating and concentric fractures becomes evident. It is highly likely that the fractures result from a gunfire injury because of the type, location, and association of fracture lines that are consistent with a gunfire injury, not postmortem damage. In cases in which the defect is not observable, there may still be metal fragments present evidence by inspection or through radiography.

Radiography and Three-Dimensional Imaging

There are several radiographic references that provide specific and useful guidelines for radiographic methodology for interpretation in postmortem examinations (Ortner and Putschar 1981; Knight 1991; Brogdon et al. 2003). Radiographic techniques specifically in cases of HHRR or political abuse have also been a focus of recent discussion (Farkash et al. 2000; Brogdon et al. 2003; Fitzpatrick 1984). For most cases involving excavated human skeletal remains, the primary objective for radiographic analysis is to locate physical evidence of weaponry such as lead wipe from a projectile or shrapnel fragments (Figures 2.58 and 2.59). A further benefit is the safety of the investigators as live munitions such as hand grenades present in clothing should be identified prior to the examination (Figure 2.60).

In skeletonized cases, radiography can be used for understanding fracture patterns, assessing the number of injuries, or sequencing multiple injuries. Injuries involving high-velocity gunfire or explosions result in significant fracturing that will appear on x-ray as a pile of bone fragments. For the investigator who reconstructs a fractured skull or long bone, radiography has little diagnostic value in interpreting fracture patterns. Rather,

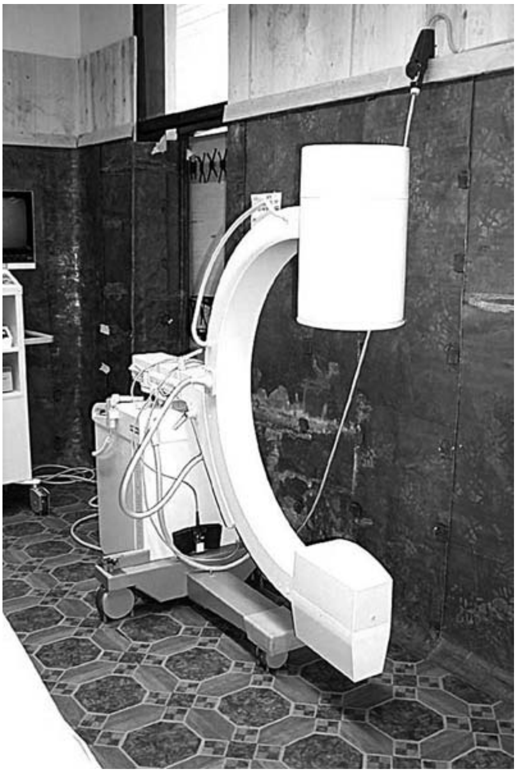


Figure 2.58 Portable Fluoroscope. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

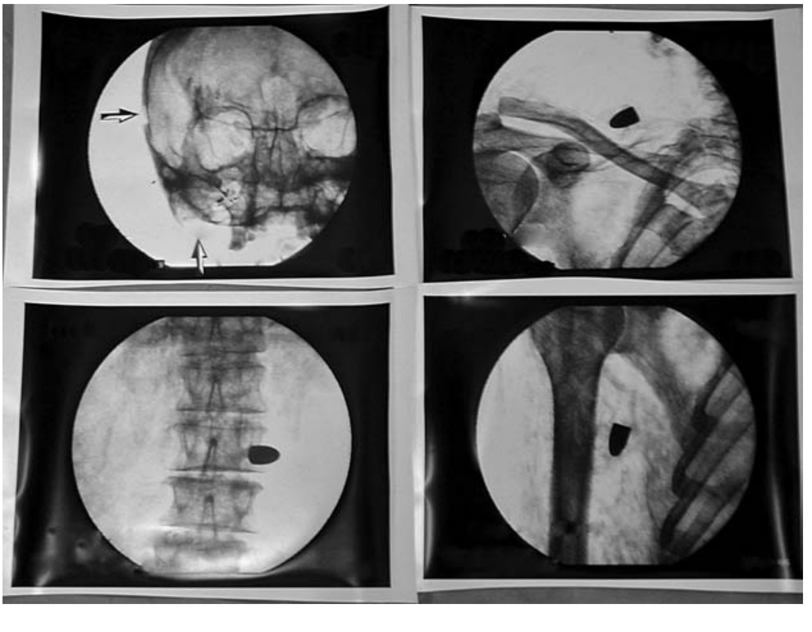


Figure 2.59 Series of images displaying projectiles embedded within body cavities. Images are from a fluoroscope. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

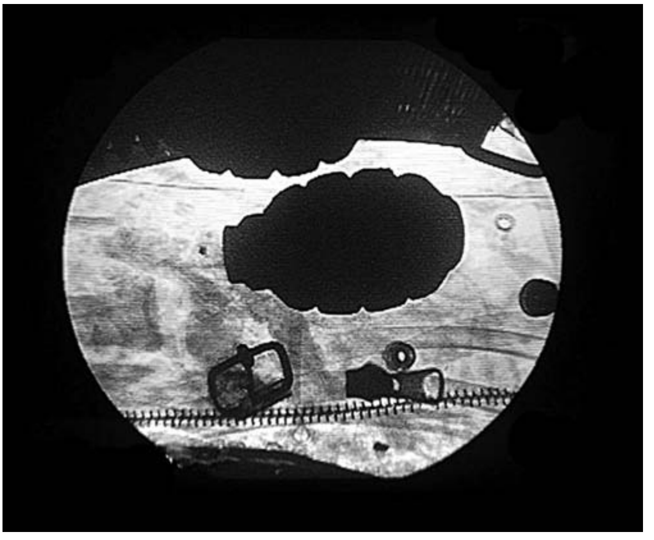


Figure 2.60a Radiography is also useful for identifying weapons, ammunitions, or unused explosives within pockets or layers of clothing. Pictured here are two grenades stuffed into a pocket. These grenades were not found in the field at the time of excavation, but later after being transported to the morgue and scanned with a fluoroscope (ICTY).

radiography as a diagnostic tool involves cases in which soft tissue is present, holding the skeletal elements in anatomical position. However, these do not make up the majority of cases for the anthropologist, as demonstrated by material presented in this book. Data may be obtained on fracture type or fragment location that are not visible or recognizable by gross inspection of the body alone. Typically, these *fresh* cases have not yet decomposed and the data yielded through radiographic techniques may prove useful in the identification of skeletal trauma (i.e., Cattaneo et al. 2006). In fresh cases, imaging is used to differentiate

