ANTHROPOLOGY

Contents

Overview

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Introduction

Anthropology (*anthropos* – human, *logos* – science) is the study of the biological and cultural aspects of humans. The field encompasses a wide scope of specialized knowledge from social behavior, language, kinship, and religion to body build, ancestry, and evolution. There are two main divisions within the science of anthropology: cultural and physical anthropology.

Cultural anthropology is the subdivision of the field that deals with behavior and beliefs organized into an integrated system that is learned and shared by specific human groups. Traditionally, cultural anthropologists have studied the cultures of existing, nonliterate, less technologically complex societies, although the research techniques developed in studying these groups have been transferred to the study of all societies. Similarly, ethnologists study both the culture of living people and cultures no longer in existence but for which there are written records, while social anthropology is usually restricted to the analysis of social organization of modern societies. There is a great overlap in the various cultural and sociological aspects studied by anthropology; interdisciplinary investigations encompassing ethnological, sociological, economical, psychological, and religious aspects of society are very common, effectively blurring the limits between these fields.

Linguistics, the scientific study of languages, is another subdiscipline of cultural anthropology. Languages – being the main tool by which humans communicate, organize themselves, and transmit their culture from one generation to the next – are an essential key to the understanding of culture in its integrity.

Archeologists are concerned with the reconstruction of cultural history and daily life of ancient cultures. In a sense, archeology is the sociocultural anthropology of extinct civilizations. By means of highly developed technologies of excavation and observation of remains, the archeologist is able to reconstruct past cultures and to study their changes, movement, contacts, and influences on each other.

Physical anthropology is the branch of anthropology concerned with the study of the biological aspects of humans; the field encompasses two basic areas: human evolution and human variation. Further subdivision within physical anthropology includes: paleoanthropology, the study of human fossils; osteology, the study of bones; primatology, the study of nonhuman primates; paleopathology, the study of ancient disease; and forensic anthropology, the application of physical anthropology techniques in questions of law.

The understanding of the morphology of the skeleton and the techniques implemented to reconstruct life histories of humans has led to the development of forensic anthropology, i.e., the identification of human remains within the medicolegal domain.

The origins of forensic anthropology can be traced to the end of the nineteenth century when the French criminologist Alphonse Bertillon devised the first classification and identification system to identify criminals based on anthropometry. During the twentieth century the discipline became well established, with forensic anthropologists all over the world collaborating in almost all stages of forensic investigations associated to, but not solely with, personal identification of human remains.

Given the fact that bones and teeth survive much longer than soft tissue, many physical anthropologists specialize in the detailed study of skeletal and dental functional anatomy, physiology, and pathology, their expertise being of substantial value in forensic casework. In addition to providing clues as to the personal identity of a deceased, anthropologists assist in sorting human from nonhuman remains, diagnose skeletal trauma, and estimate the mechanism that produced the injuries. Comparing antemortem and postmortem radiographs, examining photographs of living individuals to determine the identity of the persons depicted and establishing the biological age of living individuals are some of the tasks of the anthropologist. Finally, this discipline has been essential in the investigation of mass graves and identification of victims of mass disasters.

Scope of the Field

The first query addressed by anthropologists when law enforcement agencies or members of the medicolegal community request their services is related to the nature of the remains. Many an embarrassment could have been avoided if the anthropologist was involved from the early stages of the investigation: for example the remains submitted for examination as human are nothing but polymer-resin models of bone, the refuse of a picnic, or just a hoax (Figure 1).

Once the remains have been established as human, it is important to determine their provenance. Usually skeletal material is considered of medicolegal significance if the time of death can be estimated to be within the last 50–70 years, although this judgment is not always easy.

The state of preservation of the remains is one of the main aspects that distinguish the contemporary from the noncontemporary remains. Taphonomy, the study of postmortem processes which affect the condition of dead organisms, such as the effects of scavenging, natural dispersion, and the physicochemical influence of the environment on bones, has been extensively studied by forensic anthropologists. Examples of these would include interference by carnivores, both large and small, the effect of insect infestation, weather conditions, and other postmortem events, which alter the remains. Although highly dependent on environmental conditions, the principal indications of the state of preservation of osseous remains include the presence of soft tissue on them, their color, texture, amount of hydration, fragility, and mass.

The presence of body modifications is another important clue in the determination of the postmortem interval, certain common forms of modifications typical of ancient people, i.e., cradle-boarding, and alterations in the shape of the teeth that, when observed, easily exclude the remains from being of forensic interest. Conversely, the presence of remnants of medical interventions like dental restorations, prosthetic devices, and surgical reduction of fractures or discolorations related to antibiotic treatment is a clear indication of a modern provenance of the remains.

Personal belongings associated with the skeletal remains and the conditions of interment also provide excellent clues to their source. Bodies recovered from coffins, embalmed, or in association with grave

Figure 1 A rubber ''fetus'' found in a stairwell and submitted for anthropological examination as a suspected stillbirth or a case of infanticide.

goods, are usually of no forensic concern, while those found in shallow graves, covered by a blanket or within a plastic bag are unlikely to be archeological. Furthermore, the presence of hinges, small springs, and perforations in articulations indicate that the bones are an anatomical specimen (Figure 2).

Determining the minimal number of individuals present within the remains is of great importance not only in mass disaster situations, but also in common graves and criminal investigations, as well as in civil claims. The possibility of commingling should be considered whenever parts of a skeleton are collected from scattered areas, or when cremated remains are being studied. Anatomical examination and the discovery of duplicated parts can achieve separation of commingled remains into discrete individuals. These can be sorted according to age, sex, stature, general morphologic characteristics, ancestry, and the probability of articulation of the various segments.

Forensic anthropologists are often called upon to assist in the exhumation of human remains, either from clandestine shallow graves or from cemeteries. The exhumation process, which is carried out with techniques similar to those of an archeological excavation, is usually carried out in collaboration with forensic archeologists. The presence of the anthropologist at the excavation site is instrumental in determining the minimal number of individuals as well as distinguishing natural taphonomic processes such as fauna damage to the bones, discarding nonhuman remains, and recording all human elements present in the grave. Although most of the anthropological analysis of exhumed remains is carried out in the laboratory, proficiency in field techniques is vital to ensure meticulous removal of small and fragile items such as teeth, bullets, and personal effects, that are often critical in the identification of the deceased and determination of cause and manner of death.

Figure 2 Human skull found in the cupboard of a recently deceased dental surgeon. The presence of springs, screws, and pins in the skull indicate that this is an anatomical specimen of no forensic interest.

The investigation of attempted genocide often includes locating and opening mass graves. This task is invariably undertaken by multidisciplinary teams including forensic pathologists, archeologists, and anthropologists who work in close collaboration to obtain accurate and unbiased information regarding the fate of the victims thus interred. Frequently, the permission to investigate mass graves is granted after a protracted period of time and the cadavers are partially or completely skeletonized. In these cases the skills of the forensic anthropologist, especially in osteology, are helpful in sorting through the commingled remains in a systematic manner, thus maximizing the preservation of evidence.

Anthropological Profile

Perhaps the most important step in the identification of unknown human remains is the creation of a biological profile of the individual studied. Describing the remains in such a way as to permit law enforcement and other investigating agencies to narrow the range of possible identities is crucial; it is here that the knowledge of human variation and the application of physical anthropology techniques play a key role in individualizing the deceased.

Developing an anthropological profile entails estimating the age, sex, ancestry, and stature of the particular individual through the interpretation of skeletal shape and size of the remains. Furthermore, unique characteristics such as congenital or acquired malformations of the individual that could have been known to the relatives or friends of the missing person are recorded. Positive identification based on an anthropological profile can be achieved only if specific individualizing features like signs of medical intervention previously recorded or unique anatomic characteristics are found. Nevertheless, exclusion of identity can be easily accomplished if the antemortem information is contradicted by the profile of the remains.

Age Estimation

The estimation of age at death of an individual is based on biological changes that take place throughout life. There is a high statistical correlation between the chronological age of a person and the biological stage of growth and development; the assessment of biological age is usually most accurate in the early phases of development and decreases as the individual gets older.

The life history of an individual can be subdivided into four phases based on the developmental and degenerative changes that characterize them: prenatal, childhood, juvenile, and adulthood. The estimation of age at death in each of these phases relies on the inspection of the various sets of events that take place during the specific phase.

The pace of growth and development differs between the sexes and between various biological groups and the onset of the diverse age indicators is affected by genetic and environmental factors. Thus they should be taken into consideration whenever the sex or the ancestry of the individual is known either by the presence of remnants of internal or external sex organs, or because there is a presumed identity.

Skeletal maturation proceeds from the formation of cartilage models through the ossification of bony centers to the complete formation of the bone itself. Ossification begins by the sixth fetal month and proceeds at a bone-specific, regular rate. Age estimation during the fetal period relies on length-for-age standards of the long bones, the progressive ossification of the cranium, and the size and closure of the fontanelles.

During the fetal and neonatal periods, age estimation is based mainly on the degree of calcification of the deciduous teeth, which can be evaluated by radiographic means. The ossification standards are sometimes difficult to apply in a forensic setting, depending on the conditions of the remains. Not all bones may be present, and their absence can be misinterpreted as lack of development instead of the result of taphonomic processes (Figure 3).

In childhood, the successive development of the temporal, occipital, and sphenoid bones, the closure of the fontanelles, the rate of dental development, and the sequence of appearance of the secondary centers of ossification are useful age indicators.

The most accurate source of information for age estimation during the juvenile phase is the sequence of fusion of epiphyses and the unification of the three bones of the os coxa. The standard deviation of the estimate in this stage is greater than the assessment based on the appearance of the centers of ossification during childhood and oscillates between 2 and 4 years depending on the sex and ancestry of the individual.

The onset of puberty differs between populations; thus, extreme caution should be exercised when establishing age during the juvenile period. Forensic anthropologists generally implement dental standards when analyzing subadult remains. However, it is important to evaluate all the skeletal age indicators rather than depending on one to avoid exclusion of possible matches.

Once the individual has reached the final stages of growth and development, the estimation of age at death becomes less accurate since it depends chiefly on subtle and highly variable degenerative changes in the skeletal tissue. Postmaturity age changes involve mainly the remodeling of bony and cartilaginous structures, which are very sensitive to internal and

Figure 3 Long bone shaft of a newborn skeleton exhumed *circa* 50 years after death. The absence of epiphyses is the result of taphonomic processes.

Figure 4 Radiograph of the thoracic and lumbar spine of a 73-year-old man, found in an advanced stage of decomposition. Note the collapsed vertebral bodies, lipping and osteophytes concomitant with age-related degenerative changes.

external factors, including the health status, lifestyle, and genetic makeup of the individual.

Adult age estimation is based on degenerative skeletal changes best observed in the various articulations. Pubic symphysis morphology is considered one of the most reliable indicators of adult age. This method is especially useful in the estimation of the age of individuals from late teens until the fifth decade of life. The mineralization of the costal cartilage of the ribs is also a valuable age indicator in adults. The gradual closure of the cranial sutures during adulthood is an unreliable procedure when used in itself but helpful when considered together with other age indicators (Figure 4).

Microscopic changes in the cortical bone and dental structure can be correlated with biological age, although these histological techniques require the sacrifice of the specimens, which later on can be detrimental for comparison with antemortem records. In addition, biochemical aging techniques and age estimation from radiographic assessment of the trabecular bone are also used when studying skeletal remains; their accuracy is somewhat contestable in the forensic realm.

A variety of aging techniques are recommended in the literature, and the choice should be based on the preservation of the skeletal remains and on the accuracy of the method. Most authors recommend that, when possible, a battery of aging techniques should be applied to enhance the accuracy of the estimation.

Sexual Dimorphism

The attribution of biological sex of the remains investigated is a critical stage, as it excludes 50% of individuals within the population to be considered. Furthermore, the estimation of biological age and stature depends on the correct determination of sex, since the standards for doing so are gender-specific.

The correct determination of sex is limited to adolescent and adult individuals. Although sex differences have been quantified in fetal and child skeletons, they are subtle and highly variable until the secondary sex characteristics develop during the juvenile period. Attempts at establishing sex in prepubescent bones utilizing measurements of growth-based differences between males and females are far from definitive. Nevertheless, some traits, such as the morphological differences in the ventral aspects of the pubic bone which can be detected in individuals as young as 14 years old, have been reported in the literature.

As a rule, male skeletons are larger and have more rugged areas for muscle attachment, while females tend to be more gracile and maintain a child-like morphology. Nevertheless, most methods of sex determination are limited by some degree of morphological overlap and individual deviation from the central tendencies. Moreover, since certain populations differ in skeletal size and robustness, the researcher must be able to identify the population from which the remains come when determining the sex.

In the adult, the rate of accuracy of sex attribution in most populations is about 90%. Sexual dimorphism is most reliably diagnosed in the pelvic girdle and the skull, although most areas of the skeleton display some form of dimorphism.

In general the articulated female pelvis presents a wide outlet compared to that of the male and the subpubic angle appears noticeably wider in the female. These and other morphological differences are the result of the evolutionary adaptation that enables the relatively large-brained human infant to pass through the birth canal (Figures 5 and 6).

Aside from the pelvic girdle, the skull contains most of the morphologic characteristics that enable the anthropologist to determine biological sex. The female skull retains a “child-like” (pedomorphic) shape throughout life, while the typical male skull

Figure 5 Dorsal aspect of a female pubic bone showing scars of parturition.

Figure 6 Dorsal aspect of a male pubic bone showing rim erosion, not to be confused with scars of parturition.

tends to be larger and more robust. This is best reflected in areas of muscle attachment and biomechanical stress, such as brow ridges and mandible.

Quantification of sexual dimorphism is especially effective in the postcranial skeleton. The size of joint surfaces, particularly in the humeral and femoral head areas, the body-to-manubrium rate, and the diameter of long bones are some of the sex-related metric traits available to the investigator. There is, however, some overlap in the cut-off points of sexually dimorphic traits across biological groups. The majority of the discriminant function formulae devised to determine biological sex are highly population-specific, thus they should be applied with prudence.

The best approach to ascertain sex with the highest degree of accuracy is to assess the entire skeletal pattern of the remains. Sex adjudication of very fragmented or charred skeletal remains should be cautiously undertaken; this can be better accomplished by genetic analysis to avoid misclassification of the remains, precluding the possibility of a later positive identification.

Ancestry

There is an ongoing debate among physical anthropologists concerning the subdivision of humans into distinct racial groups. The basis for this controversy stems from the natural repugnance of enlightened scientists to the atrocities perpetrated throughout history in the name of racial cleansing. Notwithstanding, physical differences in populations are an important contribution to the process of records screening and personal identification in forensic anthropology.

The division of the populations of any species into biological races tends to be arbitrary to some degree, but when it comes to human races, the attribution of an individual to a certain population is often impossible due to the complexity of human mating and migration patterns. Racial attribution to a set of human remains may be hindered by the very wide range of variation within each racial group and the considerable overlap between members of different races; moreover many individuals bear the genes of two or more racial groups. Finally, the attribution of population membership is often socially constructed and rather arbitrary; oftentimes it reflects social group membership, which can be a matter of personal choice or happenstance.

The races of the world have been divided in different ways; most but not all anthropologists identify five basic biological groups based on morphological characteristics: (1) Mongoloids (Japanese, Chinese, and Amerindians); (2) Negroids (African and American Blacks); (3) Caucasoids (Europeans, West Asians, Asian Indians, and some American people); (4) Australoids (Australian and Melanesian Aborigines); and (5) Polynesians.

The designation of an individual to a particular biological ancestry group should always be based on the entire complex of traits associated with race. The level of experience of the forensic anthropologist with the populations that inhabit the area where the remains are found is critical.

The craniofacial skeleton holds the majority of morphometric traits useful in race determination. In Negroid individuals the lower face projects forward (facial prognathism), the skull is long and narrow, the nasal aperture is wide, and the nasal sill is guttered. Mongoloid individuals show in the malar and midnasal area an anterior projection, giving the appearance of a somewhat flatter facial skeleton than that of the Caucasoids. The white-caucasian skull tends to be high, rounder, and with an almost completely straight lower face (orthognathism); the nasal aperture is narrow and the nasal sill very sharp-edged. In Polynesians the facial and alveolar prognathism is moderate.

Other facial features helpful in race assignation include the palate, the zygomaticomaxillary suture, the visibility of the oval window through the external auditory meatus, and the morphology of the mandible. Dental morphological traits differ in their frequency among various biological groups, and their presence can be used as an indicator of race in conjunction with other skeletal traits.

In the postcranial skeleton there are few reliable criteria for race determination. Intermembral indices, such as the ratio of tibia-to-femur length and the radius-to-humerus length along with the anterior curvature of the femoral shaft and the intercondylar angle, have been suggested as good indicators for racial affinity.

Stature Estimation

Establishing the living height of an individual from skeletal remains is a routine and straightforward practice in forensic anthropology. Nevertheless, the assessed value may be deficient in the identification process, not only because of the normal changes in an individual's stature during the day and throughout life, but also because of the lack of accuracy in most antemortem records regarding reported stature. As a rule, there is a difference in the way individuals perceive their own stature from actual height; men tend to report in their driver's license that they are as much as 5 cm taller than they really are.

Stature estimation from skeletal remains can be obtained by either anatomical or mathematical methods. The anatomical technique requires the measurement of the height of the cranium and of each vertebra from C2 to S1, the physiological lengths of the femur and tibia, and the articulated height of the talus and calcaneum.

The mathematical method for stature estimation is based on the correlation between discrete bones and body parts and stature. Regression formulae based on measurements of single bones and combination of various bones specific for sex and population are implemented.

The best bones from which to reconstruct living stature are the long bones of the lower limb, since they are the most important components of height. Likewise, vertebral segments have been found to be useful in stature estimation, especially in mutilated human remains. When the preferred skeletal element is not present within the remains, stature may be estimated from other bones, but the accuracy of the estimate will be dramatically low.

When the skeletal remains are incomplete, stature reconstruction can be achieved from various segments of long bones. The application of these formulae requires some experience in osteology to be able to identify the correct landmarks in long bone fragments.

Finally, although the body build or robustness of an individual can be reconstructed from the prominence of the muscle attachments and the diameter of the long bones relative to their total length, the weight of an individual cannot be ascertained from the skeleton.

Habitus

Some occupations and activities, which involve heavy labor or repetitive actions, may leave an imprint on the bones. Enlarged areas of muscle attachments in certain bones (hypertrophy) can be indicators of specific activities, i.e., the presence of sharp tubercles in the mandibular condyles is often associated with playing woodwind instruments. Similarly, spurs or ridges of bone, facets, and grooves in areas that are normally smooth, and bone deformations can be the result of a specific occupation or habit. Since these types of markers can have a genetic as well as an age component, the investigator should be extremely cautious when stating a specific occupation as part of the anthropological profile.

Assessing the handedness of unidentified individuals would be highly desirable as approximately 95% of humans are right-side-dominant, thus determining that the remains are those of a left-handed person would significantly narrow down the search for possible identification. Unfortunately, there are several problems in the assessment of handedness and an error could impede reaching the correct antemortem records.

Figure 7 Lateral view of a male cranium found in the woods. Observe the circular healed defect on the right parietal compatible with a surgical procedure. The identification of the victim was possible after the anthropological profile narrowed the search to a missing individual suffering from Parkinson's disease who had undergone a craniotomy 15 years earlier.

Individualizing Characteristics

Personal identification of human remains is accomplished when specific features of the skeleton can be equated to data recorded in medical and radiological records during the life of the individual.

Congenital and acquired pathologies, the presence of healed fractures, and specific degenerative changes are excellent markers for positive identification of human remains. Furthermore old surgical and prosthetic devices that might be evident within the remains are invaluable to the investigator, once the anthropological profile has limited the search to a few records. Likewise, anatomic variation of osseous features – such as the spinous processes, the outline of the frontal sinuses, the unique pattern of the trabecular bone, and various abnormalities in bone fusion – can be utilized to achieve positive identification (Figure 7).

Imaging techniques, such as skull-photo-superimposition and facial reconstruction, have been used to achieve personal identification when no other techniques are accessible; the scientific value of these methods is a constant subject of debate among forensic scientists, although their value for ruling out possible identifications is universally agreed.

Skeletal Trauma

Analyzing signs of trauma on bone, i.e., patterned wounds, gunshot wounds, sharp wounds, and the presence of healed and unhealed fractures, falls within the realm of forensic anthropology. Understanding both normal anatomy and possible pathologic or anomalous variations can greatly increase the accuracy of the diagnosis of trauma by ruling out natural phenomena (Figure 8).

Usually, the remains analyzed have an extended postmortem interval and are either decomposed or skeletonized. Taphonomic processes, such as carnivore activity or geological processes, should be distinguished from perimortem trauma; however, it is not always possible to determine the age of a bone injury since detectable vital reaction takes several days.

The Role of Forensic Anthropology in Mass Casualty

The accumulated knowledge and experience of forensic investigators over the years has led to the development of standard procedures for processing and identifying victims of mass disasters and multiple death scenes. Forensic anthropologists, pathologists, biologists, and odontologists play key roles that complement each other in the medicolegal investigation of these events.

During the search and recovery phases on the site of the incident, anthropologists not only devise search criteria based on the scope and nature of the event, but organize grid systems for retrieval of human

Figure 8 Osseous callus on a pubic bone, detected after thermochemical preparation of the specimen. This finding, the result of a motor vehicular accident, was paramount in narrowing down the search within the missing persons files.

remains and associated personal effects similar to the techniques implemented in archeological digs.

At the time of initial processing of the cadavers in the designated work area, forensic anthropologists are instrumental in identifying and reassociating fragmentary bodies. On the ensuing stages of the investigation, their lore is applied to creating anthropological profiles of the victims and collaborating in the positive identification endeavor.

The prominent role of the anthropologists in the efficient resolution of incidents that require a vast number of identifications is recognized worldwide. In fact, most emergency forensic organizations and international teams investigating mass graves from war crimes include forensic anthropologists in their organic makeup.

Summary

Forensic anthropology has been defined as the application of the science of physical anthropology to the legal process. The anthropologist's skills in osteology are instrumental, not only in generating anthropological profiles and establishing the positive identity of unidentified human remains, but also in contributing data on skeletal trauma and pathology.

The academic training of forensic anthropologists worldwide includes a vast knowledge not only of osteology but also of anatomy, growth, and development, and genetics as well. Most forensic anthropologists from North and South America undergo thorough studies in all fields of anthropology including archeology, thus are well versed in field techniques. In the rest of the world, physical anthropology is mostly taught in medical and odontology faculties, being better versed in radiography, odontology, and pathology. Nevertheless, all practicing forensic anthropologists acquire the required skills as they work in close collaboration with other experts.

The techniques implemented to achieve positive identification of human remains are common to odontologists, radiologists, and pathologists. However, by virtue of the broadness of the field of physical anthropology, i.e., skeletal biology, dental anthropology, paleopathology, and human evolution, the competence of the anthropologists often provides a more comprehensive analysis of unidentified human remains.

See Also

Anthropology: Archeology, Excavation and Retrieval of Remains; Stature Estimation from the Skeleton; Bone Pathology and Antemortem Trauma; Pediatric and Juvenile; Sex Determination; Determination of Racial Affinity; Handedness; Role of DNA; **War Crimes:** Pathological Investigation

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Archeology, Excavation and Retrieval of Remains

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Introduction

The basic role of the forensic anthropologist is to determine the identity of human remains. This is traditionally accomplished by first estimating the biological profile (age, race, sex, and stature) of an individual and then assessing any unique identifying biological characteristics, such as antemortem pathology or trauma. The forensic anthropologist is also trained to interpret both peri- and postmortem trauma, i.e., those injuries sustained around the time of death (with the understanding that they may have contributed to the cause of death) and any damage sustained to the skeleton after death that may aid in understanding the history of the remains before they were deposited in the position in which they were located and from which they were retrieved.

The forensic archeologist interprets both the artifacts found and the context in which they were found in order to reconstruct the history of the scene. When combined, the evidence of forensic archeologists and forensic anthropologists can provide a very precise picture of the events leading to the death and the subsequent disposal of the individuals found at the crime scene.

Contributions of Anthropologists and Archeologists to the Excavation and Recovery of Human Remains

The fundamental challenge to forensic death investigators is to maximize the recovery of human remains and evidence. Human remains, any portion of a human body in any condition, especially those that are skeletonized, burned, buried, or disarticulated and scattered, may render them difficult to recognize and complicated to recover. Common outdoor scene issues are to: (1) locate remains; (2) maximize as complete a recovery as possible; (3) differentiate ante-, peri-, and postmortem trauma or other modification of remains; and (4) resolve taphonomic issues from the scene and its context that shed light on the relationships among the events of death and subsequent fate of the remains (Table 1).

In the forensic context, taphonomy includes the decomposition of remains, their skeletonization, dispersal, modification, or destruction. Overcoming these challenges necessitates successful search strategies, use of special techniques to maximize recovery and documentation of remains and evidence, and utilizing taphonomic data to unravel postmortem events that may involve movement, modification, or destruction of human remains. Such information, based upon the scene context, can be utilized to make supportable inferences regarding the postmortem fate of human remains. The participation of forensic archeologists and anthropologists in the excavation and retrieval of remains can provide a basis for improving the quality of the analysis of the case in later stages of an investigation.

Locating Human Remains and Graves

Contributions of forensic anthropologists and archeologists to the retrieval of human remains are summarized in Table 1. The following discussion will elaborate on search strategies for locating human remains both on the surface of the ground and buried.

Surface Remains

In the domestic context, the initial discovery of surface remains is often by chance, e.g., a dog brings home a human bone from the woods nearby; a hiker or hunter stumbles across human remains in a remote area, or a driver stops the car on the shoulder of the

Table 1 Major contributions of forensic archeologists and anthropologists in the field

Rapid field assessment
Distinguish human from nonhuman bones
Determine search strategy for surface remains and graves
Recovery of surface remains
Excavation of graves
Exposure, documentation, and recovery of remains
Provide skeletal inventories
Determine presence of multiple remains
Minimize commingling when multiple individuals are involved
Resolve taphonomic issues such as types of bone modification and periods in which they may have occurred

highway to relieve himself and in the process discovers human bones. In international investigations (e.g., former Yugoslavia), witnesses, even individuals who actually escaped death, may lead investigators to sites of ambushes or extrajudicial killings.

Upon discovery of human remains, the first question to be addressed is: are the remains human or nonhuman? The second question is: are they of forensic significance? It is generally considered that deaths that occurred over 50–75 years prior to when the remains are located are unlikely to generate a prosecution.

When surface human remains, especially those partially or fully skeletonized, are discovered, often only a portion of the skeleton is initially found because body parts or bones have often been overlain by seasonal debris, dispersed, or even destroyed, commonly by animals. To complicate matters, initial responding investigators, who are inadequately trained in the recognition of human skeletal remains, may attempt to recover these remains without expert advice or assistance. When this happens, often subsequent scene visits are necessary to address questions that arise with regard to: (1) incomplete recovery of remains; (2) detailed searches not being conducted in trajectory paths between scattered clusters of remains; or (3) documentation and/or mapping at the scene not being sufficient to respond to questions that arise about the scene.

As with all crime scenes, organized search strategies must be carried out. The strategy employed depends on the size of the area to be searched as well as the terrain. Participants in searches must be trained in the recognition of isolated skeletal elements and have qualified forensic anthropologists available to confirm their findings.

Standard grid searches may be warranted once the remains have been discovered and confined to a relatively small area. In locating scattered skeletal remains, line searches are most useful for large areas and often used with care in wooded areas as well. In conducting a line search, the spacing between participants must be adjusted to allow a complete view of the surface space between them. If any evidence is encountered along this path, it should not be moved until fully evaluated by the appropriate investigators, and a marker, such as easily visible flags, is used to mark the position. The flags are left in place until the search is concluded. This allows for the large-scale (or even aerial) photography of the area in order to document the distribution of evidence locations within the scene. Once this is completed, additional grid searches can be employed, encompassing the area where the remains are concentrated.