Figure 2.60b The actual grenades recovered in clothing. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

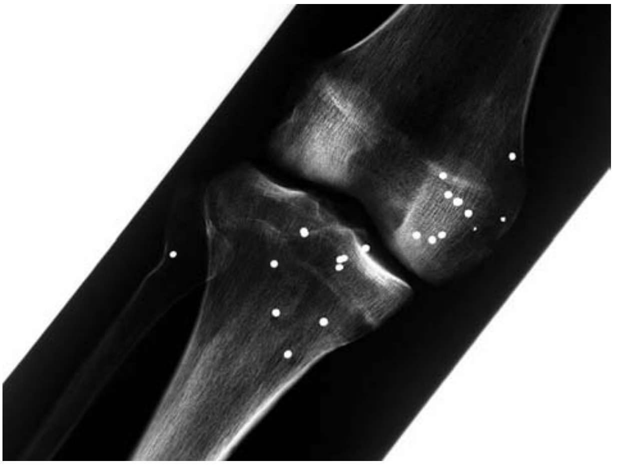


Figure 2.61 Gunshot pellets embedded in the left knee. Shot was fired right to left at an intermediate distance based on the spread of the pellets. Note also the skeletal defect on the right lateral margin, indicating an entry wound. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

different types of trauma (Oliver et al. 1997), elucidate complex fractures (Salvolini 2002; Oehmichen et al. 2003), or identify fragments from weaponry (Figures 2.61–2.69).

Radiography is very useful in cases in which trauma or skeletal pathology occurred antemortem and for diagnosing the timing of antemortem injuries or the type of skeletal reaction due to a pathogen. Radiography also serves important functions in assessing the amount of epiphyseal union among juveniles or diagnosis of skeletal pathology. In diagnosing skeletal pathology, radiography illustrates skeletal reaction on the surface of a bone or within the tissue structures and the location and distribution of bony responses. Further, radiology provides useful imaging for ante-and postmortem comparisons for

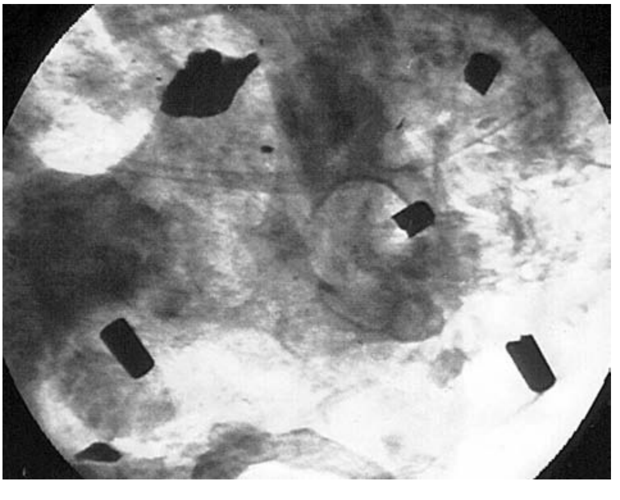


Figure 2.62 Metal shrapnel fragments resulting from a blasting injury. Note the symmetrical, rectangular-shaped pieces of metal. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.63 Two projectiles visible on fluoroscope image along lower vertebrae. The metal artifacts from clothing, such as zippers, are also evident. The same projectiles recovered from within the tissues are pictured. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

victim identification, such as dental x-rays, orthopedic hardware, or unique skeletal structures such as sinuses or trabelcular bone patterning in the pelvis or hip regions.

Radiography has another important function as a visualization tool for the courtroom presentation of injuries and illustration of circumstances around death for a panel of judges or a jury (Meyers et al. 1999; Thali et al. 2002a, 2002b). In this context, radiography is not used as a diagnostic tool, but it provides imaging, even three-dimensional (3D) imaging of reconstructed bones, that is understandable to non-experts (Figures 2.70 and 2.71).

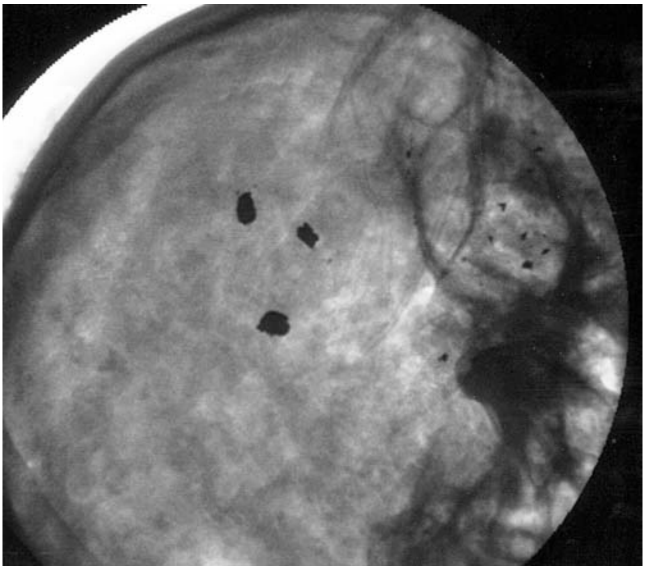


Figure 2.64 Fluoroscope image. Metal fragments from a gunfire projectile are evident in this skull. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.65 The right knee (distal femur and proximal tibia) are pictured. Two gunfire injuries are present. The projectiles did not exit either bone. The fragmented metal pieces from the projectiles are evident on the x-ray image. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

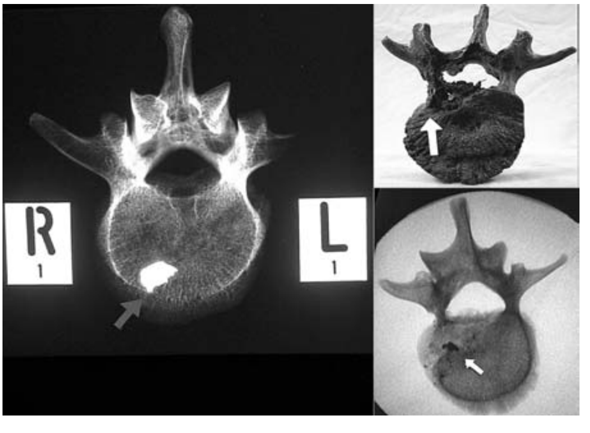


Figure 2.66 The image on the right: projectile fragment from a gunfire injury. Fragment is embedded in the body of a lumbar vertebra. The depth of the fragment and fracture line is evident in the fluoroscope image. The images on the right illustrates a lumbar vertebra from a different case that also has a fragmented metal piece of a projectile from a gunfire injury. The actual bone and an image taken with a standard x-ray are shown. The differences in visualization between fluoroscope and standard x-ray images are apparent. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

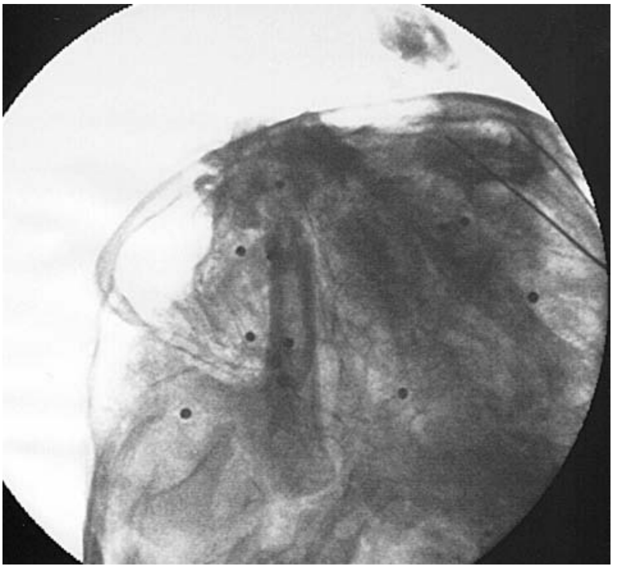


Figure 2.67 Shotgun pellets in the skull, evident in fluoroscope image. Distance among pellets consistent with shot fired from a distance. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.68 Shotgun pellets in the skull shown in the frontal view, taken by a standard x-ray. The distance between the pellets indicate the shot was fired from a distance. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

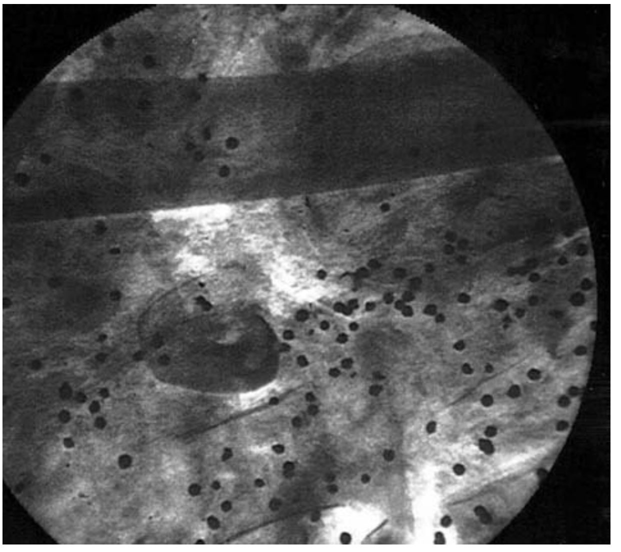


Figure 2.69 Numerous shotgun pellets present in decomposing soft tissue, disarticulated femur also evident in fluoroscope image. The pellets are close to one another, which is indicative of a shot fired from an intermediate distance. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.70 3D-CT image. Blunt force trauma to the left scapula. A compression fracture is present on the acromion process and a linear fracture extends across the scapular body (right side). The humerus was digitally removed in the image on the right to allow better visualization of the scapula and glenoid process. (Image reprinted with permission from Dr. Matthias Okoye and Dr. David Kiple.)

Figure 2.71 3D-CT image. Spine and thorax recreated digitally to demonstrate scoliosis and hemivertebra in thoracic region. Congenital defects. (Image reprinted with permission from Dr. Matthias Okoye and Dr. David Kiple.)

Any image produced from a radiograph, fluoroscope, MRI, or CT scan may be useful in this way. In particular, images reconstructed from CT scans or taken with 3D scanners present the bone in three-dimensional space that can be rotated or viewed from different angles. This is useful for illustrating the trajectory of an injury or describing how one projectile may affect different regions of the body (Donchin et al. 1994). Radiographic images such as 3D reconstructions also allow data files to be shared electronically, which is valuable for obtaining a second opinion, regardless of where investigators are located throughout the world and are being used in real-time applications such as virtual autopsies (Thali 2003a, 2003b; Thali et al. 2002a, 2002b; Thali et al. 2003a, 2003b).

The Usefulness of Clothing as Evidence

Clothing in human rights investigations is an important line of evidence in the initial phase of the identification process. Clothing is also an important tool for understanding the mechanism and number of injuries, and the trajectory path and range of fire in ballistic and shrapnel wounds (Figures 2.72–2.76). The interpretation of injuries and victim identification from clothing is relevant to the context of the situation, the nature of the armed conflict, and the victim's age, sex, and identity (i.e., military or civilian). For example, the types of clothing that are present, the amount of clothing a person may have been wearing at the time of disappearance, whether the clothing was owned by the person wearing it (or issued something to wear), and what items were contained within pockets or layers reveal important attributes about the nature and intention of crimes committed.

Protocols for postmortem examinations must always include a strategy for handling clothing and guidelines to recover all associated evidence obtained within and preserve and curate the items for future reference or use at trial. The component of a projectile, shell casings, shrapnel from blasting injuries, and small bone fragments may become embedded in clothing. Clothing should not be cut at the site to collect the bones from a clothed