Under certain circumstances a radial search pattern is also useful. This is primarily when the remains are located at a focal point, such as under a tree on the top of a hill, and/or when there are a limited number of search participants. In a radial search, one investigator begins at the focal point (the tree) and slowly walks an expanding spiral out from this point. The radial search works best if supplemented by secondary searches conducted on straight lines, or spokes radiating from the focal point; these intersect the spiral at several points and may be useful in locating additional remains. As in the line search, evidence should be flagged, but not collected, when initially encountered.

Several questions need to be addressed when processing scenes involving scattered skeletal remains. From what location(s) were the remains scattered? Often movement will occur from the original location where the individual died or where the body was originally deposited. This is usually the primary site of decomposition, except in cases of subadults (children) or major portions of adults, which can be moved by canids. Larger carnivores are capable of moving adult bodies. Movement of incompletely decomposed body components to another area results in secondary sites of decomposition. The significance of sites of decomposition is that these are the most likely areas where not only parts of remains but artifacts (portable objects such as cartridges, bullets, ligatures, blindfolds, medical appliances such as joint prostheses, clothing, and/or personal effects) may be shed. Decomposition sites may be marked by odorous, discolored staining caused by decomposition fluids soaking into the ground. The presence of insect puparium or yellowish discoloration of low overhanging deciduous foliage may also provide visual clues to where a body decomposed. Knowledge of the process of soft-tissue deterioration and the relative sequence in which bones or body parts become separated aids in distinguishing primary versus secondary decomposition sites.

What is the composition of the primary and secondary clusters of remains? It is crucial, when processing scenes of scattered remains, that not only the relative position of artifacts and human remains is mapped, but also a detailed inventory of the bones or artifacts contained in each location needs to be made. Understanding whether or not bones in separate locations represent anatomically related units helps to determine in what stage of the decomposition process scattering took place. For example, if bones of a closely grouped cluster represent bones of the same anatomical region, for example a lower leg and foot, they were more than likely removed from the remains as an articulated body unit.

A following question is: what were the most likely trajectories of dispersion? Knowledge of the decomposition site(s) and scatter pattern can often allow deduction of the most likely dispersal trajectories. It is along these trajectory paths between larger bone finds that small pieces of bone or teeth, often crucial in identification of the deceased, are found. Special circumstances that may affect dissociation and scatter are preexisting trauma, terrain, or purposeful dismemberment.

Locating Graves

Although chance discovery of buried remains may occur in the course of digging activity, such as preparation for construction, it is most common that a general area is suspected of containing a grave and it is the localization of the actual gravesite that is problematic. A variety of methods has been applied to finding buried remains and not all methods are amenable to particular environments. With all approaches to locate graves, with the exception of trenching, findings must be confirmed by actual digging.

Witness Statements

Accurate witness statements are the most reliable method of locating a grave. Unfortunately, it is not uncommon for witnesses to indicate the general area where a grave is supposed to be located, but not be able to pinpoint the exact position, even when he/she was present at the time of burial. Clandestine disposal of remains may take place under hurried or stressful circumstances, for example, at night or under other conditions of subterfuge. Over time, familiar landmarks in the landscape may change through human development or natural processes. Vegetation grows, dies, or changes in makeup. Memories of witnesses dim or fail. When relying on witness testimony, it is preferable to obtain information from more than one source if possible. Even then, disagreements may abound.

Visual Clues

Clues to the location of a grave include changes in the ground surface contours, vegetation death and subsequent regrowth, and damage to nearby trees and shrubs, as well as surface scatters of artifacts relating to the grave (e.g., cartridge casings, shreds of clothing, displaced skeletal elements). Soil removed in digging a grave is placed adjacent to the hole being dug and then used to fill the grave once the body is in place, leaving disturbance vegetation near the grave and a heap of dirt at its surface. Surrounding vegetation may be killed during the process. New plant growth will emerge, at times quite luxuriant as it is well-fertilized by the organic products of decomposition and the bioturbation of the soil from the disturbance by organisms, e.g., mixing, trampling, and plant and root penetration. Thus, to the trained botanical eye, the plant community of the grave may look quite different from that of the surrounding area. As the process of decomposition continues and soft tissue is destroyed, the soil filling the grave sinks, ultimately leaving a shallow depression. Frequently, graves are dug shallowly, in haste, too small to contain the remains and parts of the body or skeleton will stick out of the newly sunken earth.

Aerial Imagery

Aerial imagery takes advantage of an elevated point of view and relies upon the fact that surface indications of signs of digging activity or potential graves stand out from their general background. Historically, aerial photography has been the most utilized aerial imagery. An extraordinary example of the use of satellite photographs was those that demonstrated actual digging of graves and subsequent disturbance of the graves for the 7000 Bosnian victims of the Srebrenica massacre of 1995.

Probes

A simple probe can be made from a stainless steel rod approximately 1 cm in diameter with a T-shaped handle (Figure 1). Two types of probe have been utilized to explore subsurface areas suspected to hold graves: (1) a probe consisting of a solid metal rod; or (2) a core sampling probe. The utility of probing is to detect differential soil compaction and the presence of decomposing materials. Thinner probes are used when detecting remains, because the core types may cause significant damage to buried remains. Careful insertion of the thinner, solid probe allows detection of relative differences in subsurface compaction. In places where decomposition fluids have permeated the area, simply smelling the tip of the withdrawn probe will indicate the presence of decomposing materials. Use of a probe that provides a sample core can indicate subsurface strata and potentially disturbed areas can be compared with control cores from adjacent undisturbed areas. When decomposing carcasses are encountered, the odor of the probe shaft is the "tipoff." A drawback to probing is that one cannot determine the difference between the odor of decomposing human and nonhuman carcasses. When the probe is employed in areas of high water tables, localization of the grave may be problematic due to contamination by mobilized fluid components of decomposition to the general area surrounding the origin of decomposition.

Figure 1 Use of a probe, to locate graves in Rwanda 1996.

Skimming, "Peeling" off to Subsurface Levels

Skimming or shaving thin layers of surface materials and soil, a routine technique of archeologists detecting subsurface features, is also quite effective for localizing disturbances indicative of potential graves. This can be done by small hand tools as well as by utilizing machinery when dealing with large areas (Figure 2).

The mixing of soil horizons that occurs when a hole is dug frequently leaves a darker soil in the grave compared to the undisturbed subsoil around it. This soil change can often be clearly seen once the excavation is below the topsoil and the pit outline may be clearly visible as the profile is revealed in the trench. The information revealed in the profile can also help to demonstrate if the grave was reopened after the initial bodies were deposited, either to add or to remove material.

Figure 2 Heavy machinery can be used to ''skim'' the superficial layers of soil in order to locate graves when large areas are involved, Sri Lanka, Acheh Peninsula, 1999.

Trenching

Trenching simply involves excavating parallel trenches through an area suspected to contain buried remains until they are encountered. Trenches must be close enough together to insure that potential remains between them will not be missed. A case demonstrating the use of trenching was the 1995 search for two individuals who had been buried 12 years previously near the Honduran village of El Magular. At the time of their original discovery, their decomposed bodies were found by locals off to the side of a road at the edge of a banana grove. As is customary, the regional medical authority conducted a brief exam and the bodies were buried in the area where they had been discovered. Through the intervening years, the banana grove had been eradicated, and the road had been widened with its route now encroaching on to part of the old banana grove. As surface features had been drastically altered, test trenches were dug at three different areas pointed out by witnesses. Even though all three witnesses had been involved in burying the bodies, they could not agree on the location. As the work progressed, more witnesses, claiming to know where the bodies were buried, came forward with opinions as to why their memory of events was the correct one.

It was decided to extend the trenching over the whole area, first placing priority on the most reasonable scenarios. With labor provided by nearly 40 volunteers, digging work progressed for 5 days and resulted in 250 linear meters of 1.5-m-deep trenches until the remains were finally encountered.

Remote Sensing

Recent innovations in efforts to locate graves have utilized geophysical prospecting techniques routinely used in civil-engineering projects. Methods that have shown the most promise are side-scanning sonar, ground-penetrating radar, proton magnetometer, and electrical resistivity. The basis of these techniques is their ability to discern subsurface anomalies, but unfortunately not to discriminate human remains from other anomalies.

Exhumation of Buried Remains

Prior to discussing exhumation of buried remains it is necessary to address the different uses of the terms exhumation and excavation. In the USA, excavation implies only digging, not the surface recoveries or exhumations of human remains. Exhumation implies specifically the recovery of human remains from a buried context. In the UK, the term excavation may be used in lieu of exhumation to describe an organized dig (or surface recovery) of artifacts and/or remains using archeological methods and techniques.

Prior to excavation, once a grave has been located, surface features and evidence are documented. Potential evidence is then mapped and collected. The grave's boundary is then determined and a strategy for its excavation planned. Sometimes a test trench is dug across the grave and into undisturbed soil to determine the depth of the grave, its extent and condition and the disposition of remains, and the configuration of the natural stratigraphic sequence of the undisturbed area adjacent to the grave. The natural stratigraphic sequence of the subsurface can also be determined by digging a control trench away from the immediate area of the grave. Test trenching allows determination of the logistical needs of the excavation and necessary specialists for it and the subsequent examination of remains.

The grave fill on top of the remains is then removed in a layered sequence, preferably leaving as much of the grave walls intact as possible. The grave wall will have tool marks of the hand tools or machines used to dig the grave. For large mass graves, working trenches will be needed to provide drainage, sumps, or a convenient location to place removed overburden for later removal. Once remains are exposed they need to be mapped and photographed prior to removal. In dealing with mass graves it may be necessary to expose the surface of several remains in order to determine which remains should be removed first. Once the grave is emptied, a metal detector can be passed over the grave floor in order to detect metal objects, such as bullets, which may have penetrated it. Impressions of tread or track marks from digging machines or footprints should be documented. Finally, the grave should be refilled, not left as a hazard.

The Forensic Paradigm Shift

As with any discipline when applied to the forensic arena, experts must be aware of the special requirements of working in the medical–legal context. Unlike working in some areas of academia, where opinions, often based on tantalizing observations, thrive, yielding papers and theories, in forensics they may literally prove fatal. Several lessons need to be learned.

One lesson deals with legal issues crucial to the handling and documentation of evidence. Admissibility of evidence and even complete investigations may be compromised for lack of proper collection, documentation, and storage of evidence. Chain of custody, the accountability for evidence, must be maintained and documented from the time of its discovery to the time of its presentation in court. Such documentation includes a trail of where, when, why, and in whose possession evidence has been kept. Unless otherwise directed, strict discretion must be maintained as far as the investigation and its findings are concerned.

For those not experienced in dealing with death investigations, as happens increasingly, added stresses are present when working in the arena of international investigations involved with war crimes, genocide, and crimes against humanity. Experts may not be accustomed to working out of their own countries. Meeting the everyday needs of food, lodging, travel, and logistics may be daunting. Availability of potable water and electricity, security issues such as mines, and other unexploded devices create added burdens to the work. Unfamiliar circumstances such as checkpoints and the presence of military personnel and weapons may prove stressful.

For those traditional archeologists and anthropologists who deal with human remains, skeletal remains are the norm. There is a relatively safe psychological distance when working with bones and/or historic and prehistoric human remains that is not present when one deals with recently dead human remains. Instead of simple skeletal remains, the dead may be fleshed and/or decomposed. Clothing may not be unlike that worn by workers. Materials such as currency, watches, jewelry, and combs may be similar to those the workers carry with them everyday. Highly personal photographs and documents, such as letters, may reveal intimate details of the victim's life. The truth of human inhumanity to others is demonstrated by evidence of the circumstance and causes of death. For many experts, meeting surviving families is not a routine experience and may cause extreme discomfort. These are but a few of the psychological ramifications of forensic work. All of these factors tend to foreshorten empathetic distance between workers and the remains.

See Also

Anthropology: Overview; Taphonomy; Bone Pathology and Antemortem Trauma; Cremated Bones; Sex Determination; Role of DNA; **Autopsy:** Procedures and Standards; **Deaths:** Trauma, Musculo-skeletal System; **Death Investigation Systems:** United States of America; **Odontology:** Overview; **Postmortem Changes:** Overview; **War Crimes:** Site Investigation; Pathological Investigation

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Taphonomy

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Taphonomy: The Scientific Study of Postmortem Processes in Context

Forensic taphonomy is the interdisciplinary study and interpretation of postmortem processes of human remains in their depositional context, i.e., the history of a body following death. Taphonomic details are critically important for estimating time since death and differentiating injuries from postmortem changes. A careful taphonomic assessment can provide valuable information about the death event, transport of the victim's body by a perpetrator or by natural forces, and the timing and nature of events after death. Taphonomy attempts to provide an organized approach to data collection during the recovery of remains, as well as the understanding of postmortem environments and their interaction with the human body.

Historical Background

The term taphonomy was created in 1940 by combining the Greek terms for burial or grave (*taphos*) and laws (*nomos*), meaning literally the laws of burial. First applied in paleontology, taphonomy developed into a structured approach to explain the history of a set of remains, termed the "death assemblage," from the time of death until its discovery, with a focus on reconstructing ancient ecological communities. Archeologists and paleoanthropologists adopted and enhanced taphonomic methods during the 1970s with the goal of better interpreting human biology and behavior in the archeological context. For example, they studied bone modification by scavenger species, and butchering modification by modern hunter–gatherer people in order to differentiate the taphonomic signatures of nonhuman scavengers from that of human cultural food preparation. They developed models of bone weathering and devised experiments to simulate rivers and their effects on the transport of particular types of bones. Some scientists did naturalistic observation of particular species or environmental processes as they occur in nature. Others performed actualistic or experimental research. These efforts produced models that could be applied to archeological data.

In 1985 forensic anthropologists began applying taphonomic models and techniques to the understanding of forensic cases, coining the term forensic taphonomy. Early applications focused on the effects and processes of scavenger modification, primarily by wolves and dogs, as well as the effects of transport of human remains in river currents or ocean environments. At about the same time, entomologists, botanists, and other natural scientists were becoming more involved in forensic cases. They utilized plants and animals associated with bodies as biological clocks to estimate the postmortem interval, or to document the changes in the body which could have been moved, wounded, or otherwise modified. Forensic taphonomy is best accomplished using an interdisciplinary approach, to the extent possible depending on resources allocated to death investigation within a particular jurisdiction, nation, or culture.

Taphonomic Information in the Forensic Context

In many instances, the modifications to the remains that result from taphonomic processes, the taphonomic overprint, must be figuratively stripped away in order to discern information about the death event. This may involve, for example, differentiating skeletal injuries at the time of death – perimortem trauma – from postmortem artifacts.

Alternatively, postmortem sequences and processes may themselves produce forensic evidence of, for instance, transport or modification of the remains after death by the perpetrator. In both cases, the forensic taphonomy approach focuses on the condition of the remains within the context of their deposition and/or discovery. This often involves multiple disciplines such as anthropology, entomology, botany, or marine biology, thus utilizing expertise across the natural sciences to reconstruct and interpret particular aspects of the postmortem environment.

Primary Postmortem Processes

Taphonomic processes begin at the point of death, as the body begins a series of chemical and physical processes termed decomposition. Autolysis involves the dynamic chemical breakdown of cellular functions and structures due to the absence of oxygen and loss of thermoregulatory capacity. The concomitant process of putrefaction includes the action of internal and external bacteria and fungi, which utilize the body's nutrients to fuel their own physiology and reproduction. Both autolysis and putrefaction are facilitated by heat; freezing slows or stops decomposition, although it may itself produce cellular damage and breakdown. Dry heat removes the moisture essential for decomposition and creates mummification, a drying and hardening of tissues. The presence of excess moisture facilitates saponification and the generation of adipocere, a variable waxy solidification of tissues that occurs with the build-up of fatty acids and a byproduct of autolysis.

As soft tissue decomposes and is lost into the environment, the body will skeletonize, exposing cartilage and bone tissue. The subsequent loss of organic substances within the bone has a much longer time frame, on average, than soft-tissue loss. Bone in the living organism, composed of both organic and inorganic substances, tends to retain its shape after death due to the underlying inorganic or mineral matrix, unless the environment is acidic. Minerals in the bones may be replaced chemically by minerals in the sediments, while maintaining the original shape of the bones, a process termed diagenesis. This occurs over long time periods and leads to fossilization.

The processes of decomposition in both soft and hard tissues are variable in their intensity, location, and range. These processes may vary at different locations within the same body, even within the same bone element, or among multiple bodies in the same depositional context. For example, soft tissue on extremities such as hands and feet may mummify, while the torso, having more soft tissue and moisture, skeletonizes. Similarly, bodies in a mass grave, with the same postmortem intervals, may vary greatly in decomposition depending on their position in the body mass, whether more exposed to environmental factors on the periphery, or more protected by other bodies within the core of the body mass. It is important to appreciate, record, and interpret accurately such microenvironmental variation.

The Context: Ecological Perspectives

Introduction of a dead organism into an environment creates a cascade of ecological events as scavengers and processes of decomposition interact with physical and chemical factors to assimilate and recycle the remains. These processes are dynamic, as the microenvironment changes with each succession of organisms attracted by the body, or, secondarily, attracted by the presence of the scavengers of the remains.

In some cases remains may be preserved from consumption and certain forms of decomposition by body covering, burial, or somewhat extreme environmental conditions, such as freezing temperatures, excessive dryness, extremes of pH, or other shielding from scavengers. In these cases destruction of soft and/or hard tissues may be delayed considerably, for example by mummification. In the most extreme cases, such organic remains may ultimately become mineralized or fossilized.

Thus, the taphonomic history of a dead organism is the result of a complex and dynamic interplay between environmental factors that promote or delay decay and preservation. Although it is possible to understand scientifically and generally predict individual processes affecting taphonomic changes, for example, the impact of freezing on decomposition, the interaction of multiple processes and sequences associated with a particular case creates a unique history requiring interpretive judgment, combined with scientific data. For example, estimating the postmortem interval based on generic, regional models of decomposition would be complicated in a case that underwent partial decomposition indoors, after which the body was moved outside by a perpetrator, followed by bear scavenging and transport of body parts.

Forensic taphonomy has focused research on individual processes and taphonomic agents, such as observing decomposition rates in a controlled microenvironment. Research has also been done on a series of actual forensic cases in which taphonomic details are known, observations have been calibrated and documented, and a model has been produced, such as canid scavenging stages in a particular region. Taphonomic agents, including temperature, moisture, chemicals, plants, animals, sediment, and water, can theoretically be identified by a particular signature. In some cases the signatures are not unique and additional data may be needed about the context, for example, to differentiate overlapping patterns.

The Structure of Forensic Taphonomy Inquiry

Forensic taphonomy seeks to answer questions regarding time of death, location of body deposition and decomposition, sequences of events at and after the time of death, and interpretation of injury. The bulk of taphonomic research has focused on four major categories: (1) decomposition; (2) transport; (3) scavenging; and (4) associated organisms. Both terrestrial and aquatic environments have been the subject of taphonomic study for decades.

Postmortem Interval and Condition of Remains

Forensic taphonomists have utilized case series of human deaths in which postmortem interval is known to build regionally specific models of terrestrial and aquatic decomposition, most of which are based in North America. Each model, in which the condition of remains is the dependent variable, typically includes several phases of soft-tissue decomposition and skeletonization, associated in a general way with the time since death. Differences between models are due to relative amounts of atmospheric moisture and heat as well as potential for freezing, i.e., variables associated with climate. Burial and body covering alter these chronologies. Generally, a body that is not preserved by freezing can reach one of three endpoints: (1) skeletonization; (2) mummification; or (3) saponification. The more likely changes to take place are: (1) skeletonization in humid environments; (2) mummification in dry environments; and (3) saponification in wet environments.

Caution is needed in applying models to individual cases. Model case series tend to be small in size, the range of variation within phases is large, and unique microenvironmental contexts or circumstances may interfere with the usual taphonomic processes, for example, deposition in a cave or other protected area. The condition (and hence the decomposition phase) of different body parts, for example, the head versus the pelvic region, may differ within the same individual, due to the amount of associated soft tissue. Disarticulation, which refers to separation of bone elements at the joints by decomposition or scavenging animals, may hasten decomposition (i.e., appear to have a shorter postmortem interval) or hasten soft-tissue desiccation (i.e., appear to have a longer postmortem interval). Body coverings, such as heavy boots, can protect soft tissue for long periods of time, suggesting a very short postmortem interval.

The most accurate estimates of postmortem interval are produced using biological clocks, i.e., the association of the remains with organisms for which there are well-known metamorphic or developmental processes. When remains are exposed in natural settings, associated sarcosaprophagic insects (postmortem scavengers) go through a fairly well-timed metamorphosis specific to their species and region. Forensic entomologists may be able to reconstruct the postmortem interval fairly accurately within the first several weeks after death by identifying the insects and their metamorphic phases. Plant growth may also suggest general time periods. Phases of mammalian scavenger consumption and use are much less precise, but can suggest general time frames. Other organisms, such as barnacles attached to bones in marine contexts (**Figure 1**) can suggest a minimum elapsed time following exposure of the bone surface. Growth rates of associated plants can also suggest minimum postmortem intervals.

Most research by forensic taphonomists focuses on the loss of soft tissue to which they attach very broad time frames, usually weeks or months. Following the loss of soft tissue, bone may also decompose. Models associated with bone degradation, often referred to as weathering, tend to offer descriptive and qualitative phases without precise temporal referents (**Table 1**). For example, desiccation cracks are followed by

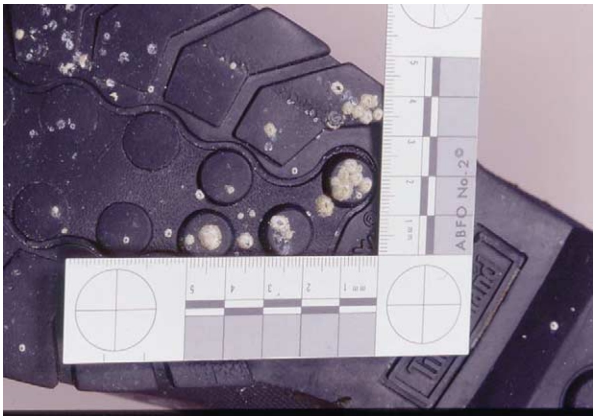

Figure 1 Barnacles on a boot sole. Marine biologists can use the total diameter of barnacles associated with human remains in some cases as an indicator of minimum postmortem interval. This requires knowledge about the specific species of barnacle in conjunction with information about the marine ecological context.

Table 1 Weathering stages in bone

Stage	*Condition of bone*
0	Soft tissue present; bone greasy
1	Bone surface exposed; thin cracks parallel to fiber structure of bone
2	Flaking of the outer surface, usually associated with cracks
3	Superficial bone surface has a rough texture, edges of cracks are rounded
4	Bone surface course, rough, and fibrous; cracks are open and invade deeper layers
5	Bone fragile and falling to pieces

Adapted from Behrensmeyer AK (1978) Taphonomic and ecologic information from bopne weathering. *Paleobiology* 4: 150–162.

exfoliation of bone cortex, but in between these phases timing is relative (Figures 2 and 3). Bone in both terrestrial and aquatic settings may break down due to abrasion, erosion, and dissolution, as well as from the actions of plants and animals (Figures 4–7).

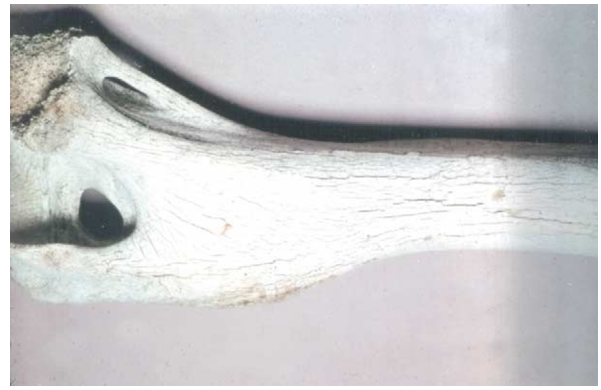

Figure 2 Bone weathering showing widening of linear cracks due to extreme drying.

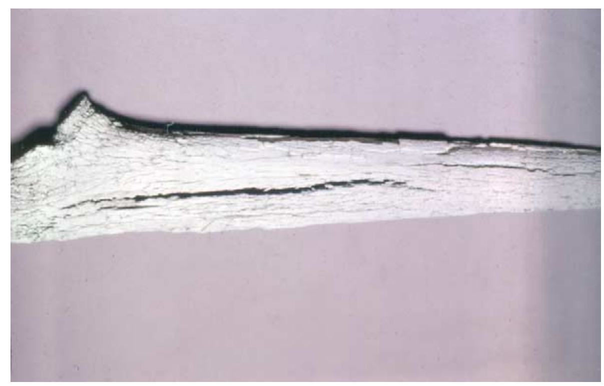

Figure 3 Bone weathering showing deep invading cracks and fragile condition with exfoliation of cortex.

Figure 4 Root patterns etched on cranial surface. Such etching is caused by secretion of acidic products.

Location of Sites of Deposition and Decomposition

A taphonomic approach is helpful in locating sites where the body may have been disposed and sites where the remains rested during the decomposition process. Tracking such sites allows the sequential movement of bodies and body parts to be determined and may prove invaluable in locating missing body parts, such as teeth, that may have been shed during the movement from one location to another.

Sites of decomposition are also of potential evidentiary significance. As soft tissue decomposes, items such as earrings, hair, clothing, and their contents are separated from the human remains. The context of the original deposition of the remains may also give clues to how the body arrived at the site.

Visual indicators may often be present at decomposition sites. Decomposition may initially depress, and then greatly enhance associated plant growth. The process of putrefaction and gas build-up can cause sediments overlying a buried body to bulge, then

Figure 5 Sea snail modification of a distal tibia, producing a circumferential pedestal effect.

Figure 6 Rodents have modified this cranium, removing elevated brow ridges and exposing spongy bone below (above right orbit). Broad, parallel-scraping defects produced by rodent incisors can be seen above the left orbit. Courtesy of Emilee Mead.

collapse; putrefaction can also increase the chances for a body in water to float, or to resurface after first sinking.

Scavengers are attracted to bodies by scent. The dispersal of scent from a body can be modeled as a cone, with decreasing concentration and increasing

Figure 7 Canid modification of an innominate, including gnawed edge (left) and canine tooth punctures (center).

diameter further from the body or scent source. Animals use olfaction to detect scent cone directionality by sensing relative concentration of the odor. Cadaver air-scent dog search teams can benefit from an understanding of the principles of scent distribution in air, sediment, and water. Scent can be moved from its primary source by wind or water currents, and the scent cone can be interrupted or rearranged by changes in topography or vegetation. It is important for searchers to interpret these potential complexities correctly in terms of their effects on dog (or human) olfaction. In some cases dogs may alert in an area where no visible remains are present because scavengers have removed them, but where decomposition scent has penetrated the ground.

Consumption of dead organisms by scavengers results in a dispersal of a set of remains within an environment. For example, a scavenger's stomach or scat at some distance from the original body deposit may contain remains. Dogs and coyotes are known to transport portions of bodies as far as 1.5 km from the original source.

Birds, fish, mammals, and invertebrates may all participate in scavenging. Knowing the taphonomic signature of the particular animal and plant taxa is helpful in reconstructing the pattern and range of dispersal, as well as in interpreting bone modification.

Reconstructing Postmortem Sequences

The reconstruction of postmortem sequences requires consideration of variation in rates of certain processes as well as in the timing and order of modification by taphonomic agents. The potential permutations are extensive, requiring the investigator to merge theoretical understanding of taphonomic change with a historical approach that considers unique events and event sequences.