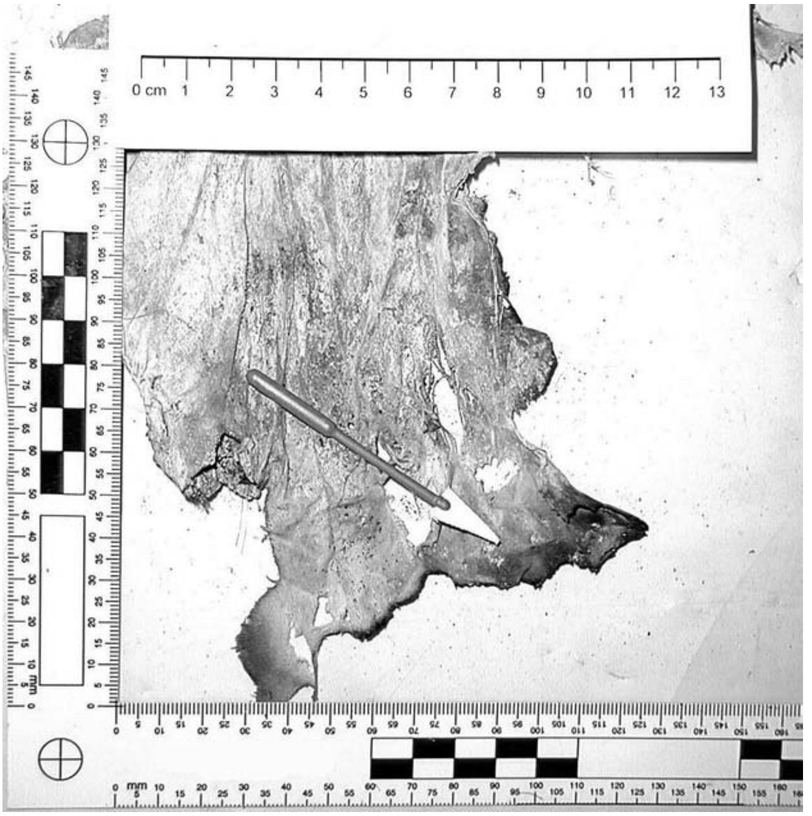


Figure 2.72 Remnants of boxer shorts with evidence of burning. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.73 Gunfire injury to the left foot. Entrance evident on left side of shoe and a corresponding injury is noted on the left sock. No burning, soot, or gunpowder is present, indicating an intermediate or distant shot. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

skeleton, nor during the postmortem examination. Further, clothing should always be x-rayed separately from the body, prior to its being washed. Clothing should be thoroughly inspected and photographed both prior to and after washing for later use in the identification process, and to review defects indicative of injuries. The clothing, by evidence of soot or burning, provides information that assists with understanding the circumstances around death such as mechanism of injury, the range of fire, and postmortem taphonomic processes that affected the remains (Maples and Browning 1994).

Clothing is also a meaningful tool to link an unidentified person to a particular family or village thereby establishing group identity. For example, textiles proved to be very useful for personal identification (Schmitt 2001; Doretti and Snow 2003) during investigations into mass atrocities against the Kurdish people in Iraq (1987–1989) and the Maya in the highlands of Guatemala (1980–1984). In both of these examples, textile patterns and colors play a significant cultural role and uniquely represent each village. In either of these cases, no attempts were made by the perpetrators of the crimes to hide the victim's

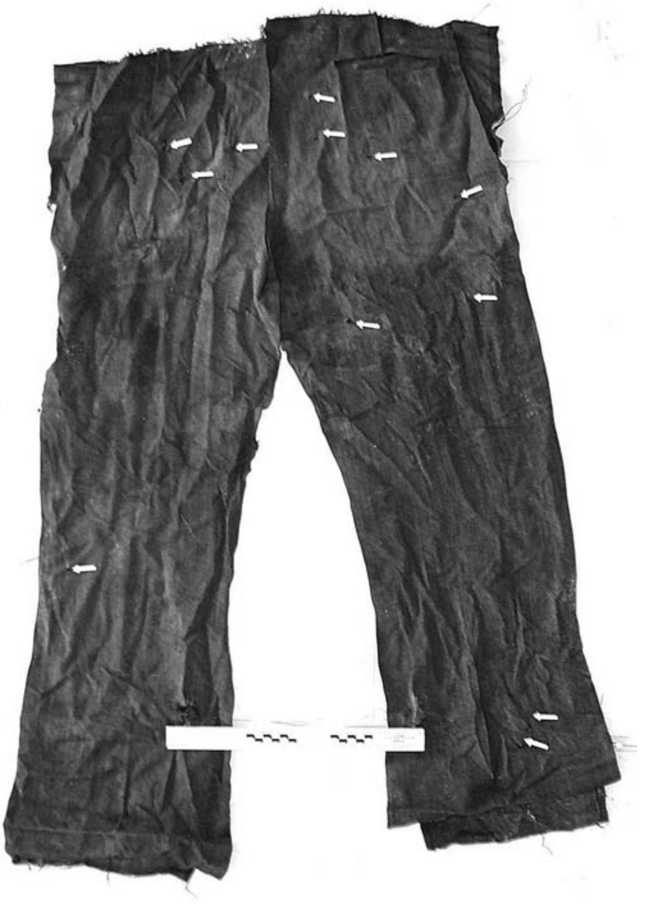


Figure 2.74 Pellets from a shotgun injury pattern consistent with pellets fired from a distance. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

Figure 2.75 A 7.62 × 39 mm full metal-jacketed bullet, fired from an AK-47, is embedded in a leather belt buckle. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

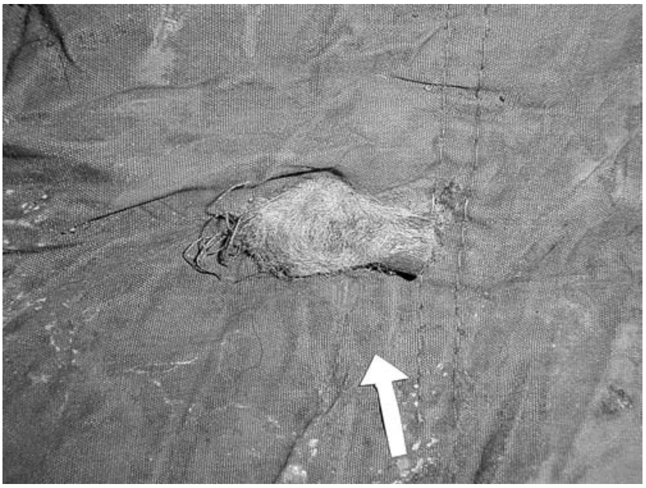


Figure 2.76 A 7.62 × 39 mm full metal-jacketed bullet, likely fired from an AK-47, is embedded in the fibers of a jacket. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

identity, such as taking their clothing, nor were the victims generally held captive prior to their executions. Therefore, *group identity* was established based on textiles.

In some cases in which victims are detained, concealing identity may not be an issue. Doretti and Snow (2003) report on the Kotebe case from Ethiopia, where 30 men disappeared after being held in custody. During detainment, family members were allowed to visit and bring clean clothing (Doretti and Snow 2003). Therefore, even though the men were held captive, clothing was useful for personal identification. Throughout the Balkan conflict (1991–1999), there was considerable variation in the events surrounding the murder of thousands of people. In cases associated with Srebrenica, as discussed in Chapter 1, men were told to leave their personal items such as suitcases and identification papers outside as they entered into buildings. Many of the bodies of those who were killed were then disposed of into mass graves and later exhumed and moved to *secondary* sites by the perpetrators in an attempt to hide the location of the graves. Ultimately, these graves were exhumed and used as evidence of violations of international humanitarian law (IHL), including war crimes and genocide. Although significant efforts were made to hide graves, clothing was not generally taken away prior to the killings. Not only the clothing that the victims were wearing but also piles of folded clothing were recovered in graves, providing evidence that civilians were intentionally killed (refer to *The Prosecutor v. Kristic IT-98-33-T*, particularly the transcripts related to the testimony of Baraybar on Nova Kasaba sites).