Table 2 General effects of moving water on bone

General patterns	*Possible effects on crania*
Bones may be moved	Facial bones are more easily damaged or destroyed
Movement affected by size, density, and shape of bone	Thin bone plates frequently become perforated
Fast currents more likely to move bone than slow currents	Exposed edges become abraded
Bone may become buried, later exposed and moved	Surface may become pitted, scratched, or gouged
Bones tend to orient with flow direction	Anterior tooth enamel may become chipped
Edge-rounding increases with transport distance	Bones may become disarticulated
Abrasion varies with riverbed type	Single-rooted teeth are more likely to be lost
Riverbed topography may affect bone movement	Algae may stain bone surfaces
	Staining tends to be circumferential
	Matrix tends to become packed into foramina

Adapted from Nawrocki SP, Pless JE, Hawley DA *et al.* (1997) Fluvial transport of human crania. In: Haglund WD and Sorg MH (eds.) *Forensic Taphonomy: The Postmortem Fate of Human Remains*. Boca Raton, FL: CRC Press.

Primary, secondary, and even tertiary taphonomic sequences may modify remains. Secondary and tertiary phases usually ensue if and when the remains change environments or locations. With longer postmortem intervals potential complexity increases, yet the available data may decrease. Evidence for the primary processes of decomposition and scavenger consumption may be superimposed by secondary processes of transport of the body or parts of the body, for example by riverine (Table 2) or flood waters. Tertiary sequences, such as associated root growth into bone that reaches a beach after floating, may overlie the signs of water transport.

Because the econiches of plant and animal taxa may be discontinuous and specific, the association of particular species with a set of remains may provide clues about movement of the remains. For this reason, plant and animal remains associated with the body or body part should be treated as potential trace evidence of prior locations.

Interpreting Injury to Bone

Taphonomic data are often critical for the correct interpretation of defects or modifications of bone. Blunt- and sharp-force defects may be related to perimortem trauma or due to postmortem artifact. The term perimortem, as used in forensic taphonomy, refers to the condition of skeletal remains at the time of the modification, rather than the physiological moment of death. Bone that is fresh has not lost substantial moisture or fat; it will tend to fracture differently than a dry bone. Bone modifications that occurred when the bone was fresh are somewhat distinctive. Vital reaction in soft tissue is used by pathologists to identify changes before death. Vital reaction in bone consists of the build-up of bone tissue associated with healing. However, this is usually not macroscopically visible for up to a week after the injury. Thus, defects in bone, which appear to have occurred while the bone was chemically fresh, and which lack any signs of vital reaction or healing, are assumed to be perimortem, i.e., to have occurred at or around the time of death. Physiologically, the perimortem period can extend into the antemortem and postmortem time frames.

Some defects are difficult to interpret. Nonhuman taphonomic agents can mimic human modifications. (Modifications produced by humans, e.g., due to dismemberment, are also termed taphonomic if they occur after death.) Pseudo cutmarks have been created, for example, by animals that have fallen into natural trap caves, survived for some time, and scratched animal bones in the cave with their hooves. Similarly, large carnivores are able to break the relatively large shafts of human long bones with their jaws, creating perimortem modification that can resemble blunt trauma. In some cases it may not be possible to differentiate human from nonhuman agents for defects occurring in the perimortem period.

Attention to the taphonomic context can be very helpful in ruling out nonhuman taphonomic mimics. The assessment of taphonomic signatures in association with access to the death/deposition scene by particular taphonomic agents can be used to rule out some hypothetical causes of bone defects.

Theoretical and Methodological Issues in Forensic Taphonomy

The development of the theoretical and methodological basis of forensic taphonomy has emerged from research in paleoanthropology, archeology, and paleontology. However, the focus of forensic taphonomists differs. First, the emphasis on the early postmortem period requires that forensic taphonomists pay much more attention to the decomposition of soft tissue. Secondly, forensic taphonomy is an applied science. The primary data, coming from cases involving human death investigation, are often collected from within a sensitive and restricted context. Ethical and legal issues strictly limit research. Rather than experimental design, forensic taphonomy is more likely to utilize individual case studies and case series to develop models and generate hypotheses. Nonhuman animal models have generally been used in taphonomic experimentation. In rare instances, donated cadavers have provided research materials.

The interdisciplinary approach and need for data regarding the taphonomic context have influenced how body recoveries are done. More attention to careful data collection and archeological technique has raised the bar in death investigation. As this field develops, and specialties emerge, it will be critical to maintain interdisciplinary collaboration.

The scientific base for decisions and interpretations in forensic taphonomy will continue to be based on model building and qualitative assessment of probability and goodness of fit of individual cases in the courtroom. Appreciation and articulation of the range of variations is critical, with careful attention to the microenvironmental taphonomic context, comparison with documented taphonomic signatures, and a disciplined process of ruling out competing hypotheses.

Each death is a unique event. Our ability to understand and explain it based on science, i.e., through the application of principles and models, is partially limited by the chaos and random disorder of unique historical sequences. However, forensic judgments about the time and place of death, as well as perimortem injuries associated with the death, are nevertheless enhanced through a disciplined taphonomic approach to both the body recovery and examination.

See Also

Animal Attacks and Injuries: Fatal and Nonfatal; Predation; **Anthropology:** Overview; Archeology, Excavation and Retrieval of Remains; Stature Estimation from the Skeleton; Bone Pathology and Antemortem Trauma; Cremated Bones; Morphological Age Estimation; Pediatric and Juvenile; Sex Determination; Determination of Racial Affinity; Handedness; Role of DNA; **Autopsy:** Procedures and Standards; **Deaths:** Trauma, Musculo-skeletal System; **Death Investigation Systems:** United States of America; **Healing and Repair of Wounds and Bones**; **Injury, Fatal and Nonfatal:** Blunt Injury; **Odontology:** Overview; **Postmortem Changes:** Overview; **War Crimes:** Site Investigation; Pathological Investigation

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Stature Estimation from the Skeleton

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Introduction

Stature is one of the characteristics that may be used to identify an individual. From birth to adulthood, stature increases until a maximum is reached. However, even during growth, stature is not a fixed measurement for any individual. It is known to decrease slightly during the day, and also with age, especially after about the age of ~30 years. Decrease in stature during the day is mostly caused by compression of the elastic vertebral disks because of the weight carried by the vertebral column. The thickness of the vertebral disks is regained during normal periods of sleep. Normally, the decrease is ~1 cm, but if, for instance, heavy loads are carried, the result may be a decrease of several centimeters. The most important factors causing decrease in stature due to age are the gradual loss of elasticity of the vertebral disks and the individual changes of posture due to aging processes in general.

Together with hair and eye color, stature is given in passports for identification purposes. Though the accuracy of individual stature given in passports has been challenged in forensic journals, such an information may still be regarded as a guideline in cases when stature estimates are being compared with passport information of missing persons. The stature given in the passport may, however, not always have been recorded in connection with issuing the passport. For instance, hearsay information may have been entered, or erroneous values may have been transferred from a previous passport. In addition, stature may have been measured according to different protocols, or at different times of the day. At any rate, however, a deviation of ~1 cm from the figure recorded may be considered as sufficiently accurate.

Estimates of the stature may be obtained from its relation to measurements of the bones of the skeleton. Methods or formulas for estimating the stature from the skeleton may be based on any measurement of any bone or part of bone. In general, the more information about the stature contained in the measurement or combination of measurements the more exact is the estimate obtained. More specifically, the higher the correlation between the body proportions expressed by each measurement and the stature, or the higher the multiple correlation between several measurements and stature, the better the result. However, since in all populations there are individuals with relatively long trunks and short extremities (and also the other way around), there is always a variation in body proportions for any given stature, and consequently, in all populations, for any given bone measurement there is a certain variation in stature. This explains why there is no guarantee that any stature estimate is exact. Every stature estimate has a certain error, which sometimes may be derived mathematically, sometimes empirically, and sometimes not known or mentioned at all.

In principle, any bone may be used, but measurements of one or more of the six long bones provide the most reliable estimates. Methods even exist for stature estimation based on incomplete bones. In general, such an approach starts with the reconstruction of a particular measurement of the complete bone according to mathematical principles. However, if a series of complete bones from some collection of skeletons is available, it is possible to compare an incomplete bone with the complete ones, and then measure the complete bone which matches the size fairly accurately, if such a bone is found.

Because the six long bones of the skeleton are paired, some methods based on these bones have been restricted to only one side. The argument in such cases is that the counterpart from the opposite side is almost equal in length. The bone from any side may therefore be used, but when the complete pair is available, the mean measurement of right and left bone should be inserted.

Methods for Estimating Stature from the Skeleton

The source materials for developing methods for stature estimation from the skeleton differ in character. They are of three basic types:

1. Collections of cadavers where cadaver lengths have been measured before and bone measurements taken after maceration. It had already been observed by the end of the nineteenth century that the length of the cadaver tended to be about 2.5 cm longer than the actual stature of the individual when living. This is explained by the relaxation of ligaments and vertebral disks as well as a flattening of the vertebral curvature after rigor mortis. This means that the bone measurements are exact, but stature has to be adjusted, both concerning the amount that has to be subtracted because of the extension of the corpse as well as corrections because of reduction due to age.
2. Collections of living individuals where stature is known but the bone lengths have to be estimated from corresponding somatometric measurements on the body. In this case, it is possible to select the material so that reduction of stature due to age is eliminated. Thus, in this case stature is known, but the bone lengths have to be estimated. The advantage of such a method is that large samples may be collected by measurement of individuals according to the same protocol, the disadvantage is the errors introduced when bone lengths are estimated.
3. Collections of individuals where both stature when living as well as bone lengths after death are known. These are considered ideal if it is not influenced by older individuals whose statures have been reduced due to age.

Four different principles have been applied for stature estimation from the skeleton. The apparently most simple is based on crude ratios between the stature and the skeletal measurements, because for every individual the stature may be expressed by the skeletal measurement multiplied by a certain factor. But within any collection of individuals, the different factors vary slightly from individual to individual. Attempts have been made to use factors based on the mean measurements of the bones, assuming more or less explicitly that the error made compared to the exact proportion between stature and bone length for a given individual is small. So far, however, the actual standard errors connected with the use of crude factors have not been calculated. The errors made therefore remain unknown, which is a disadvantage of the method.

The second principle is based upon regression equations, either as simple regression equations, when the stature is estimated from one bone measurement, or multiple regression equations, when the stature is estimated from several measurements simultaneously. Simple regression is a method in which the stature is calculated as a product of the bone measurement and a factor plus a constant term. Multiple regression involves differential weighting of the bone measurements used which means that the factors with which to multiply each of the bone measurements are differentiated according to the importance of the measurement. The stature is calculated as the sum of products of each measurement and individual factors plus a constant term. All factors and constant terms are mathematically determined from a source material where both stature and bone measurements are known according to one of three types of source materials. For this process least-squares linear regression is used. This is a mathematical method that minimizes the standard error of the stature estimate, and from that point of view this is the best choice for estimating stature. It should not be confused with an alternative solution by which stature is estimated from each bone measurement used by means of simple regression, and the mean of the estimates is regarded as the final stature estimate. The standard error of this method is, however, not simply the mean of the standard errors, because the bone measurements used are already correlated to some degree. Some of the information used is therefore common to each of the simple regression equations. Because of this, it is not advisable to use the mean value of several simple regression estimates, though it is frequently done. It is clear that the standard error of a mean value of simple regression estimates is larger than the standard error of a multiple regression estimate based on the same measurements, although how much larger has not been investigated for any of the methods published. Since multiple regression equations involve as many dimensions as the number of measurements involved, as well as the stature, such equations may be difficult to conceive, whereas simple regression equations are only bivariate and easy to understand. Since simple regression estimates of the stature based on different bone measurements generally differ, an estimate based on the mean value of the estimates may be felt to be more reliable than an estimate based on any particular simple regression estimate. Such an estimate is based on information from all bone measurements involved, though some of the information is duplicated because of the correlation between the measurements, in contrast to multiple regression where the duplicated information has been mathematically eliminated.

One negative property of least-squares regression that had been overlooked for a long time in stature estimation research was that, at least from a mathematical point of view, the tallest individuals tended to be underestimated and the shortest overestimated. The reason was that only the error between the actual and the estimated statures in the source materials was considered because the method aimed at minimizing the sum of squares of the errors.

The third principle aims at reproducing correctly the stature of the tallest and the shortest individuals, at the cost of a slightly higher standard error. This kind of method has, so far, only been developed for situations comparable to simple regression, estimates of stature based on the measurement of one bone at a time. It is related to least-squares regression. The method, known as the reduced major axis method, minimizes the sum of products of the deviation between actual and estimated stature and corresponding actual and estimated bone measurements in the source material. This kind of equation may also well be used in order to estimate the bone measurement from the stature, whereas this is not even possible for simple regression, because another regression equation is needed.

Another problem is that the regression line passes through the mean values of the bone measurements as well as the mean stature. The mean values as well as the correlation between the bone measurements and between the bone measurements and stature are used for the calculation of the different factors and constants used in the regression equations. Because every method is based on a given source material, the mean values and the correlations involved are estimates. If this is taken into account, the standard error is a minimum at the calculated mean values, but tends to broaden in a doubly hyperbolic fashion if the mean values are increased or decreased. The reason is that errors of the direction of the calculated regression line compared with that based on the parent population from which the sample is obtained are taken into account. However, although this problem in stature reconstruction from the skeleton is occasionally mentioned in the forensic literature, it is secondary when compared with the number of methods from which to choose in a given case.

The fourth principle is called the anatomical method. It is based on the sum of measurements of the skull height, the individual vertebrae of the vertebral column, the femur, tibia, and talus and calcaneus in articulated position, to which estimates of missing soft tissue are added, depending on the sum of the measurements.

Development and Use of Methods for Stature Estimation from the Skeleton

Developments before World War II

A large number of methods for estimating stature from long bones are still in use, though a small number dominates. The earliest attempt that has still some relevance today was published by Manouvrier in

France in 1893. The material used was taken from an earlier thesis in forensic medicine by Rollet who studied the relation between the long bones of the skeleton and the length of dissection-room cadavers. Following a long, theoretical discussion, Manouvrier provided a series of tables giving the estimated stature for each of the six long bones. These tables have been used and reprinted several times even after World War II.

Manouvrier's tables were empirical, and it seems that the values used in the tables have been smoothed. The range of variation of the stature and corresponding bone lengths was restricted, depending on the measurements available. For bone lengths outside the tabulated range, crude factors were given with which to multiply the bone length to estimate the stature. But if the values in the tables are plotted, it is seen that the proportion between stature and bone lengths changes along the tabulated range of variation, whereas it is fixed outside the tabulated range, a contradiction which Manouvrier did not realize. What was formally estimated, however, was the cadaver length, since a dissecting-room material was used, but it was already known that the length of the cadaver exceeded that of the stature of the individual when living by an amount of approximately 2.5 cm, which therefore had to be subtracted from the estimate.

In 1899 one of the most influential methodological papers on how to estimate stature from the skeleton was published by one of the world's greatest statisticians, Pearson, who introduced the principle of regression, which had been developed a little more than a decade earlier. Regression equations have been used for almost all subsequent methods for estimating stature. Pearson used the same material as Manouvrier, but provided a mathematical solution, in contrast to Manouvrier's empirical solution.

Pearson also turned to the problem of whether the formulas developed using a French sample might be applied to other populations and to prehistoric individuals. Pearson's test case was the Ainu from northern Japan, where a number of skeletons had been excavated. Since the statures of the individuals excavated were not known, it was assumed that their mean stature corresponded to the mean stature of the living Ainu, which in modern terms would imply that no secular changes were assumed to have occurred. The regression equations developed based on the French material seemed to fit well even to the Ainu.

Thirty years later, in 1929, the physician Stevenson working in Peiping published new formulas for Chinese individuals, based on a dissecting-room sample from northwestern China, in the journal *Biometrika* edited by Pearson. Contrary to Pearson's findings, he found that the proportions of the French material did not correspond with those of the Chinese sample, so that Pearson's regression equations should not be applied to Chinese, nor should the regression formulas developed by means of the Chinese sample be applied to the French or to the Ainu for that matter. Pearson added a lengthy editorial note to the paper, where he concluded that regional regression methods had to be developed, and also that regression equations had to be developed separately for each sex because of differences in body proportions.

Following Pearson's advice, a number of regression methods based on national criteria, i.e., from China, France, Finland, Germany, Greece, India, Japan, Portugal, and the USA have been published, and continued until the present century. The most comprehensive study before World War II was carried out by the German anthropologist Breitinger, who measured the stature of 2428 male athletes and their limb proportions as a starting point to estimate the corresponding long bone measurements. This is so far the largest study of measurements on living individuals used for estimates of stature from the skeleton.

Developments after World War II

A major breakthrough was made during the 1950s by the anthropologist Trotter and the statistician Gleser. They developed new regression equations based on measurements of long bones from World War II casualties, from the battlefields of the Pacific, in connection with a repatriation program after the war. The identity of each individual was known, as well as the stature when living. Thus both the actual stature and the bone lengths were known, a situation which was ideal. Since only males were included, regression equations for females were developed based on female skeletons from a dissecting-room collection. Prior to the calculation of the regression equations, another study based on dissecting-room skeletons had provided information about the actual decrease in stature due to age, so that age could be corrected for when necessary. A second, similar opportunity offered itself in connection with repatriation of US war casualties from the Korean war. This time regression equations were calculated for males only.

One particular result was that the regression equations from the Korean war differed slightly from those of the Pacific war. The reason was that the mean stature had increased slightly, affecting body proportions involving the long bones as well. Trotter and Gleser concluded that stature is in "a state of flux" and stressed not to use a regression equation for a different population than the one for which it had been developed.

The regression equations by Trotter and Gleser have been by far the best-known method during roughly the last half century. They have been and are still widely used, not only because they are based on a source material which is close to ideal from a methodological point of view, but also because formulas for groups of different ethnic affiliations had been developed, i.e. for Caucasian, Mongoloid, Mexican, and American Blacks. Since it is well known that secular changes of stature occur, however, and that people in virtually all countries have become taller during the last 100 years, the choice of which regression formula to use may be difficult when the mean stature of the background population of an individual is not known. This is particularly a problem in many forensic cases when a more-or-less complete skeleton of an unknown individual exists. The problem is even greater if the sex is also unknown.

Two different approaches have been made to overcome this problem. One approach by the anthropologist Sjøvold is based on an observation made by another anthropologist, Olivier, who in the early 1960s compared regression equations by Trotter and Gleser with regression equations based on a collection of identified skeletons from German concentration camps which had been measured in connection with a repatriation program after World War II. Olivier discovered that the simple regression lines were literally parallel, at a distance which roughly corresponded to the difference in the mean stature between the source materials. Supported by still more examples, it appeared that the stature/long-bone length proportion tended to be dependent on or to adapt itself to the stature.

The approach used was called "the line of organic correlation," a generalization of the reduced major axis method, and was used for Caucasian samples at first. This seemed to solve a forensic problem, that the nationality of a skeleton discovered did not seem to be necessary in order to estimate the stature. As for the need for different equations for males and females, it was discovered that much of the difference in body proportions could be explained by differences in stature, and it was therefore possible to make a synthesis of previous methods for stature estimation, valid for both sexes, based on mean values of stature and long-bone measurements. For dissection-room samples, which generally consist of old individuals, it was assumed that the postmortem extension of the corpse roughly amounted to the decrease in stature due to old age, as far as mean values were concerned. In forensic cases, the mean stature of the parent population of an individual is unknown. But it may be inferred that the most likely stature of that individual should be close to the mean value. Statistically speaking, the "expected" value of the stature is equal to the mean value of the parent population. The same arguments are applicable to the different ethnic groups, which led to a synthesis for worldwide populations.

Another argument for the use of a synthesis is that the different source materials used are ill defined from a genetical point of view. What is known is only that they were available, whereas the genetical relations between the individuals are unknown. It is even unlikely that all the individuals of a certain material originated from the area where they were studied. Strictly speaking, therefore, they just represent samples of "humans," characterized by certain mean statures and certain long-bone length proportions.

Another approach was based on the observation that the relationship between the mean stature and the mean length of the femur appears to be fairly stable around the world. Feldesman made a worldwide survey of similar samples for which the synthesis based on mean values was made. It may be inferred that similar assumptions have been made for use of the different types of source materials. This is an example of the use of a crude factor. Although the survey was based on the relation between the measurement of the femur and stature, the reverse relationship was used to estimate the stature from the length of the femur, based on the stature/femur relationship of 3.74. Although it may be shown empirically that this factor tends to overestimate tall and underestimate short individuals, one argument for its use is that every regression equation (or any mathematical formula for estimating stature from the skeleton) has a standard deviation, and tests showed the method to provide more exact results than those obtained by means of regression equations. Later tests, however, showed that a generic regression, quite similar to the weighted line of organic correlation, provided even more exact results. A standard deviation of the estimates based on the stature/femur relationship was not given, which means that only point estimates were used.

In late 1950s, the so-called "anatomical method" was developed by Fully. The source material was the identified skeletons which had been repatriated from the German concentration camps. This method consists of the sum of the basibregmatic height of the skull, the height of the vertebrae from "axis" through the first sacral vertebra, the bicondylar length of the femur, the physiological length of the tibia, and the articulated height of the talus and calcaneus. For skeletal heights between 153.5 and 165.5 cm, 10.5 cm was added to account for soft tissue, for skeletal heights above 165.5 cm, 11.5 cm should be added and 10.0 cm should be added for those below

153.5 cm. This method is independent of ethnic affiliation as well as of sex. The drawback is that it is very cumbersome to use, and requires a complete skeleton. The empirical error is the smallest among all methods for estimating stature, amounting to about 2.5 cm.

Recommendations

The more that is known about the individual such as sex and ethnic affiliation, the better. The method developed by Fully is, in principle, the best one to use, but it is very cumbersome and requires a complete skeleton. Use of regression equations based on regional samples is recommended if the mean stature fits the parent population from which the individual case derives. The methods by Trotter and Gleser are widely used, though based on a source material with a mean stature shorter than today, whereas Sjøvold's method circumvents the problem of the mean stature of the parent population. It should be recollected that all methods based on mathematical principles aim at an estimation of the maximum stature of an adult individual before decrease due to age. For older individuals, therefore, the correction derived by Trotter and Gleser should be used, subtracting 0.06 (age at death − 30) cm from the estimated stature for individuals older than 30 years.

See Also

Anthropology: Cremated Bones; Morphological Age Estimation; Determination of Racial Affinity

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Bone Pathology and Antemortem Trauma

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Introduction

The analysis and description of human remains for the purposes of assisting medicolegal investigations in assigning a personal identity to the deceased center around the premise that throughout an individual's life span, a variety of alterations to the body will occur that will be sufficiently unique to serve much as a fingerprint does for identification. The greater the number, variety, and severity of insults that a body endures throughout its lifetime, the more individual and distinctive is that person with regard to antemortem and postmortem comparison. Whilst many of the insults the body sustains may remain untreated or warrant no consultation with a clinician, the more significant the injury or trauma, the more likely it will be to leave an imprint on the skeleton and the more likely that it will warrant medical attention whether through the family doctor, the accident and emergency room, or the clinical specialist. Recourse to one or any combination of these three medical pathways will result in a formal recording of the incident and the initiation of a paper trail which will be vital to a successful investigative process and ultimately identification of the deceased. There are a variety of insults that manifest on the human skeleton and they generally fall under the headings of pathological conditions or the remnants of scars of previous traumatic injuries.

This article provides a brief overview of some of the bone pathologies and antemortem traumas that might be encountered by the forensic anthropologist and illustrates how these can be utilized to assist in the identification of the deceased. This article is not intended to be comprehensive, as only a selected few conditions can be introduced due to the restrictions of space. It is also important to realize that the types of traumatic injuries and the manifestation of pathological conditions are geographically distinctive and individual to a country, a continent, or a particular conflict. Therefore whilst some of the conditions discussed here may be typical of the northern hemisphere, they may prove rare elsewhere.

Bone Pathology

The interpretation of pathologies relies on the accurate differential diagnosis of the disease or condition presented. A pathological condition is not a static event and the presentation detected on the deceased is merely a "snapshot" of the condition at that particular moment. The condition may be in its early stages of presentation, it may be at its most active, it may be in a process of remission, or the investigator may simply be witnessing the scars of a healed and cured condition. Therefore it is important to realize that the same pathology can present in a number of forms dependent upon its phase of activity and the manner in which each individual will respond to that insult.

A pathological skeletal condition is first recognized as an appreciable alteration to the anticipated "normal" appearance of the bones and fundamentally results from an alteration to the normal equilibrium between bone formation and bone resorption. Bone is produced by osteoblasts and removed by osteoclasts and any interference with the status quo will result in an imbalance of their normal rate of activity or indeed an overabundance of one particular cell type. The appearance of excessive new bone formation can be as much a result of increased activity in osteoblasts as it is a decreased activity in osteoclasts and of course the opposite is equally true, where an appreciable alteration in bone loss can arise through an excessive stimulation of osteoclast activity or a reduction in normal formation rates. Whilst the addition and removal of bone can occur as a simple alteration in volume resulting in a bone simply becoming larger/smaller or more dense/rarefied, the reality is that abnormal stimulation of osteoblasts and osteoclasts tends not to result in a "normal" bone appearance and therefore there is not only a quantitative alteration that alerts the anthropologist to the presence of a condition but it is more likely that the qualitative appearance of the bone will be the first element to attract attention and highlight an abnormality.

Both systemic and local factors can influence cell activity and cell population density and will include aspects of endocrine control, invasion of pathogenic organisms, viruses, and fungi. As fundamentally every manifestation arises from the actions of only two cell populations (osteoblasts and osteoclasts), it is not surprising that different diseases can produce remarkably similar characteristics and a differential diagnosis will require that a number of factors be assessed.

The visual manifestation of skeletal disease can present as:

- abnormal bone formation (e.g., periostitis)
- abnormal bone destruction (e.g., osteoporosis)
- abnormal bone density or bone type (e.g., osteogenesis imperfecta)
- abnormal bone size and/or shape (e.g., achondroplasia).

The form and distribution of a condition may be classified as:

- solitary abnormality with a single focus
- bilateral multifocal abnormality
- randomly distributed multifocal abnormality
- diffuse widely distributed condition.

Any alteration to the quality or quantity of the bone will either be directly visible to the naked eye or may only manifest when the remains are subjected to additional forms of analysis, including imaging (radiology, computed tomography scans, etc.), microscopic examination, and chemical analysis.

The classification of bone pathologies is extremely variable but a simple classification is shown in Table 1. It is clear that many conditions will span more than one category and there is no satisfactory classification system that is specific to each condition. For

Table 1 General classification of bone pathologies

Infectious diseases, e.g., tuberculosis, leprosy, osteomyelitis
Circulatory disturbances, e.g., aneurismal erosion, osteonecrosis
Reticulo-endothelial and hematopoietic disorders, e.g., anemias, leukemia, myeloma
Metabolic disorders e.g., rickets, fluorosis, scurvy
Endocrine disturbances, e.g., pituitary dwarfism, hyperthyroidism, acromegaly
Congenital and neuromechanical abnormalities, e.g., hydrocephalus, kyphosis, spina bifida
Dysplasias, e.g., achondroplasia, osteogenesis imperfecta, osteopetrosis
Tumors and like lesions, e.g., benign tumors, fibroblastic tumors, malignant tumors
Arthropathies, e.g., osteoarthritis, rheumatoid arthritis, gout

example, leprosy is an infectious disease that can manifest as an arthropathy.

Abnormal Bone Formation

Proliferative reactions that characterize bone hypertrophy encompass a vast array of clinical conditions, including hemorrhagic conditions, inflammatory reactions, tumorous growths, circulatory disturbances, metabolic disorders, endocrine disorders, and other less specific conditions.

1. An example of a solitary abnormality with a single focus would be button osteomata (Figure 1). These are benign neoplastic lesions of dense lamellar bone that almost exclusively occur on the outer diploic table of the skull, either in the frontal or parietal regions. This condition presents as small discrete raised areas of smooth bone of approximately 1 cm in diameter that are sharply demarcated and rounded in profile. They are more common in males and of greatest frequency in the fourth and fifth decades. These "buttons" also become more noticeable with advancing age as they are more clearly defined on a bald head than on a head covered with hair. As a result, these can be useful corroborators of identity if photographs of the deceased or missing person are available for comparison. They are not uncommon, being present in 1% of autopsy material, and are even well documented in archeological material.
2. An example of a bilateral, multifocal abnormality would be osteoarthritic change (Figure 2). There are three dynamic components involved in the skeletal manifestation of osteoarthritis and they involve both bone loss and bone addition. There is: (1) a breakdown of articular bone which can ultimately result in damage to the subchondral bone; (2) eburnation of the articular surface; and (3) new growth of cartilage and bone at the joint margins (osteophytes). Osteoarthritis is a progressive condition that is characterized by the number of joints that become involved as the condition develops, with the joints of the vertebral column usually the first to display perceivable symptoms, followed by the knee, first metatarsophalangeal joint, hip, shoulder, elbow, acromioclavicular and sternoclavicular joints. Although there is likely to be a hereditary factor involved in the manifestation of this condition, it is closely correlated with advancing age.
3. An example of randomly distributed multifocal abnormality is typical of an infectious condition such as syphilis where the periostitis in the long bones can become complicated by ulceration of the overlying skin which will result in additional bone morphological alterations. Diffuse non-gummatous periostitis leaves the bone thick and dense, affecting not only the periosteal surface but often the entire compact structure of the tubular diaphysis.
4. An example of a diffuse widely distributed condition would be periostitis, which can be a widespread inflammation of the periosteum that covers every bone in the human skeleton. The condition can be isolated and mild, e.g., local inflammation, or can be widespread and more distinctive, as would be found in hyperostosis with pachydermia.

Abnormal Bone Loss

As with the section above, specific examples of pathological conditions could be listed that would fit within each of the criteria concerning location, distribution, and type of manifestation, but it is clear that many conditions cross the boundaries resulting in

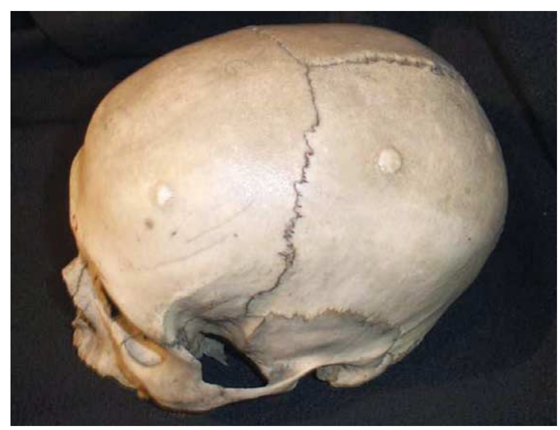

Figure 1 Button osteomata on the frontal and parietal bones.

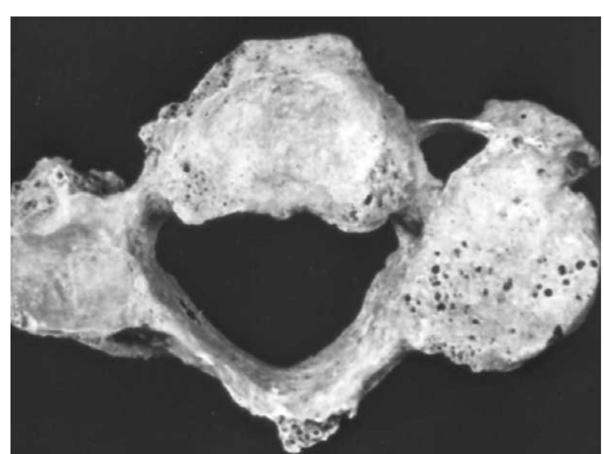

Figure 2 Osteoarthritic change in a cervical vertebra. Note the addition of bone around the superior articular facet and the margins of the body.

a somewhat unsatisfactory and perhaps therefore relatively meaningless categorization of conditions. Therefore classification may have its practical uses for differential diagnosis but within the limited scope of this contribution it would become little more than a meaningless list.

Osteopenia, osteoporosis, and osteolysis are the terms usually applied to an abnormal loss of bone. Osteopenia is a rather nebulous term that depicts a general loss of bone volume without direct specificity as to the cause. Conversely, osteoporosis depicts a normal quality of bone but an abnormal quantity. The classical understanding of osteoporosis is related to the postmenopausal condition in women where the amount of bone resorption surpasses bone formation and bone loss continues unchecked, resulting in an ultimate failure in the biomechanical properties of the structure. Osteoporosis is a widespread phenomenon that principally affects the cancellous structure and hence has implications for age-related fracture in the vertebral column, hip, and wrist. However, its involvement in the alteration of the biomechanical properties of compact bone should not be overlooked (Figure 3). Osteoporosis is naturally age-related but other predisposing conditions, surgical intervention (e.g., hysterectomy), and the side-effects of a variety of drugs can all lead to a rarefaction of bone volume.

Osteolysis can be a singular lesion or multiple discrete areas of bone loss and is easily visualized through infections such as leprosy or tuberculosis (Figure 4). Tuberculosis is a chronic infectious disease caused by either *Mycobacterium bovis*, which can be transmitted to humans from byproducts of cattle – normally milk or, more commonly, by direct transmission between humans through *M. tuberculosis* via respiratory contamination, with the primary focus being in the lungs. The bacilli circulate in the blood stream and locate within the skeleton, usually with preference for areas of hemopoietic activity, e.g., vertebral column, tarsals, ribs, and sternum. More than 40% of skeletal tuberculous lesions involve the vertebral column, perhaps because it represents the largest location of cancellous bone, but it is also known that the bacilli thrive under conditions of high oxygen tension and the vertebrae have a particularly well-developed arterial supply. In the column, the earliest detectable focus of blood-disseminated tuberculosis occurs in the region of the cartilaginous endplate at the anterior aspect.

Almost all pathological conditions can therefore be summarized according to:

- the amount of bone formed
- the type of bone formed
- the location of that new bone
- the amount of bone lost
- the location of the lost bone
- the overall shape and size of the resultant bone.

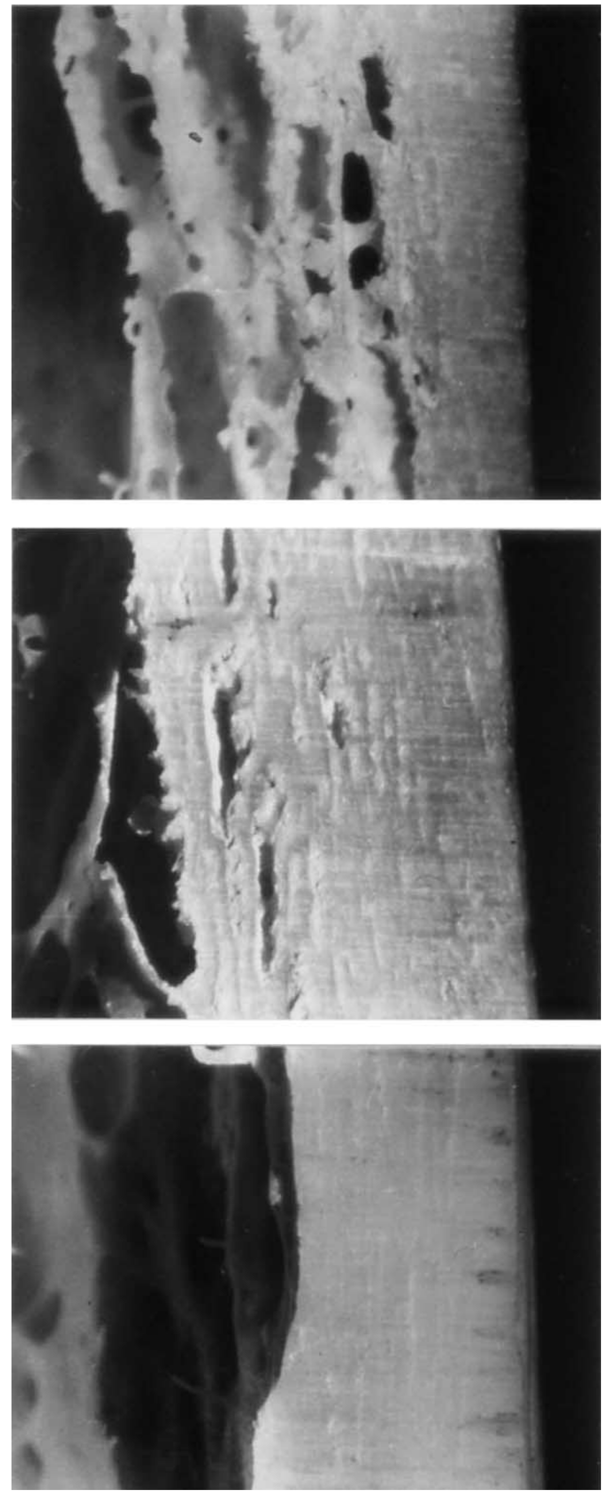

Figure 3 Osteoporosis in the compact shell of a long bone. The young individual at the bottom of the figure shows a dense cortex whilst with age it becomes more rarefied and lamellated.

Figure 4 Tuberculosis in the vertebral column. The extensive lytic lesions in the bodies of the vertebrae result from abscess formation.

The manifestation may be localized or widespread, single or multifocal, and occur within the range of minimal manifestation to gross representation. The pattern of manifestation will vary from individual to individual, depending on the stage of progression of the condition when viewed and the degree of manifestation displayed by that individual. Therefore classification of pathological conditions is highly dependent on a number of specific factors that will govern the reliability of the differential diagnosis.

Antemortem Trauma

The extent to which trauma is displayed in the human skeleton is largely dependent upon a number of factors, including:

- the nature and severity of the trauma
- the time lapsed since the trauma was inflicted
- the degree and success of repair to that injury
- the presence/absence of infection subsequent to the injury.

Trauma generally arises through contact between the skeleton and external influences, although pathologies such as some of those considered above can lead to biomechanical insufficiencies, resulting in traumatic material failure. Rather than the trauma itself being the indicator of presence, often it is the remnants of a callus formation or the subsequent posttraumatic deformity that gives clues as to the condition that may have occurred. Forensic anthropologists are particularly practiced in the identification of recent and healed traumas that affect the skeleton.

Again, there are no clear boundaries between the classifications of antemortem trauma, but a broad grouping could include:

1. accidental trauma (e.g., fractures, dislocations)
2. traumas resulting from intentional and deliberate violence (e.g., gunshot injuries)
3. cultural/cosmetic-induced trauma (e.g., Chinese foot-binding)
4. therapeutic trauma (e.g., surgical intervention).

Fracture

It is clear that fractures can occur across all four categories above and can arise through both blunt, sharp, and crushing trauma scenarios as well as intentional breaks caused for therapeutic and even cosmetic purposes. Fracture is defined as a discontinuity or crack in skeletal tissue with or without injury to overlying soft tissues. Fractures arise when external forces exceed the normal sustainable plasticity of the structure when applied either directly or indirectly to the bone. There are a number of classifications for fractures but they tend to fall largely within five possibilities:

1. Tension fracture: these are generally associated with tendon attachments to bone and are frequently associated with athletic injuries and referred to as avulsion fractures. Complications following this form of fracture can include an impairment of the normal operation of the joint through the inability of the tendon to reattach to the appropriate location, dislocation of the joint, or necrosis of the attachment site of the muscle.
2. Compression fracture: these are the result of sudden and excessive impaction and have a variety of manifestations. This type of fracture is commonly seen in the vertebral column of osteoporotic individuals or following impact from an implement where radiating fractures can be seen emanating from the original compression area (Figure 5). If the bone is depressed, then this can result in a circular pattern of fracture around the initial impact site and this is most clearly seen in injuries to the skull.
3. Twisting or torsional fracture: in this situation the force is directed in a spiral orientation when one end of a limb is fixed and the other is free to rotate. Sports injuries are frequently of this nature and because the force is in a spiral direction, so is the pattern of the fracture.
4. Bending, angulating fractures: these are probably the most common form of fracture and occur as a

Figure 5 Tumbling bullet entry wound in the parietal bone. Note the radiating fracture lines that pass forwards into the frontal bone, backwards and inferiorly into the temporal bone.

result of the pressures of a fall or the response to an external force coming in contact with the bone. The maximum stress tends to occur at one specific area but a compensating tensile fracture can also occur on the opposing surface of the bone (Figure 6). In a young person where the bone is highly mobile and elastic this can result in a "greenstick" fracture, where there is an incomplete transverse break in the bone and in this case the bone will subsequently heal with little residual evidence.

5. Shearing fracture: these occur when opposite forces are applied to bone in slightly different planes. For example, a Colles fracture of the wrist occurs when force is transferred up through the heel of the palm and the radius is sheared due to its firm attachment via the interosseous membrane.

Fractures are also classified with regard to the nature and severity of the distortion:

- A simple fracture involves a single clean break with only one separation of the bone (Figure 6).
- A comminuted fracture occurs when many fragments of bone are displaced. Comminuted fractures are more likely to result in poor alignment and bone shortening which allow easier detection of the fracture even after a considerable time has elapsed since the event. Of course, surgical intervention for fracture reduction and to address re-alignment issues can leave orthopedic hardware in the body and this is an obvious indicator of previous trauma (Figure 7).
- A compound or open fracture results when the overlying skin is broken, thereby giving potential access to factors leading to infection. Acute frac-

Figure 6 Fracture of the right femur of a juvenile. Note the extensive callus formation and overall thickening of the shaft. Misalignment has led to a foreshortening of the affected bone.

Figure 7 Fracture of the proximal one third of the shaft of the radius with orthopedic plating.

ture complications can include shock, hemorrhage, fat embolism, thromboembolism, gas gangrene, and secondary infection with septicemia. Osteomyelitis is an inflammation of bone and bone marrow caused by pus-producing bacteria. Compound fractures are a common cause for osteomyelitis, usually

through introduction of either staphylococcal or streptococcal bacteria. The manifestation of acute osteomyelitis is usually most obvious in tubular long bones where there is abscess formation and necrosis. Sequestrae form when an area of necrotic bone becomes surrounded by living bone and at the same time detached areas of periosteum become stimulated to form new bone – an involucrum – which can become perforated by cloacae, which are channels through which the abscess can drain from the bone into the soft tissues and eventually perforate the skin to form a fistula.
- A simple or closed fracture does not involve an opening of the skin and therefore potential exposure to infection is significantly reduced.

Gunshot Trauma

The degree to which a bullet or trajectory will damage a bone is dependent on a number of factors, including the type of bullet, its velocity, distance from the target, angle of trajectory, and any deflections. When a bullet passes through bone a characteristic set of wounds is produced and these will be different if the bullet is passing through compact, cancellous, or diploic bone. For example, in the skull, when the bullet strikes the outer diploic table it indents the bone and punches through, resulting in a rounded defect with little, if any, beveling of the bone at the entry margin. As the bullet exits through the inner table, small fragments of bone are displaced, resulting in an internal beveling. Conversely, as the bullet passes out of the skull it will pass cleanly through the inner table and leave beveling on the outer table (Figure 8). As the bullet passes through the bone small fragments of metal may be stripped from it and these can often be detected on a radiograph, as can other forms of ballistic residue (Figure 9). If the bullet strikes the bone at an oblique shallow angle, a characteristic defect, often referred to as a "keyhole" defect, occurs.

Figure 8 Gunshot exit wound in the occipital bone. Note the bevelling on the outer table but there is only one radiating fracture line halted by the lambdoid suture.

Figure 9 Metal fragments within the skull as a result of gun shot residue. Courtesy of M Warren, University of Florida.

Radiating fracture lines are caused by the impact and they will follow weaknesses in the bone microstructure. Fracture lines will stop when the energy dissipates or when they meet a foramen, a suture, or a preexisting fracture (Figures 5 and 8). If the ballistic energy is high, then fracture lines may meet a suture, follow it for a while, and then continue through the adjacent cranial bone. Concentric fractures are caused by an increase in intracranial pressure created as the soft tissue is compressed by the bullet. Extensive concentric fracturing occurs when gases expelled from the gun enter along with the bullet.

Sharp-Force Trauma

This includes all kinds of injury caused by a weapon or an implement with a sharp edge or point and generally results from stabbing-type injuries. The most common type of weapon is a knife, although other sharp implements such as axes or machetes combine a sharp edge with a heavy element, producing injuries that have both sharp and blunt impact features (Figure 10). It is not unknown for the tip of a knife to be snapped and remain embedded within the bone. When removed, the resulting wound is generally conical in shape with smooth edges. Axes, machetes, and other flat-bladed implements tend to produce elongated V-shaped grooves and valuable information can be gained about the weapon involved using scanning electron microscopy of the incised bone surface.

Figure 10 Machete injury to the top of the skull. The sharp impact of the blade can be seen in the center but the concentric depressed fracture that surrounds it is a clear indication of a heavy impact injury.

Amputations

Amputations can arise under a number of circumstances:

- natural accident
- surgical intervention
- war injuries
- social punishment/torture
- ritual.

It is important to be able to separate a true amputation from a malunion following fracture and subsequent resorption of one section. Postamputation survival of less than 1 week will produce no detectable signs of healing. However, around 14 days postamputation, the severed bone end commences callus formation and therefore provides skeletal evidence of survival of the incident and the commencement of a healing process. The rounded end of the bone begins to smooth over and the medullary cavity becomes obliterated at the stump end (Figure 11).

Other mutilations such as intentional deformity (head-binding, foot-binding, etc.), scalping, defleshing, trephination, and crucifixion all leave their marker on the skeleton, as can traumas such as strangulation and decapitation. The list is virtually endless.

Figure 11 Amputation of the right thigh in the lower third of the shaft. Note the rounded stump indicating a considerable survival time after the event (in this specimen that was actually 55 years).

Summary

It is not possible to summarize adequately the range of pathologies and antemortem traumas that can be evidenced from the human skeleton in an article such as this and the list of suggested reading below will allow the subject to be considered in much greater detail and depth. Therefore just a few features have been selected for illustration to offer a flavor of the abundance of information that is available to forensic anthropologists to permit them to confirm the identity of the deceased through the route map of the insults and injuries of a lifetime. Pathologies and traumas are highly specific in terms of geography, often being indicative of a country or a continent, and patterns of antemortem trauma can be equally specific.

See Also

Anthropology: Overview; **Body Recovery**; **Deaths:** Trauma, Musculo-skeletal System

Further Reading

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Cremated Bones

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Introduction

In most western countries, fire ranks as the fourth largest accidental killer, after motor vehicle accidents, falls, and poisoning. Victims of fire are commonly either the very young or elderly people. This may be because very young and elderly individuals are physically unable to escape from a fire and they may also have less tolerance for toxic gases. Most deaths are primarily due to smoke inhalation, lack of oxygen, and poisoning by carbon monoxide or other toxic gases. With the exception of mass deaths in fire accidents, heat is the direct and immediate cause of death in only a few cases.

The purpose of the investigation of cremations is not only to identify the victim but also to determine the circumstances leading to an accidental or intentional death, which makes it one of the most difficult forensic–anthropological tasks. Bone is commonly well preserved, but the level of preservation is closely related to temperature changes, and the characteristics of bone may be an indication of its thermal history. Because fire often reduces a skeleton to minute fragments of bones and teeth, termed cremains, the police investigation should be carried out in close collaboration with forensic anthropologists. An untrained person who is unfamiliar with cremated bones may not be aware of the information such pieces could produce. A famous letter from the renowned Swedish anatomist and anthropologist Carl Magnus Fürst to the chief inspector of antiquities in Stockholm, written in 1930, claimed that "cremated remains of human bones in burial urns are almost without any anthropological interest, especially in cases of such in a mass cemetery. From an anthropological point of view, therefore, these bones are of no scientific value." Unfortunately, this was a common attitude to forensic cases until a few decades ago.

Degrees of Burning

Since the intensity of temperature and oxygen supply are essential factors in the evaluation of body remains and in their possible identification, these factors are discussed first. When we study cremated bones, we soon discover that most of the material has been burnt to different degrees. Some of it is sooty, some is pale in color, almost chalky, and some does not seem to have been cremated at all. Relying on colors alone to indicate temperature may lead to error because the heat may have a local effect that is difficult to evaluate. The nature of the ground in which the bones are found should also be taken into consideration.

Even in large fires, the effect of the heat may be restricted to small areas as a result of draught, oxygen supply, and the size of the room. When studying forensic material, sometimes one part of the body of a corpse is completely charred and destroyed while another part is almost unburned (**Figure 1**).

From a technical point of view, the following factors are necessary for cremation: (1) a combustible

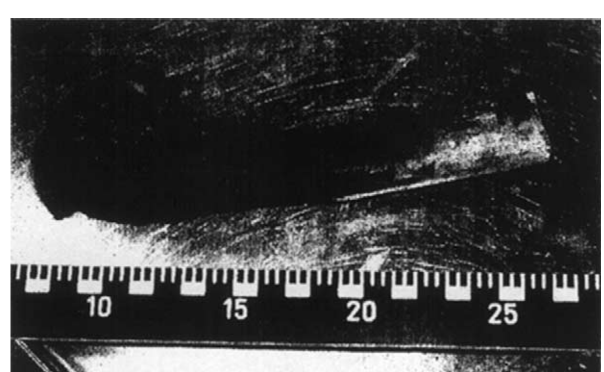

Figure 1 Local effect of fire on a thigh bone. Photo courtesy of P Holck.

Table 1 Distribution of combustible and noncombustible substances of a ''normal'' adult human body (70 kg), compared with that of a newborn baby (3 kg), with corresponding heat of combustion given in kcal kg^{-1}

	Substance	*Weight (kg)*	*Heat of combustion (kcal kg^{-1})*	*Total (kcal)*
Adult				
Combustible	Fat	11	8500	93 500
	Protein	13	5000	65 000
Noncombustible	Water	42	539	22 638
	Ash	4	200	800
Total		70		≈135 000
Newborn baby				
Combustible	Fat	0.3	8500	2500
	Protein	0.4	5000	2000
Noncombustible	Water	2.2	539	1200
	Ash	0.1	200	100
Total		3.0		≈3200

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material; (2) adequate ignition temperature; (3) sufficient supply of oxygen; and (3) technically suitable conditions. The human body contains both combustible substances, such as fat and proteins, and noncombustible substances, such as water and inorganic matter. When substances burn completely, they produce heat. When they do not, they need more heat. The thermal energy released when a substance burns is the positive heat of combustion, whereas the energy needed to burn a substance completely is the negative heat of combustion.

The total heat of combustion of a human body is the difference between its combustible and noncombustible substances (Table 1). Accordingly, cremation of a normal body creates surplus heat. However, a lean person will give out less surplus heat and in certain circumstances may be impossible to cremate completely (e.g., people who have suffered from weight-reducing diseases, such as cancer and tuberculosis). Infants and small children have a much lower body fat content than adults, and their released combustion heat produces only approximately 2% of what an adult body can produce. As a result, a child may be difficult to cremate (Table 1).

If the temperature is low and the supply of oxygen is reduced during cremation, combustible and toxic carbon monoxide will be formed instead of noncombustible carbon dioxide. In the first case, the flue gas will be dark, due to precipitation of carbon. To avoid this, modern cremations normally take place when the temperature of the incinerator has exceeded 650 °C – this is the ignition temperature of carbon monoxide.

Cremation and destruction of a human body require less heat than is commonly expected. The grade of burning depends on: (1) the temperature induced; (2) the duration of the heat; and (3) the oxygen supply. Finding melted substances, such as glass or metal, provides an idea of the temperature reached and may sometimes offer information that can assist in identification (e.g., surgical devices). It is known from modern domestic house fires that even cast iron can melt, and this indicates a temperature of more than 1550 °C. The remains of people who perish in such circumstances show great similarity to the most strongly cremated bones in archeological finds.

Classifying bones according to their different grades of cremation may therefore sometimes provide information about the temperatures and circumstances associated with the process that led to a person's death. Normally, five grades are used:

1. In grade 0 the bones are minimally affected by heat and show no external signs of having been burnt. However, this does not mean that the body has not been exposed to fire, but rather the soft tissues have all formed an insulating layer against the surrounding heat, which may have reached 150–200 °C for several hours. This may still be sufficient to destroy the collagen: this may be tested by placing bone pieces into an acidic solution such as 5% phosphoric acid. Grade 0 bones are more often found to be of interest in archeological finds than in forensic cases. However, destruction of cell material means that cremated bones are normally unsuitable for DNA analysis.
2. Grade 1 displays a bony surface of dull, grayish-black color, which may be a sign of incomplete burning due to a lack of oxygen. The changes in color can be followed deep into the bone. It is difficult to determine any upper temperature limit at this grade because carbon deposit depends more on oxygen supply than on temperature. It is, however, reasonable to assume that the temperature was not greater than 400 °C, since changes in the bone structure normally occur at this temperature.
3. Grade 2 indicates that the oxygen supply has been adequate but the heat-induced alterations to the structural nature of the bones are still moderate, probably due to shorter exposure rather than insufficient temperature. There are no longer signs of carbon deposit on the bone surface, but the interior of the bone may sometimes have a sooty appearance. The difference between grades 1 and 2 relates to the thickness of the compact layer. When heated between 400 °C and 700 °C, the color of the bone lightens from black to light

Table 2 Bone changes at different temperatures

	Temperature in °C	*Changes in bone*
Grade 0 ↓	100	Insignificant changes in bone and teeth. Collagen still intact
Grade 1 ↓	200	Only superficial color changes in bone and teeth. Considerable reduction of collagen. Nuclei (DNA) destroyed
	300	Weight reduction, loss of water. Modestly reduced volume. Collagen completely destroyed. Color: brownish/dark gray
Grade 2 ↓	400	Lowest solidity of the bone structure. Formation of microscopic fissures in the bone surface. Small cracks in the enamel of the teeth. Color: black/dark gray
	500	Deformation of the bone. Larger, net-shaped microscopic cracks in the bone surface. Color: grayish
	600	Further macro- and microscopic cracks in the bone surface. Formation of pyrophosphate (salts of heated phosphoric acid). Color: light gray
	700	Further reduction of the volume due to fusion of mineral crystals.
Grade 3 ↓		Liberation of water of crystallization. Previously formed pyrophosphate compounded with hydroxyapatite to whitlockite. Shrinkage and changes in lamellar construction of the Haversian systems
	800	Further shrinkage and deformation. Further fusion of the mineral crystals in the bone. Melting and crystallization of the dentine, but still without destruction of the dentine tubuli. Color: white/gray
	900	Marked macroscopic cracking of the bone surface. Destruction of the osteon structure. Further fusion of the mineral crystals. Cracking, melting, and destruction of the enamel of the teeth
	1000	Microscopic oval holes of various size in the bone surface. The dentine appears as ball-shaped formations with the tubuli still intact. Color: white, chalk-like structure
Grade 4	1100	Melting of the dentine tubuli
↓	1200	Total decomposition of the microstructure in bone and teeth

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gray and then to white. The hardness of the bone remains unchanged.