Later, in 1999 Kosovan Muslims were fleeing their homes as the Serbian authorities attempted to expel them from the region. Many of the victims were recovered wearing numerous layers of shirts, sweaters, trousers, and socks. Wearing so much clothing was one way to stay warm as they were fleeing to the mountains during the cold months of the year, and it provided a means to carry more items (both clothing and personal items) as they left their homes. Identification papers, money, medicine, photographs, personal papers, jewelry, and ammunition have been recovered from pockets or within the socks

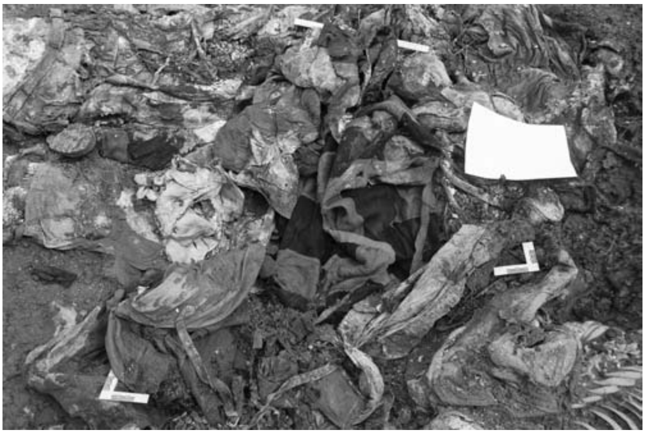


Figure 2.77 Clothing folded in a grave. Luggage taken from civilian men killed in Srebreniča in July 1995 and buried in mass graves. (Printed with permission from International Criminal Tribunal for the former Yugoslavia [ICTY].)

that people were wearing at the time of their deaths. In Kosovo, many people were also killed in or around their homes. In most cases, no attempts were made to hide the identity of victims or their murders. Most victims were left in their homes, and the bodies were not even moved or disposed of by those who committed the atrocities.

Throughout the Balkans, as elsewhere, such clothing and personal items have been useful tools for presumptive victim identifications as families identify these personal items (Figures 2.77 and 2.78) (OMPF 2004; OSCE Report 1999a, 1999b).

The cultural context in which the conflict occurs is an important consideration when interpreting cultural objects as evidence, such as clothing. Clothing is a good example of this, as it cannot always be used for identification as in the cases of Argentina and Peru (refer to Case Study 5.4 in Chapter 5).

Figure 2.78 Family members and survivors look through clothing and personal artifacts in the hope of recognizing something to identify the unknown (ICTY).

For example, in Argentina ("The Dirty War," 1976–1983), clothing was taken from individuals who were imprisoned prior to execution for the explicit purpose of taking away their identity (Doretti and Snow 2003). This was done to degrade and dehumanize victims as they were imprisoned and was one of the many forms of psychological and physical torture inflicted on detainees. Consequently, exhumations and postmortem examinations of victims, during criminal investigations many years later, has meant that clothing worn by them cannot be used for identification (Doretti and Snow 2003). In cases such as Argentina or Peru, clothing is still an important evidentiary tool for trauma analysis and for the possible inclusion/exclusion of individuals in the initial stages of collective identification.

Photography

Photography of skeletal wounds and associated artifacts is important for documenting what happened and for presenting a visual image of what is observed. Ideally, when the resources and time permit, a photography protocol should specify that both standard and special shots be taken. A photo log is kept, documenting all of the photographs taken. The log should include information on the case number, date, name of photographer, number of the shot, description of what appears in the photo, and comments on the distance of the camera to the specimen and its orientation. Traditionally, photographs were taken in black/white and in color; however, digital photography has cut costs substantially, allowing large numbers of high-quality photographs to be easily recorded and digitally stored. The photographic record of the hundreds of cases examined by the Office on Missing Persons and Forensics (OMPF) in Kosovo has primarily been based on digital photography.

Generally, the camera should be mounted on a tripod and placed perpendicular to the object being photographed. Black-colored cloth such as velvet or green medical scrubs provide strong contrasts as backdrops to bone. Standard photographs are taken of views of all every skull and innominate aging surface depicting each surface of the specimen. The shots should be in anatomical position, requiring strict guidelines for the position and angles of the skeletal materials to the camera. Standard shots of the skull include eight views (frontal, left lateral, right lateral, posterior, superior, inferior, maxillary occlusal, and mandibular occlusal). Two standard views are taken of the *Os coxa* (that illustrate the auricular surface and pubic symphyseal face for age estimation). "Special shots" should also be taken of all fractures, injuries, skeletal and dental pathology, or cultural and medical modifications. These cases require standard shots and special angles, close-up views, and multiple views from oblique angles. Experience shows that articulating anatomical parts such as the skull to the cervical spine, the mandible to the cranium, or the forearm to the humerus and gluing them together assist in depicting the extent and complexity of injuries. In addition, it is a more didactic tool to present the most visually interesting and clear image in court than the photograph of an isolated bone with an injury. Records of the site/burial/case numbers indicate where the subject is from. This label and a scale should appear in at least one photograph for reference per case. When shooting film outside the morgue or without control over the amount and direction of light, images should be bracketed with the exposure set higher and lower. Several shots with varying light will ensure the right exposure and a good result.

Summary Guidelines for Best Practice

Methods, organization, and clear terminology are needed for reliable and consistent analyses of skeletal trauma to be useful in medicolegal death investigations. Furthermore, careful and consistent recovery is needed to ensure the collection of all evidence. Radiography and the analysis of clothing are also important lines of evidence adding to information about injuries. This chapter provides a comprehensive step-by-step guide on how to reconstruct skeletal injuries. The utility of three-dimensional imaging in the assessment of trauma and the visual presentation of injuries in court are discussed. Finally, a correct diagnosis of skeletal fractures is necessary to differentiate peri- and postmortem trauma. Various examples and a list of criteria for differentiating postmortem damage from perimortem skeletal injuries are provided.

Accuracy in the skeletal diagnosis of injuries around the time of an individual's death relies on the integration of as many lines of evidence as possible. Data from a variety of sources should be used in combination; these include the anthropologist's examination of the skeletal tissues, microscopic analysis of the affected bone surfaces, radiographic data, the assessment of the individual's clothing, and the evaluation of the physical evidence of weaponry. After all of the evidence is considered, deduction is used to classify each injury category, identify the mechanism of the injury, and determine the most likely cause of death.