4. Grade 3 is most commonly found in archeological material. The bones have a cracked appearance and, when the surface is scratched with a sharp tool, a white stripe is left, unlike grade 2 bones. The stripe is an indication that the bones have reached temperatures in excess of 700 °C and that the organic matter (and water) has been completely removed. At this stage, the hardness of the bone increases considerably. There is marked shrinkage due to fusion of mineral crystals in the bone, and the contents of α-tricalcium phosphate are transformed into β-tricalcium phosphate or whitlockite, which marks the transition from grade 2 to grade 3. When heating exceeds 800 °C, the lamellar pattern of the bone is lost, which reduces the efficiency of microscopic methods used in the examination. Also, bone shrinkage is more significant in this grade of cremation – up to 25% length reduction has been observed in human bones – which makes estimation of individual height unreliable.
5. Grade 4 is easy to recognize by the chalk-like appearance of the bones. At this extreme grade, the bones have been exposed to temperatures higher than 1100 °C. The nature of bone seems to have changed completely. The color is white, the weight is reduced, the bone has a porous, chalk-like consistency, and bones are mostly found as small, fragile fragments, often impossible to identify anatomically (Table 2).

Bones Commonly Found after Burning

When findings of cremated bones are examined, certain parts of the skeleton appear to be preserved more often than other structures. Bones from the neurocranium are commonly found as pieces of up to 10 cm in size, but bones from the facial skeleton are only occasionally found as such large fragments. This means that facial reconstructions of thermally decomposed bodies are unlikely to be possible. When an adult is exposed to temperatures of approximately 700 °C, the face becomes a skeleton within 15 min.

If the forehead is more or less intact, the frontal sinus should be examined and compared with X-rays of the presumed individual because the shape appears unique and thus this may be an important part of the identification work. Despite its thin and unprotected structure, the neurocranium is frequently found because of the insulating quality of the brain and cerebrospinal fluid. However, teeth, which are otherwise used to identify deceased persons, crack when they are exposed to heat. Enamel crowns are commonly lost while the roots remain intact; teeth of younger individuals usually resist heat better than those of elderly people. Thus, it is often not possible

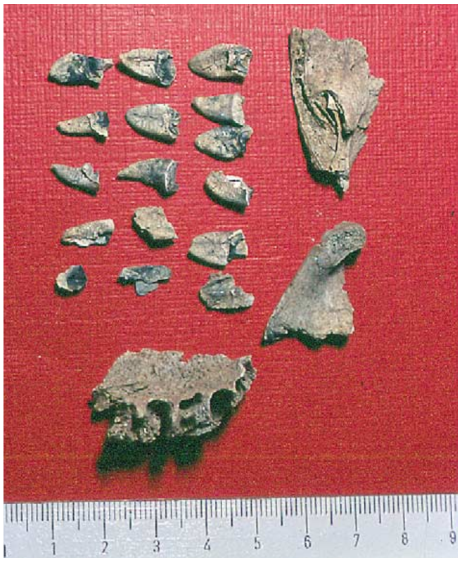

Figure 2 Typical remains of teeth after cremation: only the root dentine is preserved. Photo courtesy of NG Gejvall.

to use teeth of people exposed to fire for identification purposes (Figure 2).

The vertebral column is commonly well preserved: this may be related to the position of the body during burning. However, the sternum, ribs, clavicles, and scapulae are seldom seen in cremated material, probably because of their delicate shape and unprotected site in the body.

Pieces of long bones can be found as fragments which are several centimeters long. Phalanges are seldom found in burnt forensic material, as opposed to in archeological finds, where these bones are seen relatively often: this may be explained by the local influence of cool open air as opposed to indoor fires. Also, the pelvis is seldom found, despite its protected site in the body, with the exception of pieces from the most solid parts.

Human or Animal?

In both forensic and archeological cases, there may be doubt as to the provenance of the bones: are the pieces human or not?

Animals have much thicker, more compact bone than humans. Their trabecular units are a different size and shape, and this gives a heavier and more solid appearance than comparatively more porous and lighter human bones. The line between the spongy and the compact part of animal bone is also less distinctive than in human bones. Their outer/inner surface is often smoother and gives the examiner a feeling of unbreakable solidity.

Some experts recommend microscopic examination to distinguish human from animal bones of uncertain origin, because the human Haversian canals are much wider than those of animal bones (Table 3). In cremations, the examiner should pay more attention to macroscopic and morphologic–anatomic differences, even when limited, than to microscopic ones, because the bone shrinks and deforms, and can be very difficult to assess.

Table 3 Cross-section diameters of Haversian canals in humans and some domestic animals

Species	*Average diameter (μm)*
Humans	52.9–71.6
Cattle	47.9
Pig	32.8
Dog	21.2
Goat	21.2
Sheep	18.2
Goose	15.7
Hen	14.0
Rabbit	12.6

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Determination of Sex

This is, of course, very important in all examinations. It should be based on common anatomical features, even if macro- and microscopic techniques have also been applied. It should be kept in mind that sexing cremated bones is very difficult and uncertain and requires more material than any other examination. It is common for more than 50% of cremated bone material to remain undetermined. This may be surprising to the police and others unfamiliar with such examinations, but it is always better to present a smaller number of certain determinations than a more impressive series based on suggestions.

It is well known that the degree of sexual dimorphism varies between individuals and between different human races; nevertheless, the cremation process will sometimes emphasize sexually dimorphic criteria. Since larger and heavier parts of the skeleton, usually associated with men, are normally better preserved than smaller parts, some experts have suggested that sex criteria appear in cremated material as distinctly as in intact bones.

Measurements and sexing based on mathematical or statistical methods should be used with the greatest care. As previously mentioned, the original shape of the bones shrinks and deforms in an unpredictable way. In fact, distinguishing features that are supposedly certain, such as the narrow male sciatic notch, may change into a wide, female-appearing structure after cremation in an incinerator.

Estimation Of Age

Since there can be considerable miscalculations of certain age groups, especially in cremated material, the term "age determination" should be avoided. It is well known that the accuracy of age estimations in human skeletons decreases in proportion to age. This means that children's age may be determined with relatively high accuracy, whereas age estimations of older persons are connected with miscalculations of 10–15 years or more, if the age can be estimated at all.

Epiphyseal closure and tooth development are normally used to estimate skeletal age in children and young individuals. Adult age is frequently estimated on suture closure and root transparency of the teeth are frequently used, even though these criteria are associated with inaccuracy and individual variations. In cremations, however, tooth development is commonly unsuitable as a criterion of aging because heat easily cracks enamel and turns roots opaque.

Even the shape of the pubic symphysis can seldom be used as a criterion for age estimation because this part of the skeleton is rarely found preserved after exposure to fire. Neither is the morphology of the sternal end of the ribs helpful, because this part of the body normally appears skeletonized after only 20 min at a temperature of 700 °C.

Since so many methods for estimating age are unreliable, the skull sutures should be used to study age development when examining cremated bones, because skull pieces with sutures are often found. It is important to remember that the sutural pattern is controlled by biological factors alone, and unaffected by external, individual changes: the bones of the neurocranium undergo a slow process of fusion from early childhood to old age.

Cremated bones have one advantage: the cracking of the sutures allows for the study of their fractured edges as well as the skull surface. Their pattern changes with age, even before any sign of ossification can be seen on the external surface of the skull, and their total appearance may thus indicate the person's physical age to a relatively high degree of accuracy (Figure 3). By studying the suture of a young person, it can be seen that the only fusion of the skull bones is a thin zone near the internal lamina. This zone forms the first visible ossification of the suture at 10–12 years; it increases in thickness and reaches the external surface of the skull as the suture closes completely at old age.

Although anatomical determination of the examined skull fragments is often difficult or impossible, one is still able to give an indication of individual age because all the fractured edges undergo approximately the same age-related changes, even though the suture closure does not occur simultaneously. This is therefore a more reliable measure of age development than the sutural pattern seen on unburnt skulls. It is also important to consider the increasing thickness of the skull vault with age when aging cremated bones (Figure 4).

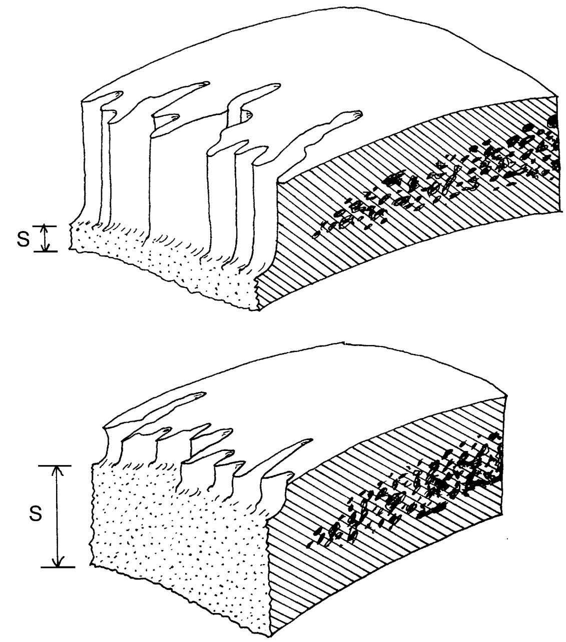

Figure 3 Age development of skull sutures. Top: a piece of the neurocranium from a young individual is shown with a short fractured ossification surface (S); bottom: the same surface is shown from an older person with a high fracture surface. Reproduced with permission from Holck P (1997) *Cremated Bones. A Medical–Anthropological Study of an Archaeological Material on Cremation Burials*, 3rd edn. Oslo, Norway: University of Oslo, Anatomical Institute.

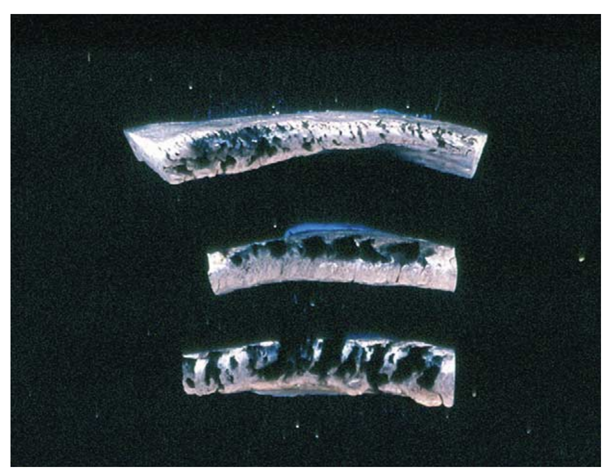

Figure 4 Three pieces of skull bone from persons of known age, with edges displaying an increase in the ossification line. Top: bone from an 85-year-old: complete closure of the suture (i.e., the ossification has reached the external surface of the skull); middle: bone from a 58-year-old: half of the skull bone is ossified; bottom: bone from a 37-year-old (bottom): only the internal lamina is ossified. Photo courtesy of P Holck.

Figure 5 Situation from a mass disaster. Separation of cremated remains should, if possible, be executed by forensic anthropologists. Photo courtesy of the National Bureau of Crime Investigation, Oslo, Norway.

Theoretically, a rough estimation of age on post-cranial parts of the skeleton can be assisted by studying the changes in the microstructures, because the width of the Haversian systems normally increases with age. However, the shrinkage of the bone substance, especially above 700–800 °C, may result in miscalculations.

The approximate age of children can sometimes be estimated by measuring the transversal diameter of the long bones, if these are preserved, in addition to examining the epiphyseal closure.

Height

In cremated material, it is not possible to estimate height with the same accuracy as in unburnt bone material. In cremations, long bones are rarely found to be complete and measurable; if they are, shrinkage must be considered. Also, correlations between the breadth, which is less often destroyed, and the corresponding length of the bone could theoretically be used and directly transferred to common anthropological tables (Figure 5).

Commercial Cremations

The first incinerator was constructed by the Italian professor Lodovico Brunetti and presented at the World Exhibition in Vienna in 1873. It attracted enormous attention, and after improvements made by the German engineer Friedrich Siemens, the first commercial cremation occurred in Germany in 1874. Two years later, the first crematorium was built in Milan, Italy, and soon most of the larger cities in Europe and the USA followed suit.

The frequency of cremations differs throughout the western world but may exceed 85% of all burials in some larger cities. Cremation is more prevalent in Protestant countries than in Catholic ones.

The incinerators are mainly of two kinds: electric or oil-heated. Because the normal body creates a certain surplus of heat during cremation, the temperature inside the incinerator will increase. It therefore starts at 650–700 °C, which is the lowest temperature for the prevention of formation of toxic and explosive gases. From the moment the corpse is placed inside, a sharp increase in temperature occurs (exothermal reaction), caused by the ignition of the most combustible parts of the body and surrounding materials (e.g., the shroud and coffin, usually after 3–5 s), despite a constant supply of heat energy from the incinerator. After 40–50 min, the temperature will decrease during cremation of the less combustible parts of the body. However, the final temperature will be approximately 50 °C higher than the initial temperature after each cremation.

Because of the incinerator's increasing radiant heat, in addition to the higher temperature of combustion gases, some of the surplus heat will gradually disappear so that the final temperature increase will be 200–300 °C or more after a "normal" series of cremations during a work day. Each cremation normally lasts 1–2 h.

When the cremation ends, the bone remains are placed in a metal box to cool. There may still be large pieces of bone that are cracked and twisted but sometimes complete. The remains are then placed into a crushing machine to be transformed into the small bits appropriate for urns. The contents of urns are commonly called "ashes" but are actually bone fragments of several millimeters.

Unfortunately, some countries allow the ashes to be spread in nature as a sort of ceremony instead of a cemetery burial. Finds of such human bones can create many problems for police and forensic experts. Even pet animals are sometimes cremated, put into urns, and dispersed in the countryside.

Conclusion

The effect of fire on soft tissues and bones in a human body can be compared to a mechanical injury, where the depth of burning depends on temperature, the length of exposure, and the supply of oxygen to the part of the body in contact with the heat. The significance of the body's fat content has been mentioned previously. Also, the type of clothing influences the rate of burning.

Examinations of cremated bones are difficult, and the investigator must be very reserved, careful, and exact. It is difficult to make assured determinations of sex, age, and height, which are all important factors in the identification work of a forensic anthropologist.

However, some pathological changes and injuries can sometimes be found in cremated bones and these may lead to identification, although only 10% of modern western diseases cause changes in the skeleton. Cut marks can occasionally be seen and identified by their smooth and flattened edges, in contrast to the curved heat-induced cracking of bone; microscopic fractures can commonly be seen in the surface line of the impact area.

See Also

Anthropology: Overview; Bone Pathology and Antemortem Trauma; **Autopsy, Findings:** Fire

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Morphological Age Estimation

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Introduction

Estimation of age from the skeleton is based on the knowledge that during a person's life his/her bones are constantly undergoing changes, and that these changes follow a chronological pattern. In the early stages the skeleton is characterized by the development and growth of bones and dentition, in the form of ossification centers and tooth buds. In childhood and adolescence, bones take shape and grow, and epiphyses develop and fuse with diaphyses. In the dentition, teeth grow and erupt, and deciduous teeth are lost and replaced by permanent teeth. When adulthood is reached, the basic skeleton is complete, but age changes are visible in the obliteration of sutures, changes in trabecular and microstructure of bone, and other degenerative changes.

When an attempt is made to estimate the age of skeletal remains, it is important to distinguish between age at death and time since death. Age at death is the estimation of the age of the person when he/she died, whereas time since death refers to the amount of time that has passed since the person died. Age at death can be estimated with reasonable accuracy, depending on the amount of skeletal material present, the parts of the skeleton that are represented, and the condition of the remains. Time since death is much harder to estimate due to the great variation produced by environmental factors such as burial depth, type of soil, and climatic and seasonal fluctuations. In this article, only the estimation of age at death will be discussed.

Estimation of age at death also needs to take into account the difference between chronological age and biological, or skeletal, age. Chronological age refers to the age of the individual measured in units of time (usually in months/years since conception or birth). Biological age refers to the age of a person based on the development and health of his/her bones in comparison to normal standards. A person who has suffered ill health throughout life and has not had access to regular medical treatment may appear at death to be considerably older in biological rather than actual chronological age. A person who suffered from a serious illness or from malnutrition during childhood may exhibit signs of a delay in maturation, and his/her bones will appear to be younger than the actual chronological age. When a skeleton is examined for the purpose of estimating age, it is only the biological age that can be interpreted. The relationship between chronological and biological (or skeletal) age is not constant, nor is it linear, which adds to the difficulty of estimating age. As a result, factors such as delays or advances in development and/or variability in the rate of degeneration on the skeleton need to be considered when estimating chronological age. For age estimation, sex and population of origin also need to be determined before attempting to age the skeleton. This is because population factors influence the aging process in individuals, as do differences due to sex.

Methods used in forensic anthropology to estimate age at death are usually based on population standards, generated from the major population groups around the world. However, individual variation between people from within the same population is often overlooked or underestimated. It can be difficult to estimate the age of an individual with accuracy when he/she is viewed in isolation from other specimens, as is usually the case in forensic situations. Variability in the skeleton arises through genetic and biological influences, and ultimately is the basis for our individuality, i.e., there is no such thing as an "average" individual. Over the years, scientific study has generated data that describe the central tendency of biological traits, for example, the most common age that epiphyseal union occurs in a particular bone. This average age has been established through the study of normal people – those who vary from the average to an acceptable level (nonpathological development). Therefore, when estimating the age of an individual, the scientist will always include an estimate of the possible variation due to age for that feature. This can be interpreted as an estimate of how closely the age of that person resembles the central tendency of the population. For example, estimating the age of a person using the rate of closure of cranial sutures is very variable, and age estimates are generally based on decades of development, with a standard error of about 5–10 years. It is for this reason that many researchers believe it is best to obtain an age estimate from as many sites as possible, and arrive at an overall age estimate based on a summary of all the findings.

Generally, seven age groups are used when assessing human remains. These are: (1) fetal (before birth); (2) infant (0–3 years); (3) child (3–12 years); (4) adolescent (12–20 years); (5) young adult (20–35 years); (6) middle adult (35–50 years); and (7) old adult (50+ years). Due to the amount of growth present in fetal, childhood, and adolescent years, estimation of age can usually be determined to quite a narrow range. Estimation of age of adults is complicated by individual variation in senescence, which is influenced by interactions between genes, culture and environment, and the individual. Often, it is only possible to assign a skeleton to a particular decade or period of life.

Estimating Subadult Age

There are a number of criteria that can be used to estimate the age of a subadult individual. These include eruption of the dentition, epiphyseal fusion, and measurement of the diaphyseal length of long bones. Estimation of fetal age is not always straightforward, due to variation in developmental factors. Consequently, relying on the size of bones as a means of estimating age has some associated problems. Modern research has established the existence of a close relationship between the development of the cervical vertebrae and age, which seems to be more reliable than some of the more traditional methods. Advances in medical imaging have also allowed better investigation of tooth germ formation and dental eruption.

The pattern of eruption of the dentition has been established through the study of development of teeth of people of known ages, generally through observations taken on longitudinal X-ray data. These studies have published findings on the times of formation, eruption, and loss of the deciduous dentition, and the formation and eruption of the permanent dentition. When estimating subadult age from the dentition, careful examination of the skull and comparison with the reference diagrams in the literature should enable an age estimation to be made.

Subadult age can also be estimated from the growth of long bones, in the fusion and union of the epiphyses, the ends of the bones, and in the overall length of the diaphysis, or shaft (Figure 1). A long bone usually has three centers of ossification – the diaphysis, which is the primary ossification center; and two epiphyses, the secondary ossification centers. Some long bones only have one epiphysis, but others, such as the long bones of both upper and lower limbs, have two epiphyses. Each epiphysis has a layer of cartilage called the epiphyseal plate, which lies between the epiphysis and the diaphysis. This is where growth of the long bone takes place. Cessation of growth occurs with the union of the epiphyses and the diaphysis. The stages of fusion between epiphysis and diaphysis have been carefully documented through research. A summation of the degree of epiphyseal fusion in different long bones in the body can be used to estimate age. The age at which epiphyseal fusion

Figure 1 Neonatal right humerus. Note the unformed ends where the epiphyses are yet to fuse.

occurs varies according to population, sex, and individual differences. Females undergo epiphyseal fusion about 2–3 years earlier than males. Consequently the average female has a shorter period of growth and smaller body size than the average male. The last epiphysis to fuse is at the medial end of the clavicle. The average age at which this fuses is around 21 years of age. There is also a considerable variability, with reported findings of complete fusion at 18 years of age in some individuals, while other individuals aged over 30 years still had incomplete fusion.

Estimating Adult Age

Timing of cranial suture closure was one of the first techniques used to estimate the age of adult individuals. It is well known that the sutures between cranial bones ossify at different times during life. The sphenooccipital suture on the skull base is particularly useful for aging young adults, as fusion is completed in 95% of individuals between 20 and 25 years. The other cranial sutures show more variation in timing of closure. Sutures ossify on the endocranial surface before they ossify on the ectocranial surface, and this must also be taken into account when using this method. Overall, most researchers conclude that cranial sutures can be used to estimate age, but that their inherent variability makes them considerably less useful than other morphological characteristics.

Adult age can be estimated from the dentition based on patterns of wear and attrition; however this is fairly unreliable unless the individual is from a population whose pattern of wear is known to be fairly homogeneous. Other factors, such as variability caused by diet, pathology, or the use of teeth as tools must also be taken into account when estimating age from the dentition (Figure 2).

Figure 2 Mandible with worn molars as a result of an abrasive diet in addition to normal aging.

Estimation of age of adult skeletal remains can also be performed on the pelvis. The surface of the pubic symphysis shows degenerative changes during life. An understanding of the systematic osteological changes that the normal symphysis undergoes enables an estimation of age at death to be made. In young adults, the symphyseal surface is rugged in appearance and is characterized by horizontal ridges. By age 35, the sharp features of the surface are less defined, and a rim forms around the edge. The following years are characterized by progressive degenerative changes, including formation of a rough symphyseal surface, and irregular borders. Until recently, the most commonly used method for estimating age using the architecture of the pubic symphysis was that of Todd, who described 10 stages of pubic symphysis change during aging. More recently, researchers Suchey and Brooks described six phases of degenerative change in the pubic symphysis. These phases are well described but still suffer the limitation of relatively arbitrary classification of a continuum of change in a biological structure.

Degenerative changes in the epiphyseal surfaces of the vertebrae, in the form of osteophytes, develop in individuals from about the mid-20s onwards. These signs of vertebral osteoarthritis can be used to estimate age by judging the severity of the lipping around the superior and inferior borders of the vertebrae. Using this method, an individual can be categorized as being from a particular decade of life at the time of death (Figure 3).

Recent Developments in Age Estimation

Since the 1980s, traditional morphological methods of age estimation have been supplemented by newer methods. These include histological and microradiographical examination of bone structure and the analysis of mitochondrial DNA of skeletal muscles. Age can be assessed histologically by counting the number of osteons and other structural factors of lamellar bone which have been found to be correlated with age. This technique has also revealed high variability in bone structure at the microscopic level, from factors such as nutritional status, sex, hormones, and mechanical loading. However, this method is also destructive, and as a result should only be performed when all other examinations have been conducted on the bone in question. Examination of microradiographs of bone has also been useful for estimating age. This technique is based on the correlation be-

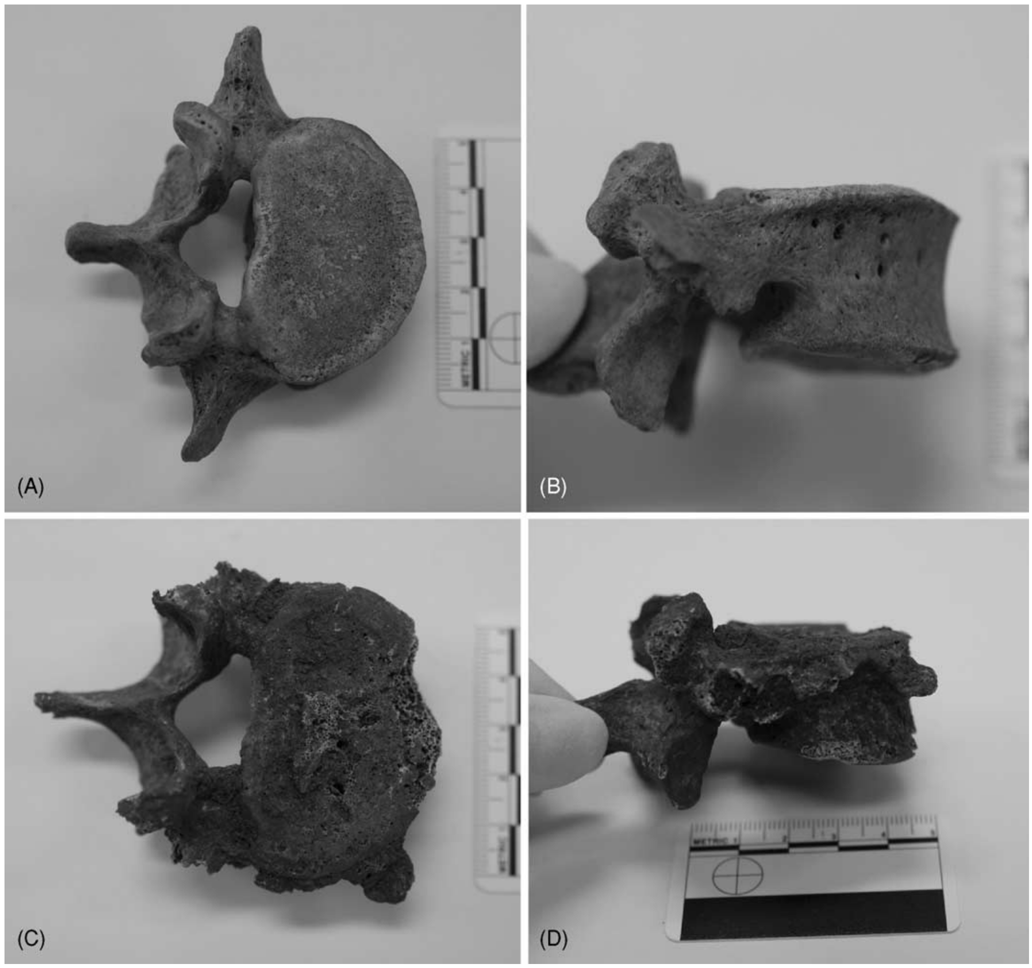

Figure 3 Contrast between a normal vertebra ((A) superior view, (B) lateral view, right side) and one showing age-related pathology ((C) superior view, (D) lateral view, right side). Note the superior and inferior lipping of the vertebral body margins, as well as the large osteophyte on the anterolateral region. Other degenerative changes can be seen on the superior surface, including pitting and Schmorl's nodes.

tween increasing age and loss of bone through natural remodeling processes. While this method does not destroy bone tissue, interpretation is also subject to the same factors of variability seen macroscopically in bone. Other studies have been instrumental in verifying the validity and reliability of the traditional methods used to estimate age, for example, recent studies confirming the inherent variability in ectocranial suture closure and pubic symphyseal surfaces. Studies on the sternal end of the fourth rib suggest that this feature is a much more accurate and reliable method of estimating age. Other researchers have used larger sample sizes and more complex data-processing and statistical methodology to test and validate hypotheses originating from earlier research.

The above review has highlighted a number of methods for the morphological estimation of age. The choice and application of these methods will depend on the condition and completeness of the specimen being examined, and on the presumptive age estimation (adult versus subadult). Partial or incomplete skeletons may be restrictive in the amount of information available for assessing age. Complete skeletons are much more informative and age estimations based on this material are generally quite accurate and reliable. Most authors suggest using a multifactorial approach to age estimation for maximum reliability, but others propose selecting a single factor, such as the auricular surface of the ilium, with other anatomical regions given a lesser role. It is difficult to conclude which is to be preferred, but for the most part, the possibility of error due to method, technique, or inexperience is most likely to be reduced by applying as many different methods of age estimation as possible.