Some of the unusual skeletal pathologies that occur during conflicts and the implications for the process of victim identification are discussed. During wartime and human rights conflicts, individuals often do not have adequate health, nor dental care or proper nutrition, because of imposed embargoes, military seizures, the dissolution of the social infrastructure, or forced refugee status. Consequently, a number of health-related issues arise as medical problems are untreated or child growth and development are inhibited. As a result, the postmortem record of skeletal and dental pathology may not match potential antemortem records of the affected individuals. Moreover, juvenile age estimation may be skewed as a result of growth delays from malnutrition. Documenting this at autopsy may illuminate HHRR atrocities or critical human insecurities.

Case Study 2.1: Finite Element Models of the Human Head in the Field of Forensic Science

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Until recently, the legal system relied on the testimony of medical experts to determine whether the force imparted to the human head in a given scenario was consistent with the resulting human head injury. Finite element models (FEMs) can provide interesting tools to the forensic scientist when different human head injury mechanisms need to be evaluated (e.g., adult and child head injuries, and ballistic human head injuries). Human head FEM are not in common use in forensic science and are mainly used for car crash safety evaluations. Technological progress has resulted in creating more simple tools that can be used in forensic cases. The last 40 years have seen biomechanical studies emerging in forensic research. Many of these aimed at establishing whether a head injury of an infant was the result of accident or abuse and, if it was abuse, what were the possible mechanisms leading to certain injuries such as subdural hematomas (Cory et al. 2003; Jones et al. 2003). Other works such as multibody dynamics reconstruction of adult head injury accidents and biomechanical studies of falls have recently been published (Bandak and Chan 1999; Vock 2001; Zhang et al. 2001; Ruan et al. 2003).

FEMs are considered a promising tool to investigate the dynamic response of the human head under impact conditions. Moreover, by reconstructing well-documented real-world accident cases it has been possible with these models to derive tolerance limits for skull fracture, subdural hematoma, and neurological injuries. Recent work has been published using the Université Louis Pasteur FEM for the evaluation of human head injuries in forensic cases (Raul et al. 2005; Raul et al. 2006; Roth et al. 2006).

Standards for car safety and head protection systems rely on criteria for human tolerance, which are based on biomedical research performed more than 30 years ago. Measures designed to improve human head protection are typically evaluated against the measurement of a rigid mass acceleration and the calculation of the head injury criterion (HIC). The predictive capability of this criterion has been widely criticized because of its limited ability to predict the wide range of head injury mechanisms. It has been suggested that specific deformation or stress of the skull and brain tissue, as well as a measure of the relative motion of the brain and skull, would be much better injury mechanisms to assess human head protection.

To date, more than ten different three-dimensional human head FEMs have been described and validated against skull deformation, as well as brain pressure data from experimental impact tests onto the front of the head of cadavers, and against brain skull relative motion, with data obtained from high-speed x-ray experiments. Most advanced approaches were proposed by Ruan et al. (1993), besides NHTSA (National Highway Traffic Safety Administration) by Bandak et al. (2001), Wayne State University (WSU) model by Zhou et al. (1996) and Yang and King (2003), and ULP-Strasbourg (Université Louis Pasteur) by Kang et al. (1997).

To derive tolerance limits from these models, Zhou et al. (1996) simulated a fully documented road accident with the WSU model; the shear stresses predicted by his model agreed approximately with the location of axonal injury described by the medical report. More recently, Newman et al. (2000) presented a detailed methodology for the assessment of mild traumatic brain injury based on the reconstruction of accidents of the American National Football League, using the human head FEM in Zhou et al. (1996) and the ULP head model in Willinger and Baumgartner (2003).

The WSU brain injury model was also used to correlate brain Von Mises shearing stresses with angular head acceleration on the one hand and brain pressure with the head linear acceleration on the other hand. Correlation coefficients of 0.86 and 0.82, respectively, were found in the study by Yang and King (2003). In 2001, Bandak et al. (2001) presented a first version of a human head injury assessment tool based on a very simplified human head FEM called Simulated Injury Monitor (SIMON). In this approach, tolerance limits were established for subdural hematoma, diffuse axonal injuries, and brain contusions by scaling up animal test results from the literature. In other studies, SDH (Subdural hematoma), the parasagittal elongation of bridging veins, or their elongation rate, are computed with the FEM by Bandak et al. (2001). For contusion and diffuse injuries dilatation and brain strain are computed respectively.

Currently, real-world accident analysis is used in an attempt to correlate a known human head injury parameter with the AIS (Abbreviate Injury Scale) value sustained. An attempt by Chinn et al. (1999) to correlate initial human head impact velocity, maximum linear and rotational acceleration, HIC value and General Acceleration Model for Brain Injury Threshold (GAMBIT) value (which takes into account not only linear acceleration but also rotational acceleration of the human head) versus AIS gave correlation coefficients of 0.3 to 0.6, which is not satisfactory. The main reason for the poor correlation between a given parameter and AIS was that the same AIS levels can be reached from very different injury mechanisms. A much better approach is to take into account the likelihood of the human head injury mechanism.

When the type of lesion, rather than the AIS, is used for comparison, Willinger *et al.* (2003) showed by simulating sixty-six (n = 66) head trauma with the ULP-Strasbourg head model, that brain Von Mises stress is a good indicator for brain neurological lesions, whether they are moderate or severe. Moreover, this mechanical parameter allows distinguishing these lesions into two categories: moderate or severe. The tolerance limits for neurological moderate or severe injuries with a 50.0% risk are established for brain Von Mises stress of 18 kPa and 38 kPa, respectively. These values can be compared to previous reported data such as 11 kPa by Zhou *et al.* (1996), 15 kPa proposed by Kang *et al.* (1997), or 27 kPa suggested by Anderson (2000) on single cases. The reconstruction of this high number of head trauma with a ULP model also shows that global strain energy in the cerebro-spinal fluid (CSF) layer and in the skull structure is a reasonable indicator for subdural hematoma and skull fracture respectively. Brain pressure has been shown by Ward et al. (1980) to be correlated with brain hemorrhages resulting in brain contusions, edema and hematoma when reaching values above 200 kPa.