See Also

Anthropology: Overview; Archeology, Excavation and Retrieval of Remains; Taphonomy; Stature Estimation from the Skeleton; Bone Pathology and Antemortem Trauma; Cremated Bones; Pediatric and Juvenile; Sex Determination; Determination of Racial Affinity; Handedness; Role of DNA

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Pediatric and Juvenile

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Introduction

Forensic anthropology may be defined as the identification and analysis of human remains for medicolegal purposes. This procedure normally begins with the establishment of the four basic parameters of biological identity – sex, age, stature, and ethnicity – and, if successful, proceeds to the confirmation of personal identity. In the case of immature remains, both the demonstration of these factors and the techniques required are of an order different from those needed for adults. The forensic anthropologist can be called upon to confirm a suspected identity or assist in the identification of unknown skeletal remains from homicides, suicides, and unexplained or natural deaths. The forensic anthropologist's expertise has been used in identifying the remains of children who died as a result of mass disasters and war crimes and also those found in war graves.

There are also situations in which either the actual or the chronological age of a living child is unknown or the stated age is suspected as being incorrect. Most legal systems require an established age so that appropriate procedures may be observed, for example, when the statutory age for criminal responsibility has to be certified. In some countries, refugees arriving by sea or air who lack personal documents may be obliged to prove adult or dependent status in order to obtain a residence permit. It may be necessary for an official to assign an age and the forensic anthropologist may aid in this process.

This article is devoted primarily to the identification of juvenile skeletal remains, but aging in the living child and legal procedures are also discussed.

Remains of Dead Children

When skeletal or badly decomposed remains are discovered, investigating officers usually need to know immediately whether the remains are human, how long they have lain there, and how many individuals

Figure 1 A mixture of perinatal human bones and chicken, duck, and rabbit bones. The human bones are labeled ''H.''

The next aim is to establish the biological identity of each individual through the assessment of sex, age, stature, and ethnic background. The purpose is to limit the search of the missing persons list, leading to the establishment of personal identity.

Of the four principal biological parameters, only the age can be estimated with any degree of reliability in juveniles. Although there are small skeletal morphological differences between the sexes from an early age, they are not significant for reliable determination of sex until after pubertal modifications have occurred. Therefore, sex determination is tentative at best. The age of most juveniles is so closely linked to stature that it is generally used to predict height, which is particularly variable during the pubertal growth spurt. It is difficult to establish ethnic identity from skeletal remains in the adult, and in the child it is even more difficult because sufficient data do not exist on which to base conclusions.

Age

The terminology applied to different periods of life varies both in different countries and as used by clinicians, skeletal biologists, and anthropologists. There are some commonly accepted definitions (Table 1), but other terms have a variety of meanings in different contexts (Table 2). Certain key ages in the life span of an individual are important legally, and the forensic anthropologist may be involved in determining whether these are relevant in a specific case. For example, is a dead baby a full-term infant, or is a runaway young person of an age to marry without parental consent? For the purposes of this article, juvenile is used to describe any stage of development before complete growth of the skeleton ceases at approximately 28 years of age.

Table 1 Definitions accepted by embryologists, clinicians, and pediatricians

Embryo	First 8 weeks after fertilization
Fetus	From 8 weeks of intrauterine life to birth
Preterm infant	Live birth <37 weeks (258 days) LMP
Full-term infant	Live birth from 37 to 42 weeks (259–293 days) LMP
Post-term infant	Live birth >42 weeks (294 days) LMP
Stillbirth	Infant born dead after 28 weeks LMP (UK definition)
Neonate	First 4 weeks of life
Infant	Birth to the end of the first year of life

LMP, last menstrual period of mother, a clinical timing. Fertilization dates are 2 weeks later.

Table 2 Some commonly used age terms with variable meanings

Perinate	Around the time of birth
Early childhood	First 5 years – often preschool age
Late childhood	From about 6 years to puberty
Puberty	Time of secondary sexual change – about 10–14 years in girls and 12–16 years in boys
Adolescence	Used by some authors synonymously with puberty and others as referring to behavioral and psychological changes at puberty
Young adult	Period from cessation of growth in height until final fusion of all other bones (see text)

Estimation of age of the juvenile uses the many incremental changes that occur during the period of growth and development. Growth consists of two main components: increase in size and increase in maturity. Although these elements are usually closely integrated, their relationship is not always linear. For example, an 8-year-old girl may be several centimeters taller than her friend of the same age. Similarly, two boys of the same height can be at different stages of skeletal maturity.

Biological Identity

When age is unknown, the concept of biological age is adopted as an indicator of how far along the developmental continuum an individual has progressed in terms of growth and development. Biological age may be expressed as dental age or skeletal age, depending on which elements of the skeleton are available to be employed in the estimation. Dental age may be estimated either from the times of eruption of teeth into the mouth or from the degree of their mineralization (Table 3). Skeletal age is estimated from the size and stage of development of the bones of the skeleton. Both methods require the unknown individual to be compared to a known standard, and this may introduce areas of incompatibility.

Dental Age

Estimation of age from the teeth has several advantages over skeletal aging. First, teeth normally survive inhumation better than any other part of the skeleton. There have been cases in which teeth were the only recognizable remains of an individual, either because of decay due to burial conditions or because there was an attempt to destroy a body by dismemberment or burning. Second, the development of the deciduous and permanent sets of teeth can be studied over the whole range of the juvenile life span, beginning in the embryonic period and lasting into early adult life. Finally, it is generally accepted that the relationship between chronological age and dental age is stronger than that between chronological age and skeletal age. Dental development is less affected than bone development by adverse environmental conditions, such as nutrition and disturbances of endocrine function. Additionally, the formation of all the deciduous dentition and part of the permanent dentition takes place before birth in a protected environment, whereas skeletal growth is exposed for increasing amounts of time to external influences. This is reflected in the increasing divergence between chronological and skeletal age, as environmental factors have more time to affect the growth of the skeleton.

Two aspects of tooth development have been used in the estimation of dental age: the emergence of teeth into the mouth and the stage of mineralization of their crowns and roots during development. Eruption is the continuous process by which a tooth moves from its crypt in the bone of the jaws to its position of occlusion in the mouth. Most studies are confined to actual emergence, which is wrongly referred to as eruption. In a skull or mandible, emergence is defined as the superior part of the crown of the tooth appearing level with the surface of the alveolar bone.

Estimation of dental age using mineralization stages of crowns and roots of developing teeth entails visualization from a radiographic image in order to view both erupted and unerupted teeth (Figure 2). Each available tooth is assigned a score based on the fractions of the crown and root that have developed, and then weighted scores are added to produce a total maturity score, which is plotted against age. It is a more accurate method of estimating age than emergence because emergence is an event whose exact time of occurrence is not accurately known, whereas the observance of mineralization indicates a defined point in the life span of all the developing teeth. However, mineralization has several disadvantages. First, it

Table 3 Some key stages in dental development

Age	*Dental state*
Birth	Deciduous incisor crowns 60–80% complete Deciduous canine crowns 30% complete Deciduous first molar crowns complete occlusal cap Deciduous second molar crowns separate cusps mineralized Crowns of first permanent molars just beginning to mineralize
2.5–3 years	All deciduous teeth emerged into the mouth
6–7 years	First permanent molars emerge into the mouth
8–12 years	Deciduous teeth replaced by permanent successors
12 years	Second permanent molars emerge into the mouth
18+ years	Third permanent molars (wisdom teeth) emerge into the mouth

Figure 2 Radiograph of a damaged archeological hemi-mandible from a Romano-British skeleton from Peterborough, UK. The deciduous canine, first and second molars, and the first permanent molar are in occlusion. Visible unerupted teeth are the permanent canine, both premolars, the partially complete second permanent molar, and the incomplete crown of the third permanent molar. Reproduced from Scheuer L, Black S. ''The Head, Neck and Dentition''. In: *Developmental Juvenile Osteology*. p. 150. © 2000 with permission from Elsevier.

requires training and experience in reading the radiographs. Second, problems have arisen with the production of the standards of early infant and childhood stages because of the difficulties of radiographing very young children. Finally, there are many methodological problems that may cause discrepancies in results due to both sampling and the use of different statistical methods. In a forensic situation, when a presumptive age is urgently required, emergence may be the only practical way to obtain an estimate.

The study of dental microstructure, which involves counting perikymata (incremental lines on the surface of tooth enamel), can provide an even more accurate method of age determination. This method is independent of growth standards of a specific population, so it may prove relevant in individual forensic cases. Disadvantages are that it requires the services of a hard-tissue laboratory, experience in the technique, and it is very time-consuming and therefore expensive. One particularly pronounced incremental line, the neonatal line, can be of medicolegal significance in determining whether an infant was live-born or stillborn. It is formed very soon after birth and can be visualized by light microscopy if the child survived for about 3 weeks or by electron microscopy within 1 or 2 days of birth.

Skeletal Age

Aging a juvenile from skeletal remains requires both an understanding of the mechanism of bone growth and a detailed knowledge of the anatomy of the juvenile skeleton. Nearly all the elements of the skeleton begin development in prenatal life, and bone forms either directly in embryonic mesenchymal tissue or in an intermediate cartilaginous template of a future bone. Within each bone, osteogenesis starts in one location, the primary ossification center, and gradually expands until the precursor is totally replaced by bone. Most primary centers develop *in utero* and include the bones of the skull, the vertebral column, the ribs, sternum, the primary centers of the long bones of the limbs and their girdles, and the phalanges of the hands and feet. Many are recognizable by mid fetal life and most by birth (Figure 3).

Most postcranial bones also develop secondary ossification centers known as epiphyses, which are situated at the ends of long bones and at traction sites associated with irregular bones. Not all bones possess secondary centers; the major ones are those of the skull and the small bones of the wrist and ankle. The bones of the skull vault are formed from primary centers by a process of intramembranous ossification. The carpals and tarsals develop from a primary center that forms within a cartilaginous precursor where the ossification front expands until it fills out the original template.

Nearly all secondary centers commence ossification after birth, although a few develop in the last few weeks of intrauterine life. In some situations, the state of maturity of a fetus can have medicolegal consequences. Visualization of the secondary ossification centers of the distal femur and the proximal tibia and commencement of ossification in the calcaneus and talus is usually accepted as signifying a full-term fetus.

Secondary ossification centers are separated from the primary center by a growth plate or physis, which is an area of cartilage that organizes further growth of the bone. They appear at a reasonably predictable rate in a well-documented pattern over a time period from the perinatal period until young adult life. When a skeletal element reaches its final size, the growth plate is totally replaced by bone as the epiphysis fuses to its primary center. As a general rule, the secondary centers of the limb bones that appear first are the last to fuse, whereas the late-forming epiphyses reach union with their primary centers in a shorter time period. In the major limb bones, early-forming epiphyses are found in the upper limb at the proximal humerus and distal radius and ulna and in the lower limb at the distal femur and proximal tibia.

The timing of fusion varies greatly in response to the function of the soft tissues with which the element

Figure 3 The head, neck, and hands of a fetus of approximately 14 weeks *in utero* showing the developing bones. The darker-colored bones are those developing from a cartilaginous template. The bones showing a network of trabecular bone are those developing intramembranously directly in mesenchyme. Adapted from Berkowitz BKB, Holland GR, Moxham BJ. *A Colour Atlas and Textbook of Oral Anatomy*, p. 247, © 1978, with permission from Elsevier.

is associated. For example, the skull and vertebral column that enclose the precociously developing nervous system reach union either before birth or in the early childhood years, whereas the epiphyses of the limbs fuse during the adolescent period when growth in height ceases. The timing of fusion is also significantly affected by the variability in onset of the adolescent growth spurt. The inability to sex juvenile remains until sexual dimorphism is well under way complicates the use of fusion times in this group until secondary sexual characteristics begin to show in the skeleton. This means that any estimated age bands have to be wider than if sex was known from other evidence, such as soft tissues.

There are a few sites in the skeleton that do not reach maturity until young adult life in the third decade. These include the jugular growth plate of the skull, the sacral vertebral bodies, the iliac and ischial epiphyses of the hip bone, the annular rings of the vertebral column, the peripheral epiphyses of the scapula, the costal notches of the sternum, and the epiphysis at the medial end of the clavicle.

From this brief description, it can be seen that by observing the stage of development of different parts of the skeleton, it should be possible to estimate the age of a juvenile from the perinatal to the young adult period (Table 4). Obviously, in the case of skeletal remains, accuracy depends strongly on which bones are available for study and on the stage of development of each particular bone. Greater accuracy will be obtained from those bones that show distinct changes in a relatively short period of time. For example, the fusion time of the pubic and ischial bones at their rami is quite variable, and fusion may take place at any time between the ages of 3 and 10 years; thus, this site is not very useful. The proximal epiphysis of the tibia is preferred because it shows well-defined stages at certain ages (Figure 4).

Table 4 Some key stages in skeletal development[a]

Birth	Lower femoral and upper tibial epiphyses present
	Calcaneus and talus start to mineralize
End of year 1	Skull bones develop diploe
	Anterior fontanelle fuses
	Two halves of mandible fuse at symphysis
	Vertebral half arches fuse posteriorly
By year 6	Four parts of occipital bone fuse around foramen magnum
	Vertebral centra and arches fuse in thoracic and lumbar column
Early childhood	Most early-forming epiphyses present
Late childhood	Most later-forming epiphyses present
Early adolescence	Late-forming epiphyses fuse
	Innominate fuses in the acetabulum
Late adolescence	Rest of long bone epiphyses fuse
Young adult	Late epiphyseal fusion of various elements

[a]This is a very abbreviated table and details can be found in the further reading section.

Personal Identity

After a biological profile is established and a potential list of individuals is developed, the search for personal identity can begin. If successful, the individual can be positively identified by next of kin and can be given a name.

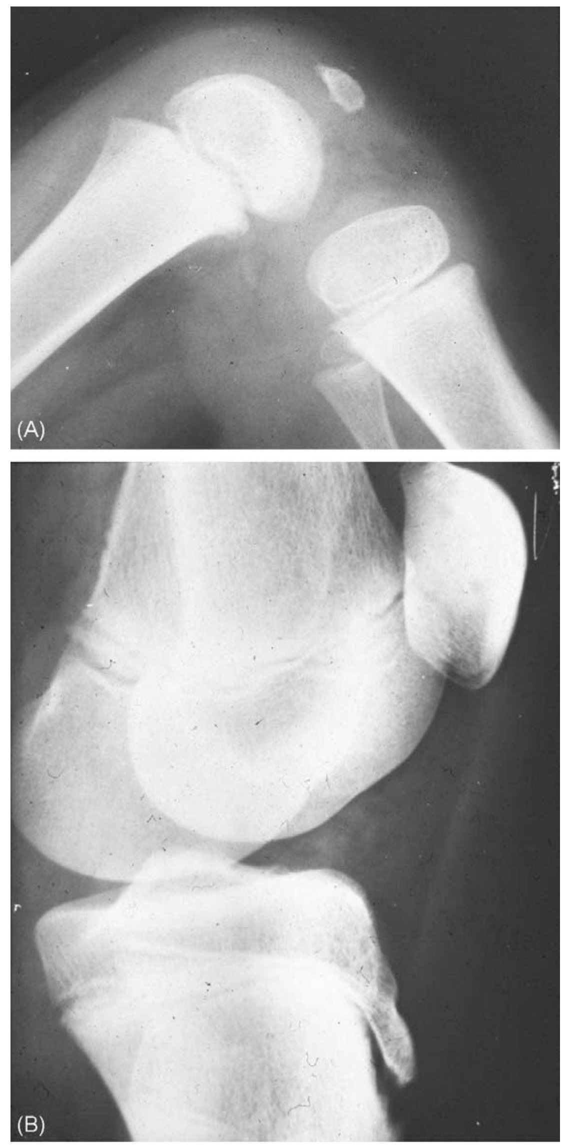

Figure 4 Lateral radiographs of juvenile knees. (A) A child between the ages of 5 and 9 years. The lower femoral and upper tibial epiphyses are small and separated from their diaphyses by wide growth plates. The patella is very small. (B) An adolescent. The epiphyses of the femur and tibia are much larger and overlap the ends of the diaphyses. The upper tibial epiphysis has developed its anterior tuberosity and the patella is of adult size. Reproduced from Scheuer L (2002) Application of osteology to forensic medicine. *Clinical Anatomy* 15: 297–312. © 2002 with permission from Wiley.

This step will rely on some feature that will separate individuals with similar biological profiles and that must match secure information from premortem sources. For instance, this may be a previous medical condition such as a fracture, a dental record, or a school record. Unfortunately, in the case of a young child, there may not have been enough time to accumulate any distinguishing features. Facial superimposition using a photograph of the missing person may prove useful, especially if there is a smile showing the anterior teeth.

The most important factor in the confirmation of identity from skeletal remains is DNA extracted from bones or teeth. This is only possible when an individual has been tentatively identified and samples can be matched with those from living relatives. It is also a technique involving the statistics of probability that is not easily understood by nonscientists or the general public. There may be problems with amplification and contamination, and methods are time-consuming and expensive. However, genetic investigation is a rapidly developing field that has the potential to produce many new techniques. It is currently possible to use breakdown products of the amelogenins, organic components of the enamel of teeth, for sex typing because these proteins are produced by a gene with copies on the X and Y chromosomes.

Unless the choice of personal identity rests on very secure evidence, it is important for the forensic anthropologist to resist any attempts to be pressurized into making an identification by the investigating authorities. The outcome can have profound legal and personal consequences. If a crime is suspected, it could mean the arraignment and trial of a suspect. In the case of any missing person, it can mean the end of painful uncertainty and possible eventual closure for grieving relatives and friends.

The Living Child

Occasionally, a forensic anthropologist may be called upon to aid a police surgeon, immigration official, or similar legal officer in examining a child whose stated age is under suspicion. Obviously, this situation will entail the most likely estimate of age because the actual chronological age cannot be proved if withheld.

In a perinatal infant, the weight and length of a normal-term baby are population-dependent. In the UK these are taken to be 2550–3360 g, 28–32 cm crown–rump length, and 48–52 cm crown–heel length. However, gestational age is also frequently estimated in the live newborn infant by an evaluation of the infant's neurological maturity.

In children, age may be estimated, as from skeletal remains, from both the teeth and the developmental state of the skeleton, although ethical considerations inhibit the use of some of the methods that can be freely applied to dead remains. Chief among these is the use of radiographs such as orthopantograms showing the total number of emerged and unerupted teeth or X-rays of the innominate bone, which would expose a young person to a considerable dose of radiation.

In older children, inspection of the mouth may be carried out by a dentist, odontologist, or anthropologist to observe the total number of emerged teeth. This can give a reasonably accurate estimate of age, especially between the ages of 6 and 12 years. Clinical emergence is judged from the time when the first part of the tooth is seen to pierce the gum or, on an X-ray, when resorption of the overlying alveolar bone is evident.

Skeletal development may only be viewed by means of some method of scanning. Cessation of growth in height at the end of adolescence may be gauged by an X-ray of the wrist because the lower radial and ulnar epiphyses are some of the last, easily accessible long-bone epiphyses to fuse. The state of the development of the dentition will give a more accurate estimate of age than the state of epiphyseal fusion because it is less subject to population variability or the vagaries caused by the timing of the adolescent growth spurt.

Legal Procedures

In the examination of either skeletal remains or a living child, the forensic anthropologist should be aware of various legal and political procedures. These often involve cooperation with other professionals, such as the investigative police team, the forensic pathologist, archeologists, or odontologist, with whom there should be agreement as to methodology. Each member of the investigation team needs to appreciate the others' skills and requirements and act accordingly. For instance, the anthropologist and the facial reconstruction expert need to have access to a skull that is as undamaged as possible, so the forensic odontologist must not resect parts of the jaw before others have had a chance to examine it.

The forensic anthropologist also needs to be aware of important issues such as confidentiality, continuity of evidence, and consent to treatment. In international situations, such as mass disasters and war crimes, there are additional matters concerning legal requirements in different countries and presentation of evidence that need to be taken into account.

Often, a written report by the investigating officer, the coroner, or procurator fiscal will be accepted, but sometimes a personal appearance at an inquest or other court is required. These proceedings may take months, or even years, after the initial investigation, when recall of a case may be difficult under the sometimes harassing conditions of a courtroom. Care must also be taken when giving evidence not to be drawn outside the areas of expertise by a lawyer trying to prove incompetence. It is advisable to ensure familiarity with the original report, which must be as detailed, accurate, and free from jargon as possible so that it may be understood by nonscientific personnel.

See Also

Anthropology: Stature Estimation from the Skeleton; Sex Determination

Further Reading

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Sex Determination

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Introduction

Anthropology is employed in a forensic setting to help create a biological profile of unknown skeletal or decomposed remains in order to arrive at conclusions or inferences regarding provenance. Sex determination is one of the key questions addressed when formulating this profile – its knowledge immediately eliminates 50% of the population from the process of identification.

Sex-distinguishing characteristics of the skeleton are dependent on the existence of sexual dimorphism, due to the influence of sex hormones, the adaptations of the female to the function of childbearing, as well as cultural differences between the sexes. Although present to a degree at all ages, sexual dimorphism becomes most apparent after puberty when secondary sexual characteristics have fully developed. For this reason, sex can be most accurately ascertained in skeletons from mature individuals, although senility and pathology may influence these characteristics and therefore alter reliability in the aged. It is worth noting that sex determination is rarely based on any one skeletal feature alone. An expert forensic anthropologist is aware of the range of variation of sexual traits within the skeleton and the degree of overlap that normally exists between males and females. As with assessment of other parameters that lead toward a successful identification of the deceased, as many criteria as are available are assessed before coming to a definitive conclusion.

It is apparent that subtle race-related differences may exist in the degree of development of sexual characteristics within the skeleton, and there may also be geographic variation. Where possible, the racial affiliations of skeletal material should be ascertained at the same time as criteria used to determine sex are applied. As with sex-distinguishing characteristics, however, many racial traits do not appear fully until puberty, and even in adolescence they may not be completely formed. These racial and geographic differences may be partially overcome by carefully observing individual sex-distinguishing traits in a subsample of a specific population. For example, accurate measurement and recording of the articular surface of a long bone in a set number of separate skeletal remains may allow for the successful determination of sex, provided these measurements have been taken carefully, the population is sufficiently sexually dimorphic in size, and both sexes are represented. In this way trait-specific information for a given population group may be collected. This is particularly useful when only partial remains are available for examination due to taphonomic factors, such as predators or fire.

Principles of Sex Determination

The determination of sex is normally undertaken by examining appropriate elements of the skeleton and scoring a list of traits as male, female, or ascertained at the same time as criteria used to determine sex are applied. As with sex-distinguishing characteristics, however, many racial traits do not appear fully until puberty, and even in adolescence they may not be completely formed. These racial and geographic differences may be partially overcome by carefully observing individual sex-distinguishing traits in a subsample of a specific population. For example, accurate measurement and recording of the articular surface of a long bone in a set number of separate skeletal remains may allow for the successful determination of sex, provided these measurements have been taken carefully, the population is sufficiently sexually dimorphic in size, and both sexes are represented. In this way trait-specific information for a given population group may be collected. This is particularly useful when only partial remains are available for examination due to taphonomic factors, such as predators or fire.

Principles of Sex Determination

The determination of sex is normally undertaken by examining appropriate elements of the skeleton and scoring a list of traits as male, female, or indeterminate. Each trait is scored separately and the overall results are weighted for a final assessment. Observations are generally made of the cranium or the bones of the postcranial skeleton, in particular the pelvis and os coxae. The modifications that occur in the pelvis at puberty generally provide a more reliable estimate of sex than do cranial measurements. Important sex differences begin to develop in the skeleton before birth and, while there are recent reports detailing sex-distinguishing characteristics in fetal, neonatal, and infant skeletal remains, it is not usually until the individual approaches the age of 14–16 years that decisions on sex differences can be made with any degree of confidence.

Morphological (visual) examination remains the quickest and easiest method of determining sex in the great majority of unknown skeletal remains and in experienced hands will result in 95–100% accuracy when the whole skeleton is available for assessment. The accuracy of such assessment is, however, only as good as the expertise of the examiner. Because of their less subjective nature, metrical analysis (particularly of the skull) as well as discriminant function analysis should also be applied because of their objectivity and reproducibility. Metrical methods use statistically determined discriminant functions with sectioning points, above or below which one or other of the two sexes will fall. The reliability and accuracy of metrical indices vary depending on the bones assessed and relate, in part, to the original data on which sectioning points were calculated. While various skeletal collections around the world have been used to provide data sets, the majority of indices are based on the Terry and Hamann-Todd collections in the USA, that were put together in the early part of the twentieth century. These two collections comprise skeletons of known race, sex, age, and stature, but are heavily biased toward whites and blacks from lower socioeconomic groups who lived in the central west of the USA at the end of the nineteenth century. In recent years, it has become apparent that, for a variety of reasons, the use of these formulae may be becoming less applicable when applied to modern populations and population groups different from those upon which the formulae are based. Such functions as are available should, therefore, be restricted in their application to those population groups from which the functions were originally derived. Nevertheless, the development of discriminant functions based on skeletal measurements has helped greatly in removing the subjective bias from sex determination. Their use tends to back up the morphological assessments made by the expert anthropologist and makes reliable sex assessment available to the less experienced.

The skeletal elements that are of most use in sex determination are listed below, in descending order of reliability:

- the pelvis: os coxae and sacrum
- the cranium
- the long bones: especially the femur, humerus, and tibia
- other bones, e.g., the sternum, clavicle, and calcaneus.

The accuracy of sex determination in adults is approximately as follows:

- entire skeleton: 100%
- pelvis alone: 95%
- skull alone: 90%
- skull and pelvis: 98%
- long bones: 80–90%
- long bones and skull: 90–95%
- long bones and pelvis: >95%.

In immature (prepubertal) skeletons the chance of a correct sex allocation is only 50% unless the pelvis is present, which improves the chances of correct sex allocation to about 75–80%.

Table 1 Sex-distinguishing features of the female pelvis

General morphology
Gracile and smooth (rugged with marked muscle attachments in male)
Overall shape
Female pelvis wide and shallow, with larger pelvic outlet (pelvis high and narrow in male)
Pubic bone
Wide and rectangular body of pubis (narrow and triangular in male)
Wide subpubic angle (narrow in male)
Ventral pubic arc (absent in male)
Curved ventral pubic concavity or lateral recurve (straight or convex in male)
Greater sciatic notch
L-shape in female (J-shape in male)
Auricular region
Preauricular sulcus frequently present (absent or slight in male)
Elevation of the auricular surface above the adjacent postauricular area (coplanar in male)

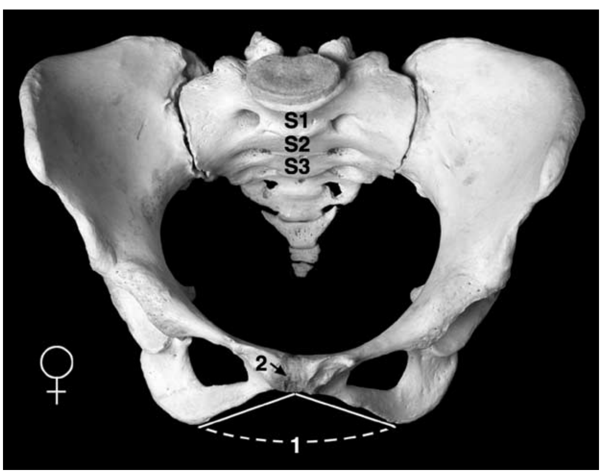

Figure 1 Female pelvis. 1, subpubic angle; 2, ventral arc.

Figure 2 Male pelvis.

Figure 3 Hip bone. 1, auricular surface; 2, preauricular sulcus; 3, greater sciatic notch; 4, body of pubis; 5, symphyseal surface; 6, lateral recurve.

Sex Determination from the Adult Pelvis

Morphological Determination

The pelvis in general and the pubis in particular have long been regarded as the best sources of information for determining the sex of an unknown individual. While sex differences begin to develop in the skeleton before birth it is not usually until about the mid-teenage years (particularly in western societies) that decisions on sex differences can be made with any degree of certainty. Both morphological and metrical characteristics may be used in this assessment. The morphological sex features of the pelvis and os coxae are listed in Table 1 and illustrated in Figures 1–3. Reference casts of the pubic symphysis and auricular surface of both males and females have been developed and these may help with correct sex assignment. However, these are not useful unless the examiner has seen large numbers of symphyseal and auricular surfaces to be able to distinguish between age-related and pathological changes.

Metrical features of the hip bone also assist with sex assessment, especially the ischiopubic index. This is the length (in mm) of the pubis divided by the length of the ischium (in mm) multiplied by 100. In males the index ranges from 73 to 94 and in females from 91 to 115. However, as there may be some difficulty in locating the exact reference points, for example those within the acetabulum, this measurement is usually best performed by someone with knowledge of the anatomical landmarks.

Morphological characteristics of the sacrum (Figures 1 and 2) that are often quoted as assisting with sex determination are:

1. the relative width of the ala of the sacrum compared with the width of the first sacral body (1:1 in the female; 1:2 in the male)
2. the shape of the ventral (pelvic) concavity (flattened anterior contour from the first to the third sacral vertebra in the female; regular curve anteriorly from the first to the fifth sacral vertebrae in the male)
3. the extent of the auricular surface relative to the lateral masses of the second and third sacral vertebrae (limited to the lateral mass of the second sacral vertebra in the female; it extends on to the lateral mass of the third sacral vertebra in the male).

The sacrum is not always the most reliable of bones for sex assessment as it often shows variability in the number of segments present. For example, in prefixation of the vertebral column there is part-fusion of the first sacral vertebra with the last lumbar vertebra (sacralization of the fifth lumbar vertebra). The reverse of this, partial or complete separation of the first sacral vertebra (lumbarization of S1), is not uncommon.

Sex Determination from the Cranium

Morphological Examination

The factors that contribute to sexual dimorphism in the cranium are many, but the most important may be seen from the front and from the sides (Figures 4 and 5). A detailed tabulation of traits diagnostic of sex features in the cranium is summarized in Table 2, however some are noted here.

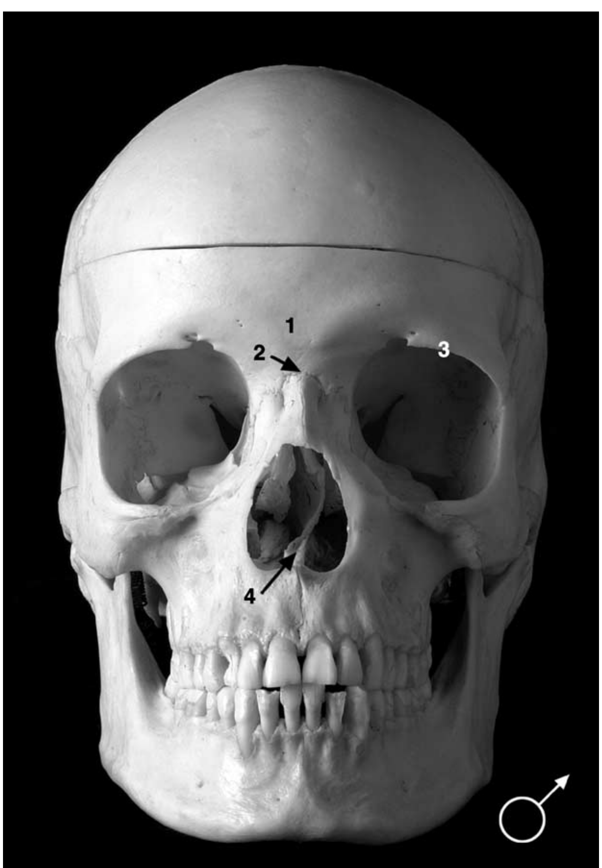

Figure 4 Male skull (view from front). 1, glabella; 2, nasion; 3, superior orbital margin; 4, nasal spine.

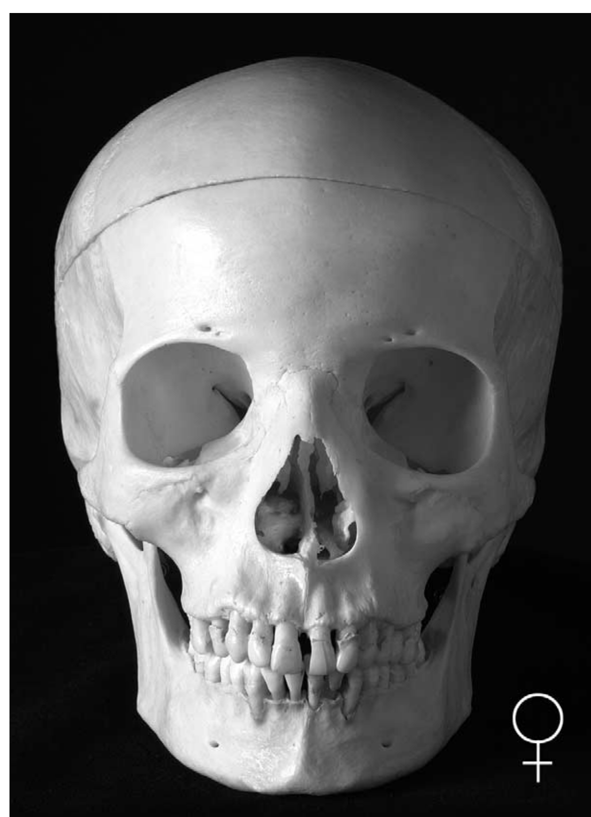

Figure 5 Female skull (view from front).

Table 2 Sex differences in the appearance of the skull

Trait	*Male*	*Female*
General size	Large	Small
Architecture	Rugged	Smooth
Supraorbital ridges	Medium to large	Small to medium
Mastoid processes	Medium to large	Small to medium
Occipital region	Marked muscle lines and protruberances	No marked muscle lines and protruberances
Frontal eminences	Small	Large
Parietal eminences	Small	Large
Orbits	Square with round margins	Round with sharp margins
Forehead	Sloping, less rounded	Vertical
Cheekbones	Heavier, project laterally	Light, more compressed
Palate	Large, broad, U-shape	Small, parabolic
Occipital condyles	Large	Small
Mandible	Large, high symphysis and broad ramus	Small, lower symphysis and smaller ramus
Chin shape	U-shaped	V-shaped
Gonial angle	Angled	Vertical
Gonial flare	Pronounced	Slight

From Clement and Ranson, 'Craniofacial identification in forensic medicine.' Hodder Arnold 1988.

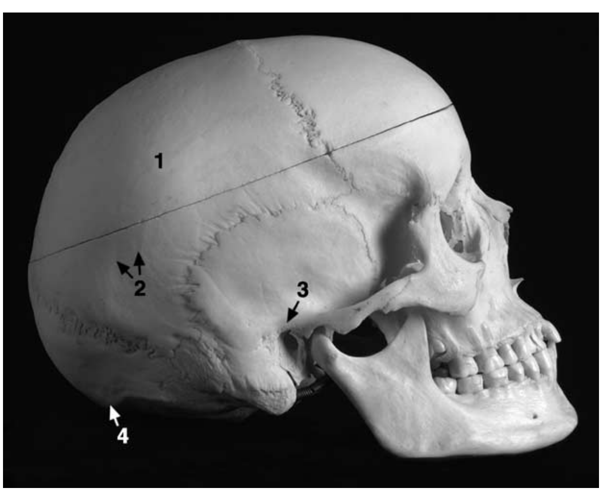

Figure 6 Male skull (view from side). 1, parietal tuber; 2, temporal lines; 3, supramastoid crest; 4, external occipital protruberance.

The bones comprising the frontal view are generally smaller in the female, with smoother and less pronounced landmarks (Figure 5). The contour of the forehead, due to a more prominent frontal tuber, is higher and more vertical in the female than in the male; the superciliary arches are much less strongly developed than in the male; the orbits are higher, more rounded, and relatively larger compared to the upper facial skeleton; and the orbital margins are sharper and less rounded than in the male. In the male the nasal aperture is higher and the nasal bones are larger.

Figure 7 Female skull (view from side). 1, frontal tuber.

Figure 8 Palate.

One of the distinguishing sex characteristics seen from the lateral view (Figures 6 and 7) is the size and degree of projection of the mastoid process. Mastoid processes are larger and more prominent in males than females, and this may be determined by measur-

Table 3 Discriminant function weights from cranial measurements in American white skulls of known sex

Measurement[a]	*1*	*2*	*3*	*4*	*5*	*6*
1	3.107	3.400	1.800		1.236	9.875
2	4.603	−3.833	−1.783		−1.000	
3	5.786	5.433	2.767			
4		−0.167	−0.100	10.714		7.062
5	14.821	12.200	6.300	16.381	3.291	19.062
6	1.000	−0.100		−1.000		−1.000
7	2.714	2.200		4.333		4.375
8	−5.179			−6.571		
9	6.071	5.367	2.833	14.810	1.528	
Sectioning point	2676.39	2592.32	1296.20	3348.27	536.93	5066.69
% correct	86.6	86.4	86.4	84.5	85.5	84.9

Adapted from Giles and Elliot (1963) Sex determination by discriminant function analysis of the crania. *American Journal of Physical Anthropology* 21: 53–68.

[a]The following measurements are multiplied by the above weights, the totals are summed, and the value compared with the known sectioning points:

1. maximum length (from glabella in the midline to opisthocranion).
2. maximum breadth (perpendicular to median sagittal plane, avoiding supramastoid crest).
3. basion–bregma height (midpoint on anterior border of foramen magnum to bregma).
4. basion–nasion maximum diameter.
5. maximum bizygomatic diameter.
6. basion–prosthion (basion to most anterior point on maxilla in median sagittal plane).
7. prosthion–nasion.
8. external palate breadth.
9. mastoid length.

ing the index of mastoid length to mastoid height (greater in males than females). In addition, the posterior end of the zygomatic arch extends its (supramastoid) crest further in males than females, often beyond the external auditory meatus.

Examination of the occipital region of the cranium is often worthwhile as it provides evidence of the robustness of the skeleton and hence a further clue as to sex. For example, the external occipital protuberance is much larger in the male, as are the occipital condyles, and the transverse (nuchal) occipital lines are more evident. The distance from the opisthocranion, from just above the external occipital protuberance (where the skull attains its greatest posterior extent) to the glabella, provides an index of maximal cranial length. Maximal cranial length is usually greater in males than in females.

Examination of the cranium from above reveals the ellipsoid shape of the cranial contour with the point of greatest maximal breadth of the vault at the parietal eminence (parietal tuber), a primary center of ossification and more prominent in females. While possessing few distinctive sex-related bony features, examination of this view of the skull is important as it may help confirm the racial affiliation of the deceased and allow application of the appropriate metric standards of measurement.

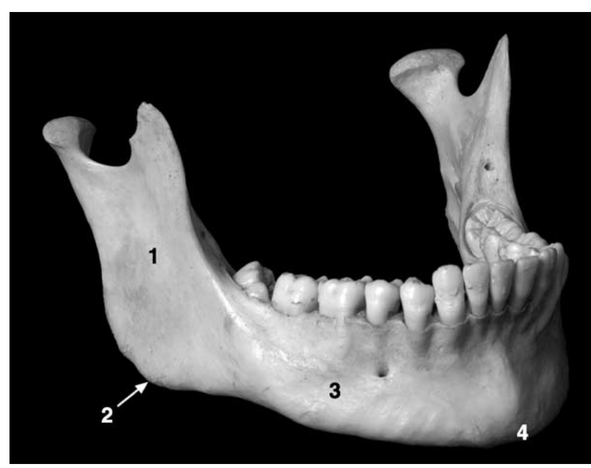

Figure 9 Mandible. 1, ramus; 2, gonion; 3, body; 4, gnathion.

The inferior view of the cranium contains the hard palate of the maxilla and palatine bones (Figure 8). The width of the hard palate, as measured between the outside of the second molars, is quite variable, although it tends to be broader and shallower in males than females.

Metrical Analysis

Some of the features of the skull useful in determining sex lend themselves to measurement in numerical

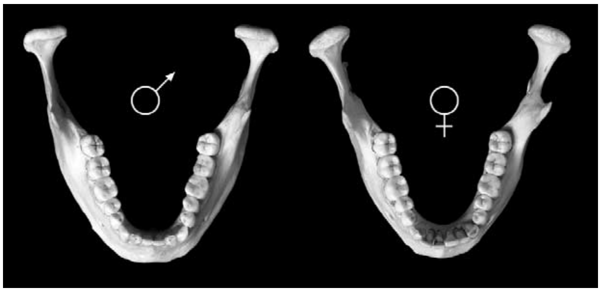

Figure 10 Male and female mandibles.

units, whereas others may only be differentiated in terms of presence or absence, or degree of development. Measurements and discriminant function weights suitable for differentiating sex in adult American white and black crania are summarized in Table 3. Reported accuracy is between 82% and 89%.

Sex Determination from the Mandible

The lower jaw or mandible is a separate bone which articulates via its condylar processes with the squamous temporal bone of the cranium. It consists of two rectangular plates on each side, a horizontal plate called the body, and a vertical plate called the ramus (Figure 9). The body contains the teeth, within sockets in its alveolar process, while the ramus is for articulation and attachment of the muscles of mastication. On the body in the midline is the mental protuberance, with a median ridge above and an elevated triangular area below, representing the site of fusion of the two halves.

Posterolaterally, the angle of the mandible is referred to as the gonion. It represents a point of intersection of lines drawn along the inferior and posterior borders of the bone. The gonion is often flared (gonial flare) or everted, particularly in males, by the attachment of a powerful muscle of mastication (masseter) and in these situations the bigonial breadth is widened. The ramus diverges above into condylar (behind) and coronoid (in front) processes, with an intervening mandibular notch. The coronoid process receives the tendon of temporalis, a very large muscle of mastication which, along with other masticatory muscles, may leave prominent impressions on the bone, especially in the male.

The mandible is often used to determine the sex of skeletal remains (Figures 9 and 10). In the male it is more robust, larger, and thicker, with greater body height and a broader ascending ramus. The gonial angle is less obtuse (less than 125°), the condyles are larger, and the chin is square, in contrast to a V-shaped chin in females. The bicondylar breadth, the direct transverse distance between the most lateral points on the two condyles, is usually greater in males.

Table 4 Measures of selected postcranial bones and bony features

Bone	*Females (mm)*	*Indeterminate (mm)*	*Males (mm)*
Shoulder			
Scapula length	<129	140–159	>160
Glenoid cavity length	<34	34–36	>37
Clavicle	140		158
Mean length			
Humerus			
Vertical diameter head	<43	44–46	>47
Mean length	305		340
Mean epicondylar breadth	57		64
Radius			
Diameter of head	<21		>22
Femur			
Vertical diameter of head	<41.5	43.5–44.5	>45.5
Femoral length	439		477
Bicondylar width	<72	74–76	>78

Sex Determination from Other Bones of the Skeleton

In general the limb bones of females are more gracile and less well marked by muscle attachments than those of males. The articular ends of the bones are smaller and the shafts less robust. The above observations are reflected in the metrical features of the bones and to date almost all bones of the skeleton have been used in determining sex of an individual through statistical analysis. This is particularly the case with reference to the diameter of the articular ends of the humerus, radius, and femur, and to a lesser extent the circumferences of the long bone shafts. However, size differences between different population groups mean that sex determination from the limb bones is population-specific.

Special attention has been given to long bones such as the femur as this is the largest bone in the skeleton, it is surrounded by the largest limb muscle mass, and parts of it are likely to remain preserved even after prolonged incineration. The same comments may be made for the calcaneus, which is often protected due to the presence of footwear. In most populations the dimensions of femoral breadth and circumference, in particular the maximal diameter of the femoral head, tend to be more dimorphic than length. Similarly, measures of the maximal vertical diameter of the glenoid fossa of the scapula are greater in males than females. Sex differences are reported for other postcranial bones, including metacarpals, metatarsals, the ribs, vertebral bodies, and the clavicle; however, in most cases these have not been extensively studied, nor their reliability in assessing sex adequately tested. Nevertheless, because a skull may be damaged or removed from a forensic scene and a complete pelvis is not always present, knowledge of sex-related features of other skeletal elements is important.

Some measurements used to estimate sex in postcranial remains are indicated in Table 4. More details, including range and standard deviation, are presented in manuals of human osteology.

Sex Determination in Fetal and Juvenile Bones

Lack of availability (and hence of studies) of large samples of fetal and juvenile skeletal material of known age, sex, and race has made confident determination of sex of the isolated fetal or juvenile skeleton difficult. However, recent reports suggest that there may be detectable skeletal differences in sex between birth and 5 years, including a more prominent chin in boys, as well as an anteriorly wider dental arcade and deeper and narrower sciatic notch in boys than girls. These observations are, however, based on very small sample sizes and should therefore be viewed with caution.

Sex Determination from DNA Analysis

Where suitable samples of bone or teeth are available, DNA analysis provides a more objective assessment of sex identification. Perhaps the most famous recent identification case involving DNA analysis relates to bones found in a grave in Yekaterinburg in the Ural mountains in Russia. Comparison of both nuclear and mitochondrial DNA extracted from femora and tibiae, with blood samples taken from the ancestors of the Romanov family involving the maternal line to the Duke of Edinburgh, indicated that five of the nine skeletons located at this site were those of Tzar Nicholas, his wife, and three female children.

Conclusions

There are important indicators that appear throughout the life of an individual that allow for the determination of sex with a reasonable degree of accuracy. However, it is worth recognizing that there are always limitations on the information that a forensic anthropologist can provide toward a successful identification of an unknown deceased. It is appropriate to restate that sex of a set of skeletal remains should be determined not only from a single parameter, but from a battery of observations, and should never be made without justification. Each individual trait should be scored separately and the overall results weighted for a final determination. In this way, data can be viewed by independent reviewers, and more importantly, trait-specific information for the sample under analysis can be collected. This will come in useful when examining remains from a population group for which there are few or no baseline data or where the influence of factors such as minimal dietary intake has an effect on skeletal maturity and therefore on sex-related differences in the skeleton. In this way, population-specific traits can be assessed and determination of sex made with some confidence.

See Also

Anthropology: Stature Estimation from the Skeleton; Cremated Bones; Morphological Age Estimation

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Determination of Racial Affinity

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Introduction

Racial assessment at autopsy may be straightforward in fresh remains. The task is more challenging with mutilated or fragmented remains where the focus shifts to hair form, melanocytes, DNA, or skeletal biology. In a decomposing or a skeletal stage the duty is nearly impossible without the collaboration of an experienced forensic anthropologist. This task is daunting due to intra- and interpopulation skeletal variation and the incongruence between the biology and sociology of race. Soft-tissue autolysis and putrefaction following death cause skin discoloration, distortion of facial features from gas accumulation and fluid loss, hair loss, and eventual skeletonization. As many homicide victims are concealed, deposited rurally, or curated to thwart discovery and identification, decomposition processes force assessment of race from diagnostic skeletal morphology.

Forensic anthropology provides a biological profile for the medicolegal community by estimating age, sex, race, stature, and ante-, peri-, and postmortem trauma. The medicolegal community has developed a reliance on this demographic evidence from forensic anthropology. Age and sex evaluations are achieved using established qualitative visual criteria and quantitative metric methods from skeletal and dental anatomy. Stature estimation involves measurements and formulated regression equations. Bone trauma is more difficult to interpret as it requires knowledge of perimortem biomechanical events. Assessment of racial affinity, the most challenging aspect of completing the biological profile, has become an integral and evolving part of the expertise of forensic anthropology.

Definition of Race

Biological and forensic anthropologists use the term "race" to reference a population that shares a common geographic and genetic history. What constitutes group membership varies between populations based on a mosaic of social, religious, economic, and physical attributes. How individuals classify themselves according to the chosen attributes constructed and accepted by their group is not universal. From a shared history, a unique combination of skeletal traits characterizes groups that may be absent or less frequent in other groups due to geographic distance and/or isolation. These differences provide the basis for identification and interpopulation comparison. Unfortunately, science has not deciphered the complex polygenic mechanism of inheritance of skeletal traits and how they correlate to soft-tissue similarities or differences.

Use of the term race has fallen out of favor amongst many biological anthropologists due to the historic and contemporary social misuse and abuse of racial categorization. Not immune from the stigma of the race concept elsewhere in the social sciences, the race notion specifically deepens the schisms (a) between forensic and biological anthropology and (b) within the discipline of anthropology. During the 1990s, a desultory attempt has been made to distance forensic anthropology from this sensitive issue by renaming the exercise as estimation of ethnicity, ethnic affiliation, racial ancestry, ancestry, population, etc. Ethnicity is a term of social and/or cultural identity that may or may not have a biological basis. The social and biological meanings of race are separate public and academic areas and should not be defined, compared, or contrasted in terms of each other. Whatever criteria, motives, or incentives are used to define, delineate, divide, or unite contemporary populations – ethnic, social, religious, historic, economic, political – they are in no way scientific, irrespective of the means used in forensic anthropology.

Why is Race Important?

Concurrent with providing social self-identity, race is a significant variable in skeletal biological research. Regional populations differ in the degree of expressed skeletal sexual characteristics. This is particularly evident in the skull, where both sex and race traits are present. There is variation between populations in the age and rate of skeletal and dental maturation in children and adolescents. This is evident in the chronology of tooth emergence and appearance and fusion of long-bone epiphyses. Also, adult proportions vary between populations in torso length and between pectoral and pelvic limbs. Cognizance of this variation is critical when applying stature estimation formulae. Finally, some methods of adult aging are population specific, e.g., pubic symphysis, cranial sutures, and sternal rib ends. Comprehensive skeletal collections of known individuals are limited, and research standards on aging are generally based upon collections of individuals from the USA and Europe. Although multiracial, these collections are biased toward European and African descendants.

Besides routine, case-based human identification work, the increased involvement of forensic anthropology in human rights issues has raised critiques in the applicability of these standards to other populations. This is particularly important when the objective is war crimes prosecution. Additional legal implication for race assessment in US casework involves prosecution related to illegal excavation, curation, and sale of remains of American Indians in violation of the 1990 Native American Grave Protection and Repatriation Act (NAGPRA).

Historical and Modern Studies on Race

Colonial exploration and imperialism revealed an unsuspecting degree of human biological and cultural diversity. Prior to the 1960s, with limited understanding of genetic inheritance, these historical pernicious perceptions led to the conclusion that individuals more similar in appearance were more closely related than those dissimilar. Hence, systematic studies of human diversity placed local populations within classification schemes of relatedness. Early criteria included skin and hair color gradations, variation in hair form, and differences in proportions of facial features. These characteristics were viewed as nonevolutionary invariants and defined races as fixed types. Multiple classificatory schemes of races have been proposed with the traditional anthropological studies, recognizing Caucasoid, Negroid (African), Mongoloid (East Asian and the Native Americans), and Australoid (Australasians). These racial divisions were based on loosely distributed world population variation prior to the mid-fifteenth century when these regions were relatively isolated.

Today, research has shifted from type categorization to adapting/evolving populations. The human phenotype is highly responsive to the environment, and characteristics such as facial features, skin color, and body size and shape are biological adjustments through adaptation and chance genetic mutations that our ancestors have made to their particular geography. Anthropological research includes anthropometry of the body and head of living people, including measurement of height, weight, fat distribution, a variety of limb lengths, and body breadths and circumferences. Craniofacial anthropometry and craniometrics are particularly sensitive indicators of population history. Quantification of other complex traits includes skin color, dimensions of teeth, and fingerprint patterns. The level of genetic diversity in a population provides clues to past events affected by evolutionary forces, i.e., mutation, gene flow, and genetic drift. Molecular research on population relatedness evaluates genetic variation through world distribution patterns of classical genetic marker variants, for example, blood type, and allele frequency mapping of DNA marker variants, that is, nuclear and mitochondrial DNA sequence and/or Y-chromosome allelic variation, to calculate linear convergence estimations or group distances. In general, these studies support early visual appraisals of regional clustering while adding a temporal dimension by providing estimates of when regional lineages may have diverged.

Population Movement and Admixture

Clearly, races are not static entities – they continue to evolve. Today, it is the norm for people to travel and migrate. Over generations, many once-distinct social and biological borders became obscure. The physical characteristics attributed to race, be they soft, osseous, or dental, therefore, have gradually modified over time across the landscape. The popular concept of race includes the cultural dimension of self-identification. The US Census Bureau reflects self-identification through sociopolitical categories and not by anthropological or scientific design. In

Table 1 US population by racial category[a]

Race	*Total population*[b] *(%)*	*Hispanic population*[c] *(%)*
White	75.1	47.9
Black or African American	12.3	2.0
American Indian and Alaska Native	0.9	1.2
Asian	3.6	0.3
Native Hawaiian and other Pacific Islander	0.1	0.1
Some other race	5.5	42.2
Two or more races	2.4	6.3

[a]Race as defined by the US Census Bureau does not reflect biological race and is self-identified.
[b]Total US population is 281 421 906 individuals.
[c]Equals 100% total. The total number of self-identified Hispanics was 35 305 818, or 12.5% of total respondents.
Source: US Census Bureau, Census 2000.

Table 2 US citizens reporting two or more races[a]

Race	*Total individuals selecting one race or in combination*[b]	*Individuals selecting one race*	*Individuals selecting in combination*[b]
White	216 930 975	211 460 626	5 470 349
Black or African American	36 419 434	34 658 190	1 761 244
American Indian and Alaska Native	4 119 301	2 475 956	1 643 345
Asian	11 898 828	10 242 998	1 655 830
Native Hawaiian and other Pacific Islander	874 414	398 835	475 579
Some other race	18 521 486	15 359 073	3 162 413

[a]Race as defined by the US Census Bureau does not reflect biological race and is self-identified.
[b]In combination with one or more of the other listed races.
Source: US Census Bureau, Census 2000.

1790, the first US census was collected in which free individuals were selected "White" or "Other" based on physical appearance. Slaves were counted separately. Growing diversity in the US has resulted in an increased number of social race categories in addition to national-origin groups. Also, for the first time the 2000 census allowed individuals to select multiple groups/races in consideration of the growing number of children and minorities who identify themselves as multiracial. Of the total population, 97.6% selected one racial category while 2.4% responded to the two or more categories (see Table 1). Of respondents selecting two or more races, 72% identified as White and another race.

The Hispanic population is the fastest growing group in the USA. Latin America has a complex heritage and many Hispanics and Latinos, ethnolinguistic categories indicative of Spanish speakers and people of Latin American descent speaking either Spanish, French, or Portuguese, e.g., Brazilians, do not identify with a particular racial group (see Table 1). Approximately 12.5% of the US population self-identified as Hispanic or Latino in the 2000 US census. The largest constituent of Hispanic speakers in the US are Mexican (66%) who identify themselves as either ethnic Mexican–American or Chicano. In terms of distribution, Hispanics and Latinos on the west coast of the USA are mostly of Mexican origin while those on the east coast are predominantly of Cuban and Puerto Rican origin.

In anthropological genetic studies of contemporary Americans, Mexican Hispanics display American Indian (36–58%) and White traits, and those of Cuban and Puerto Rican origin display combinations of White, American Indian (with contribution less than 21%), and African traits. The African contribution to the Hispanic population was similar in both regions at less than 17% with increasing tendency amongst Puerto Rican and Cuban descendants. The mixed expression of traits may be indicative of Latin American origins. Admixture in the African American gene pool with European Americans averages 20–25%. There is trace introduction of American Indian genes into the African American gene pool at less than 2.6%. Introduction of African genes into American Indian gene pool is slightly larger at 5%. American Indian admixture with non-Indian genes is estimated around 15%. Population estimates of admixture are region dependent within the USA providing wide ranges and estimates.

In the USA, when mixed traits of White and a minority group are present, the individual most likely identifies with the minority population as phenotypic characteristics, particularly Black, are generally dominant to White. In addition, increasing ethnic identity among Black Americans is confirmed by US census data where Blacks, like Whites, are less likely to report more than one race (see Table 2).