The global strain energy of the subarachnoid space has been shown to be correlated with hemorrhages resulting in subdural and subarachnoid hemorrhage when reaching values above 5.5 J with a 50% risk of occurrence. For skull fracture a 50% risk was established by a skull strain energy of 2.2 J. This later limit is well confirmed by tolerance limits for skull fracture reported from experimental data in terms of impact force (4 to 14 kN) by

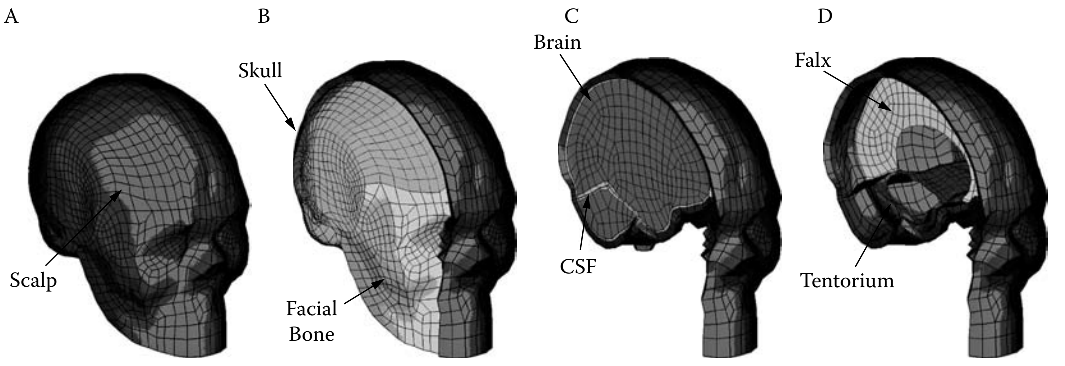

Figure 2.79 ULP-Strasbourg finite element model of the human head.

Yoganandan and Pintar (1994) as well as in terms of strain energy (around 2 J) by Gurdjian and Webster (1958). More recently, Marjoux et al. (2006) reconsidered the previous head trauma database and computed the injury prediction capability of HIC, SIMON, and ULP criteria and concluded that the ULP criteria are the most accurate, especially for moderate neurological injuries.

FEMs also give a good cinematic image of ballistic wound cases studied and can be a complementary tool when discussing the effect of ballistic impact wounds to the head (at the present time, the effect of penetrating gunshot wounds to the head by FEMs is still in a research stage). In the framework for the analysis of the rear effect of military helmets Deck et al. (2004) developed an improved version of the ULP model by considering the skull thickness variation and by integrating the reinforcement beams. It was possible then to reproduce not only linear fractures but also local depressive fractures of the skull. Using injury criteria calculated by simulation, some injuries sustained by the victim may be discussed—such as brain hemorrhage, subdural hematomas, or a loss of consciousness.

The human head FEMs presented in Figures 2.79–2.85 consider the head segment only without any boundary conditions at neck level. Therefore, impacts to the human head can be discussed with only minor uncertainty. The possible effects of impacts to the trunk or to the arms and legs preceding the impact to the human head can be taken

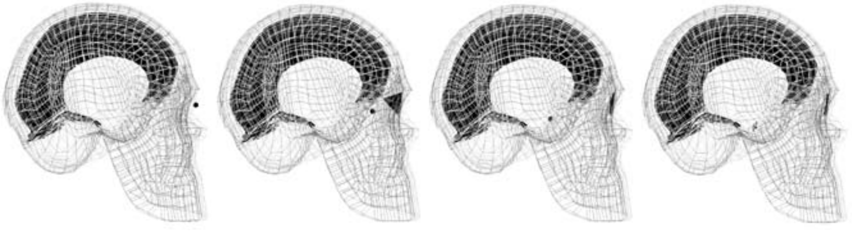

Figure 2.80 FEM cinematic illustration of a .22 caliber bullet shot between the eyes and ending its course in the dorsum sellae in a case of multiple gunshot to the head suicide.

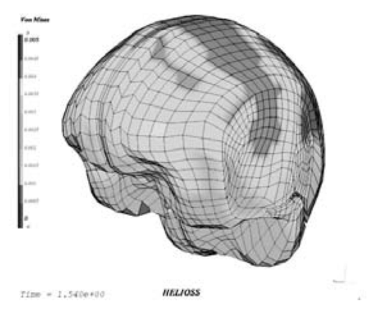

Figure 2.81 Von Mises Stress distribution after 1.5 4ms (same case as Figure 2.81).

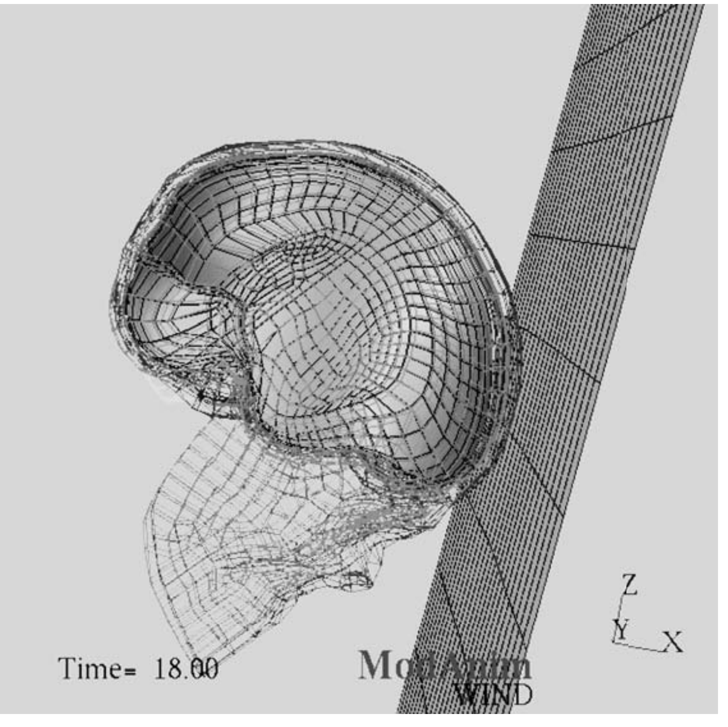

Figure 2.82 Blunt force trauma: impact simulation configuration: frontal impact.

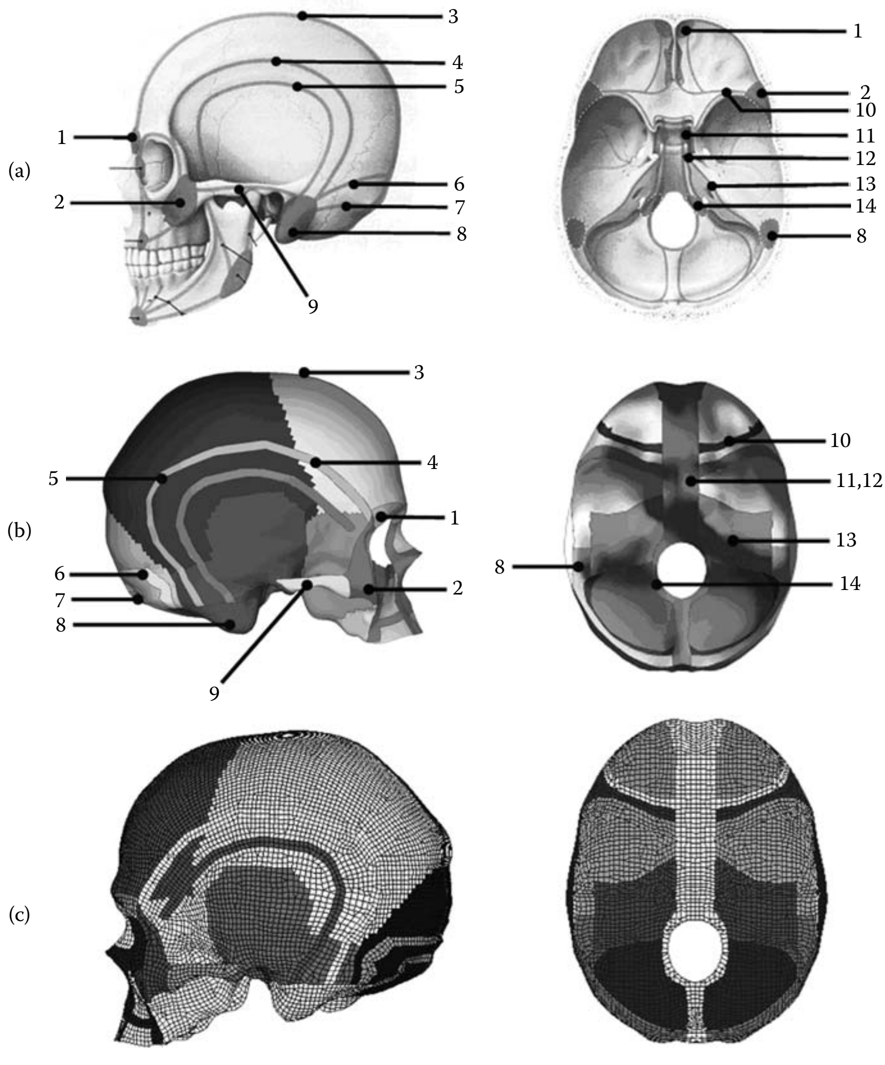

Figure 2.83 Location of the reinforced beams (a), outer and inner surfaces (b), the meshing (c). 1. Frontal beam, 2. Zigomatic arch, 3. Spheno-frontal beam, 4.5. Lateral superior and inferior arches, 6.7. Semi-circular occipital arch, 8. Mastoïdian pilar, 9. Zigomatic arch, 10. Spheno-frontal beam, 11. Sphenoïdal arch, 12. Occipital beam, 13. Petrouse beam, 14. Occipital beam.

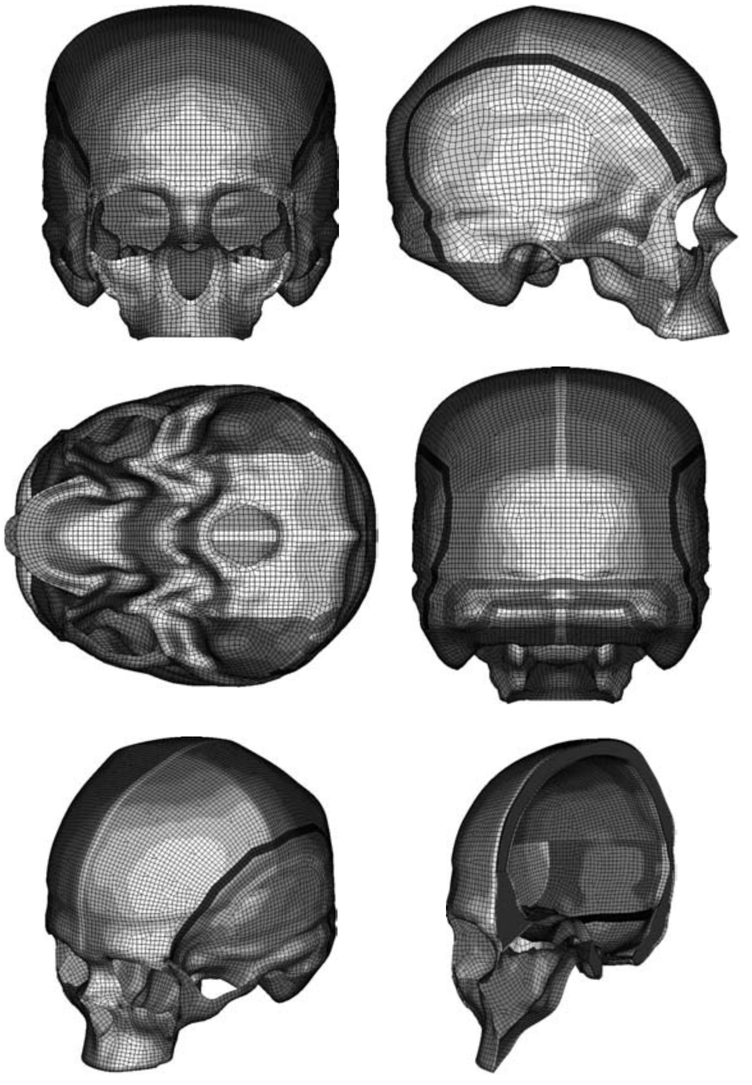

Figure 2.84(a–f) Reinforcement beams on the new ULP head model.

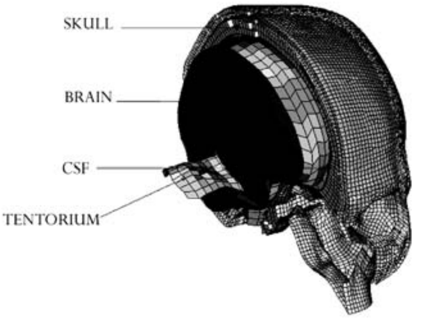

Figure 2.85 New ULP Head model: global view.

into account but may raise many questions concerning the energy of the impact to the human head. Therefore, the biomechanical study can be completed by the use of multibody dynamics.

A biomechanical approach can be very helpful to investigate forensic cases, and there is a need for collaboration between forensic sciences and biomechanics to objectively and scientifically evaluate adult and infant head injuries using well-documented cases.