Craniofacial Morphology

Craniofacial detail has long been recognized as differentiating populations. Here, many traits are byproducts of the entire developing craniofacial complex resulting from both genetic and environmental components. No region is independent during growth. All expand, remodel, and function interdependently as a result of soft-tissue development to provide unique cranial form, facial profile, and dental occlusal type. The expanding fetal, neonatal, and infant brain establishes head form and cranial base design. The base, in turn, provides a template for facial projection and proportion. The maxillary palate is an extension of the anterior cranial fossa and the palate perimeter, in turn, establishes the shape of the apical base of the maxillary dental arch. Predispositions for retrusive and protrusive mandibular variation as well as the tendency for dental

Table 3 Craniofacial indicators

Morphology	*American Black*	*American Indian*	*American White*
Face			
Profile	Projecting	Intermediate	Flat
Shape	Intermediate	Wide	Narrow
Orbits	Rectangular	Round	Angled
Nasal root	Low, rounded	Low, ridged	High, narrow
Nasal bridge	Low	Low	High
Nasal width	Wide	Medium	Narrow
Nasal spine	Small	Medium	Pronounced
Lower nasal margin	Round	Flat, sharp	Sharp, still
Teeth			
Palatal shape	Hyperbolic	Elliptical	Parabolic
Maxillary incisors	Spatulate	Shovel-shaped	Spatulate
Posterior occlusal surfaces	Crenulated	Simple	Simple
Vault			
Brow ridges	Nondescript	Nondescript	Pronounced
Muscle attachment	Nondescript	Nondescript	Pronounced
Sutures	Simple	Complex	Simple
Postbregma	Depressed	Straight	Straight
Texture	Smooth, sheen	Intermediate	Coarse, matte

Source: Adapted from (1) Gill and Rhine (1990) *Skeletal Attribution of Race*. Albuquerque: Maxwell Museum of Anthropology. (2) Byers SN (2002) *Introduction to Forensic Anthropology: A Textbook*. Boston: Allyn and Bacon.

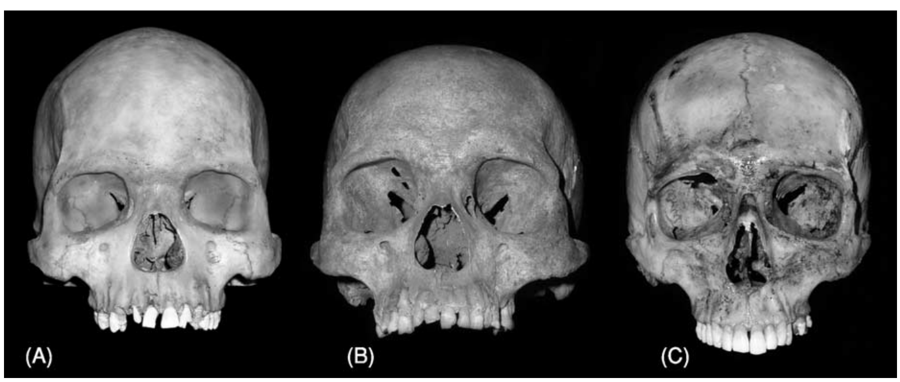

Figure 1 Frontal view of classic representatives of (A) American Black, (B) American Indian, and (C) American White female skulls. Note the subtle craniofacial variation listed in **Table 3**.

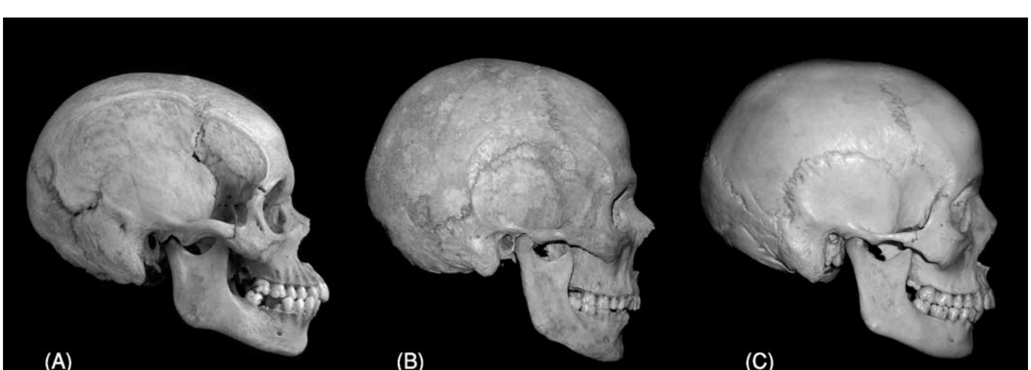

Figure 2 Right lateral view of classic representatives of (A) American Black, (B) American Indian, and (C) American White female skulls. Note the subtle craniofacial variation listed in **Table 3**.

Figure 3 Palatal views of classic representatives of (A) American Black, (B) American Indian, and (C) American White male skulls. Note the respective parabolic, hyperbolic, and convergent tooth rows.

Figure 4 Occlusal view of classic representatives of (a) American Black and (B) American White male premolars and molars demonstrating complex and simple pit and fissure morphology.

malocclusion types are a consequence of head form and facial morphology.

The experience of the skeletal biologist and familiarity with reference populations is key to establishing successful assessment. Only after years of study on numerous samples can the expert develop an appreciation for the inherent variation within and between populations to confidently diagnose race from craniofacial morphology. Skeletal features represent the same degree of continuum seen in any soft tissue and no single specimen will demonstrate every feature in the classic sense. Consultation by an experienced forensic anthropologist versed in regional variation is a must for accurate race diagnosis.

Table 3 is a generalized subset of the target visual variables utilized by anthropologists for racial estimation. As with soft-tissue gradations, this variation is subtle and subjective. As mentioned, target bony traits include facial structure and relative proportions, dental traits, and neurocranial morphology (Figures 1 to 4). Also, the traits in Table 3 represent classic morphological expressions characteristic of each group. It is important to bear in mind that these traits are derived from combined sex designations and certain traits are more sex-sensitive than others. Finally, all traits are adult manifestations, i.e., postpubertal, beginning between the ages of 17 and 21 years, and not discernible on subadult crania.

Metric Craniofacial Indicators

When visual morphology is nondiagnostic, numeric analysis from crania and/or postcrania can provide assistance through a statistical comparative population approach. The success of metric methods is highly dependent on the investigator's familiarity with the population sample from which the comparative analysis is taken. Anthropometric studies have demonstrated skull size and shape, relative body proportions, and skeletal robustness differs between populations as well as between sexes within a population.

The Forensic Data Bank

In 1984, the National Institute of Justice sponsored the formation of the Forensic Data Bank within the Anthropology Department at the University of Tennessee. Essentially, the purpose of the Forensic Data Bank is the collection of metric skeletal data from contemporary populations. From this, a discriminant function-based, user-friendly computer program was created which generates a population classification based on cranial and/or postcranial metric measurements from complete or fragmentary remains. Furthermore, the program provides sex and stature estimation. The current expanded edition, Fordisc 2.0, contains a known age, sex, and race database of approximately 1550 individuals from seven specific geographical regions. With the exception of many American Indians, all were born in the twentieth century. The African American or Black sample is drawn from across the USA as also are the American Indian and White samples, although a few Whites were European-born. Chinese, Japanese, and Vietnamese males were drawn from Hong Kong, Japan, and Vietnam, respectively. Additionally, historical craniological data from approximately 2500 individuals representing worldwide local populations established prior to European expansion are included. Six main geographical regions are included representing Europeans, Africans (sub-Saharan), Far Easterners (Japanese, Chinese), and Australo-Melanesians, Polynesians, and the Americans.

Fordisc results do not diagnose skulls by populations. Statistical classification within groups in the database is achieved by typical probabilities that allow the analyst to draw conclusions. The program is qualified through selection of reasonable populations for comparative analysis. Ongoing data collection in several regions of the world strengthen the prospect of program revisions to incorporate the expanding body of metric skeletal data.

Conclusions

The anthropologist's holistic consciousness provides a seamless integration of biological and social perspectives. Race is a complex construct that can be studied and debated and used and misused by those with sociological, anthropological, political, religious, educational, economic, or other agendas. Biological anthropologists studying population genetics, anthropometrics, and osteometrics have aptly demonstrated that the biology is no less complex. Forensic anthropologists assess race to deliver any and all evidence that may allude to victim identification. It is no less important than any other demographic variable we study. For success, the investigator must be familiar with the wide range of human skeletal variation. More than any other exercise in forensic anthropology, racial evaluation is an estimation based on subjective experience and objective measurement. No single trait can correctly evaluate race on a majority of occasions. Racial assessment reflects the recognition of a suite of skeletal traits most consistent and diagnostic with a specific population. Regardless of population, there is for now significant and subtle bone morphology that differentiates them. As human variation evolves, admixture will continue to morph new designs that will make group differentiation increasing by difficult and the most daunting task in forensic anthropology.

See Also

Anthropology: Archeology, Excavation and Retrieval of Remains; Stature Estimation from the Skeleton; Sex Determination; **War Crimes:** Site Investigation; Pathological Investigation

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Handedness

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Introduction

The assessment of handedness from skeletal remains is based upon observable morphological asymmetry in the bones and joints of the pectoral girdle and upper extremity. The asymmetry results from hypertrophy of bony elements exposed to excessive forces or chronic loading, in accordance with Wolff's laws of bone remodeling. In theory, a right-handed person should exhibit stouter bones or modified joint surfaces, indicating overuse, on the favored right side. However, research suggests that such asymmetry is not always observable and, in some cases, the opposite side may be larger. Thus, in practice, the assessment of handedness is potentially troublesome.

Defining Handedness

"Handedness" describes the consistent, unequal use of one limb over the other in a certain set of prescribed tasks. The antiquity of handedness and its inextricable link to humanity continues to be a focus for anthropological reconstructions of past populations and characterizations of individual ways of life. The supposition of links between the behavior of handedness and its anatomical presentation, cerebral asymmetry, language, and manual manipulation is the basis of much of this research. Many assume that handedness is a readily observable phenomenon, that modern humans are mostly right-handed, that handedness is universally defined and measurable, that evidence of handedness in a few fossils represents that of the whole population, and that handedness is conclusively linked to brain laterality and thus brain complexity.

Humans are considered unique among animals because right-hand dominance is defined as a cross-cultural, population trait. According to traditional estimates, right-handers have comprised 90% of the human population throughout history. Many accept this as a standard ratio and use it to confirm observed asymmetries. However, current studies reveal that handedness is expressed in degrees and hand usage is rarely strictly unilateral. Additionally, differing definitions and problems in its measurement highlight some of the problems inherent in handedness assessment. For example, most use the task of writing as the main criterion for handedness assignation, even though it many not coincide with the limb choice for other activities. Many overlook, neglect, or forget the fact that the nondominant limb has the potential to undergo heavy loading during tasks not classically used to define "handedness." Such loading conditions could stimulate bone remodeling, thereby reducing anatomic asymmetry or even forcing the asymmetry in the opposite direction to that expected. In addition, preferential limb usage may vary according to the specific task and across the many joints or segments comprising the upper extremity, making assessment of "handedness" from skeletal remains far from certain.

In defining handedness, questions also arise as to which quality – power or precision – and which activity – active or passive – should be included in the task list. Traditionally, it seems that activities requiring more coordination and cerebellar involvement are deemed more important in the assignation of handedness, even though crude, assistive, passive activities may generate greater forces that affect the bones to a greater extent. Ultimately, the tasks used by the victim or victim's family to define handedness and those used by the anthropologist may not correspond, resulting in inconsistencies in the relationship between asymmetry and handedness.

Previous Research

Numerous studies unquestionably document morphological asymmetry in the skeleton. However, subsequent interpretations attributing such asymmetry to handedness are potentially flawed if the antemortem handedness pattern for the sample is not known and the researcher is relying on the assumed 90% frequency of "right-handedness." If handedness of the sample is "known," one must be critical of the task set used to define handedness. Overall, results have been mixed in the establishment of a link between asymmetry and handedness.

One of the earliest studies was performed by Schultz in 1937 in which he compared asymmetries in long bone lengths (upper and lower limbs) in humans and nonhuman primates. He found that the human arm bones exhibited a greater degree of asymmetry than those from the nonhuman primates. In addition, he noted a magnification of asymmetry in the upper limb relative to the lower limb that was suggestive of handedness but dismissed the link since it was contrary to his earlier fetal research.

Approximately 30 years later, T. Dale Stewart observed a difference in morphology of the right and left glenoid fossae while analyzing Korean War dead and in subsequent analysis of skeletons in the Terry collection. He reported that the right side of the scapular glenoid exhibited increased beveling, dorsal inclination, and arthritic change. Handedness for both of Stewart's samples was not known. However, in 1980, Schulter-Ellis replicated Stewart's study using 10 cadavers of known handedness and corroborated his findings.

One of the strongest correlations between asymmetry and excess limb use was established by Jones and his colleagues in 1977. Upon analyzing humeral radiographs of 84 professional tennis players, they found a 28.4–34.9% increase in cortical thickness of

Table 1 Summary of previous studies

Author	*Year*	*Study*	*Findings*
Schultz	1937	Compared human upper-extremity bone lengths with those of nonhuman primates in an attempt to compare degree of asymmetry between human and nonhuman primates	Human (n = 753) arm bones exhibited a greater degree of asymmetry than those from nonhuman primates (n = 530)
Garn *et al.*	1976	Examined the degree of cortical asymmetry of the second metacarpals in radiographs of 227 patients with chronic renal disease; handedness was self-reported by patients	Reported a paradoxical occurrence of asymmetry in the cortical thickness of the second metacarpal; all exhibited a greater right-side cortical area, even the 19 left-handed individuals
Stewart	1976	Compared the morphology of the glenoid cavity between the right and left sides and compared these to differences in humeral length using the Terry collection; handedness is unknown for this sample	Right glenoid exhibited increased beveling of the dorsal border and the entire face tended to be more dorsally inclined; these occurred often with greater right humeral length and right-sided arthritic changes
Jones *et al.*	1977	Compared radiographs of humeri of 84 professional tennis players	Humerus on the ''playing side'' exhibited marked hypertrophy in cortical thickness (34.9% males; 28.4% females)
Schulter-Ellis	1980	Tested Stewart's study using 10 cadavers of known handedness	Corroborated Stewart's findings
Glassman and Bass	1986	Studied the relationship of the jugular foramen to limb asymmetry (a correlation used in the past to indicate handedness) in the Terry collection; handedness is unknown for this sample	Demonstrated that the hypothesis is unfounded due to a lack of correlation between the sides of the larger structures
Roy *et al.*	1994	Measured the anterior and posterior cortical bone thickness of the second metacarpal on plain radiographs of a large living sample for which handedness was assessed by ''personal impression''	Found statistically significant correlation of handedness to their variables calculated from the cortical thickness measures (cortical bone area, periosteal area, medullary area, and second moment of area)
Czuzak	1998	Compared asymmetry of the humeri, radii, ulnae, and first metacarpals using osteometric data, joint surface areas, midshaft cortical thickness, and osteoarthitic score on a sample of 39 cadavers for whom the handedness was assigned by next of kin	Frequency analysis revealed an overall trend of misclassification of handedness, with greater misclassification for the nonright-handed individuals, females, and when using joint surface area and cortical thickness data

the humerus on the "playing side." This study indicates the degree of loading and constancy of limb use necessary to result in asymmetry marked enough to allow one to postulate handedness confidently.

More recent studies attempting to document asymmetry in order to predict handedness have met with varying degrees of success. In 1986, Glassman and Bass attempted to test the relationship of the jugular foramen to limb asymmetry, a correlation used in the past to indicate handedness. Assuming that handedness is linked to cerebral asymmetry, the cerebral hemisphere controlling the dominant limb would require a greater blood supply and, by default, a larger drainage system. The venous drainage of the brain is primarily via the internal jugular veins, which pass through the jugular foramina of the skull. Though working with a skeletal sample of unknown handedness (the Terry collection), the authors demonstrated that the hypothesis is unfounded due to the lack of correlation between limb and jugular foramen asymmetry.

Roy and colleagues measured the anterior and posterior cortical bone thickness of the second metacarpal on plain radiographs of a large living sample for whom handedness was self-reported. They found a statistically significant correlation between handedness and several variables calculated from the cortical thicknesses. However, an earlier study performed by Garn and his colleagues on the cortical thickness of the second metacarpal in patients with chronic renal disease resulted in a paradoxical occurrence of asymmetry. Among the 227 individuals in the study, all exhibited a greater right-side cortical area, including the 19 self-reported left-handed individuals. The authors conclude that the paradoxical asymmetry may be specific to their particular sample or it suggests that left-handed individuals use the right hand more than suspected.

In a comprehensive study in 1998, Czuzak analyzed gross osteometric measurements, proximal and distal joint surface areas, midshaft cortical thicknesses, and osteoarthritic scores in the humeri, radii, ulnae, and first metacarpals of 39 cadavers. Right–left asymmetry was compared to handedness, which was assigned by next of kin. Interestingly, there was an overall trend of misclassification of handedness based on skeletal asymmetries and the misclassification was exaggerated in nonright-handed individuals, females, and for measures of cortical thickness and joint surface area. As found by Garn, it is probable that these 39 individuals were also using their nondominant limbs more than expected or defined by any handedness questionnaire (Table 1).

Handedness in Forensic Practice

The assignation of handedness is often not a typical feature of the forensic biological profile unless the skeletal asymmetry is so grossly obvious that it warrants remark. Such obvious asymmetry may be apparent in individuals experiencing excessive unilateral loading of a limb, as may occur in tennis players or baseball pitchers. Alternatively, unilateral disuse due to paralysis may also result in noticeable asymmetry. In these cases, postulation of handedness based on the observed asymmetry may be helpful in corroborating identification. However, since most individuals are not exposed to excessive unilateral loads, asymmetry may not be as obvious. Assignation of handedness based upon minimal asymmetry and/or the assumption that 90% of individuals are right-handed may compromise identification of skeletal remains. Care must be taken not to overinterpret the remains.

Summary

From this brief overview, one may conclude that the concept of handedness is not as conspicuous as personal experience might suggest. There is no doubt that one limb is preferred/specialized to perform certain tasks but the opposite limb is never inactive. Humans are truly bimanual; unless incapacitated, the opposite limb assists the one performing the primary activity. The "nondominant" limb can even take over the activity during times of fatigue. Activities used to define handedness vary greatly, with no universally accepted set of tasks to guide researchers. Based on the ambiguity of handedness itself and the paucity of studies supporting its interpretation from skeletal remains, caution should be exercised in the assignation of handedness.

See Also

Anthropology: Stature Estimation from the Skeleton; **Autopsy:** Procedures and Standards

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Role of DNA

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Introduction

Deoxyribonucleic acid (DNA) is used by forensic scientists as a means of identification, for example of criminals and corpses and now it has also been found to be relevant in anthropology, in fields such as human evolution, population movements, and paleodiseases. In the 1990s, it became possible to extract DNA from very old tissues such as skeletal remains. Such DNA permitted discovery of aspects of past social organizations that were previously unknown or difficult to ascertain using conventional

More recently, Y-chromosomal markers (STRs and biallelic markers) have also been used for human identification in forensic casework and paternity testing as well as for the study of human evolution. These markers are of special interest because they are haploid and paternally inherited; the fact that they do not undergo recombination offers the possibility of directly tracing male lineages back in time.

Mitochondrial DNA

Every human cell has a "second" genome, found in the cell's energy-generating organelle, the mitochondrion. Each mitochondrion has several copies of its own genome, and there are several hundred to several thousand mitochondria per cell. The entire DNA sequence of the human mitochondrial genome (16 569 nucleotides) was determined in 1981. The mitochondrial DNA (mtDNA) contains 37 genes, all of which are involved in the production of energy and its storage in adenosine triphosphate (ATP).

Apart from its maternal inheritance (fathers make no contribution to the mitochondria of their children) and lack of recombination (due to the lack of paternal mtDNA with which to recombine), two aspects of mtDNA make it particularly useful for the analysis of forensic and archeological material: (1) its high copy number, which increases the chance of survival of a few molecules in the face of molecular damage that may affect forensic or ancient biological samples; and (2) the fact that it accumulates mutations faster than nuclear DNA, resulting in the ability to discriminate between individuals or populations. Among the possible analyses of mtDNA, those concerning two hypervariable (HV) regions of the control region (specifically the noncoding regions HVI and HVII) are the most frequent, since they contain the highest degree of polymorphism.

Techniques

Analysis of restriction fragment length polymorphisms (RFLPs) and cloning of DNA fragments from ancient samples were the two techniques initially used in molecular anthropology. While highly efficient and reliable, these techniques often reach an impasse when the quantity of DNA available for analysis is very limited, or when the DNA is too severely damaged.

In 1985, a process was reported by which specific portions of the sample DNA can be amplified almost indefinitely. This has revolutionized forensic and ancient DNA analyses because the process, the polymerase chain reaction (PCR), has allowed the amplification of extremely low concentrations of DNA. Nowadays PCR is the most widely used technique in the field of molecular anthropology because even degraded DNA can be amplified and subsequently analyzed.

PCR amplification is achieved by denaturing the DNA sample into separate individual strands. Two synthetic oligonucleotide primers are then used to hybridize to the DNA sequence of interest and a heat-stable DNA polymerase extends these primers to create a complete and complementary strand of DNA. In this fashion, two new copies of the sequences of interest are generated. This process is typically repeated sequentially 25–40 times thereby creating millions of copies of the target DNA sequence. The amplified sequence can then be detected by gel electrophoresis.

Ancient DNA

The DNA molecule extracted from ancient preserved biological material, called ancient DNA (aDNA), is fragmented into small pieces ranging from only a few base pairs (bp) to a few hundred at most. Some of the bases may have undergone chemical changes and the DNA content available for analysis is extremely small, sometimes fewer than ten molecules per gram of bone.

Little is known about the optimum preservation conditions; temperature, pH, and moisture levels are probably the most important factors, followed by the degree of protection from the external environment. Burial in wet soil may be unsuitable for DNA survival, leading to extreme fragmentation of the DNA, and microbial activity and microenvironmental variation around bones also play important roles. There is no method available for the rapid screening of bones for indications of DNA survival, and there is no direct correlation between DNA content and the age of a bone. Nevertheless, the age limit for successful retrieval seems to be around 100 000 years.

Bone and teeth are the major sources of DNA in archeological studies. These tissues are more likely than soft tissues to persist, due to their physical durability, and conditions within the bone are relatively more favorable for the preservation of DNA. Compared to other organs, bones have low water and catabolic enzyme content which may allow a rapid mummification of the individual osteocytes or cementoblasts. The cell material is also abundant in compact bone with 20 000 osteocytes per cubic millimeter. The important characteristic of bone and tooth tissues is that their matrix is composed of crystalline calcium phosphate (hydroxyapatite), which is known to bind to double-stranded DNA. The binding of the DNA molecule to the bone matrix may play a role in the long-term protection of DNA from chemical breakdown. The hardness and the high hydroxyapatite concentration of tooth dentine may preserve DNA to an even greater extent than occurs in bone.

Applications of DNA Analysis in Anthropology

The main applications of these analyses are identification of sex of human remains, kinship analyses, the study of paleodiseases, and tracing the migrations of populations and their gene distributions. DNA data are also used to test the hypotheses of the origins of anatomically modern humans; in this context, comparisons have been performed with the Neanderthal DNA sequences.

Sex Identification

Identification of sex by morphological criteria is dependent on the survival of either skull or pelvis and assumes that their morphology has not been affected by any pathology. However, skeletal remains are frequently incomplete or ambiguous in juveniles and infants. DNA analysis provides an accurate and reliable method for the sex determination of human skeletal remains. These molecular investigations are based on the PCR amplification of repetitive DNA sequences from both X and Y chromosomes. For this purpose, the amelogenin gene (present in both sex chromosomes) is chosen since the sequences on the X and the Y chromosome are nonidentical. The number of repeats in the two chromosomes is different so that the PCR products show sex-specific size differences: the amplified products have 112 bp for the Y chromosome and 106 bp for the X product. Partial amplification failure of either the X or the Y template DNA can occur, but this failure occurs more frequently when larger sequences are amplified. For example, the amplification of three different PCR systems based on the amelogenin gene can be achieved in a single reaction using three primers. Primers 1 and 2 anneal to the X chromosome, while primers 1 and 3 anneal to the Y chromosome, which has a 64 bp deletion. The PCR product from the X chromosome has 195 bp and is larger than that from the Y chromosome, which has only 132 bp. These sequences are large and, in ancient samples, partial amplification may be responsible for the visualization of only one band in male samples (of 132 bp), the other sequence located on the X chromosome being too large and possibly degraded for correct amplification. Another method is based on the hybridization of the PCR products with probes specific for the X and Y sequences but partial amplification failure has also been reported.

Kinship Analysis

The "genetic fingerprinting" techniques which have been widely employed in the identification of murder victims and sexual assault criminals and in settling paternity disputes have also been used widely for determining kinship within a group of burials. The DNA sequences used in kinship determination are called microsatellites, which are located in the intergenic regions and have no known functions. These STRs consist of a 2, 3, 4, or 5 bp sequence repeated 5–30 times. More than 10 000 STRs have been described in the human genome but only about 60 are used for identification purposes. The chosen STRs must be hightly polymorphic in the human population, and each marker has to be found in several versions. These alleles have different numbers of repeats and, therefore, their own diagnostic length. PCR primers are designed for each STR to yield amplification products of 100–450 bp; for analysis of ancient tissues, the smaller the products the better the identification. Except for monozygotic twins, no two living persons have exactly the same combination of STR alleles, so the examination of 16 polymorphic STRs allows the identification of a given person by their unique genetic fingerprint. The frequency of STR alleles is determined in various populations in order to calculate the probability of occurrence of a genetic profile more than once. For past populations not enough individuals are available for calculating the allele frequencies, but by increasing the number of studied STRs we can achieve the identification of human remains, within the burial group, to determine kinships. As an example, the present authors and coworkers have successfully extracted DNA from the skeletal remains of 62 individuals excavated from a burial site of the Xiongnu people, in northern Mongolia. Three types of genetic markers were used to determine the genetic relationships between the people buried in this necropolis. Results from autosomal and Y-chromosome STRs as well as from mtDNA analyses showed close relationships between several individuals and provided additional background information on the social organization within the necropolis as well as the funeral practices of the Xiongnu people.

Paleopathology

Recently, molecular biology has become a powerful tool for identifying bacterial, protozoan, and viral infections in ancient human remains. This approach has been extensively used for the detection of the *Mycobacterium tuberculosis* complex, *Mycobacterium leprae, Yersinia pestis, Plasmodium falciparum, Trypanosoma cruzi*, and the influenza virus. The study of residual bacterial DNA in skeletal or mummified tissue samples has allowed not only a confirmation of the diagnosis made, notably on bone lesions, but has also added to the progress in the knowledge of the history of some infectious diseases and of their prevalence in past civilizations. For instance, it has been proved, through DNA analysis of ancient tissue, that tuberculosis was present before European contact in the New World, and that infection with this mycobacterium was relatively frequent in ancient Egypt. Molecular detection of ancient microorganisms has also provided nucleic acid sequences that could be compared with those of modern isolates. Such comparisons of ancient pathogens with their modern counterparts at the DNA level may reveal the evolution of a pathogen over time and help to identify variations in its virulence. As an example, gene sequences of the 1918 "Spanish" influenza virus have been used to frame hypotheses about the origin of this pandemic virus, and to look for clues as to its virulence. It is likely that knowledge gained by studying these human pathogens will in the future be applied to prevent, or at least predict, the emergence of new infections with pandemic potential.

Evolution

Molecular biology also permits us to tackle ambitious goals, such as studying the genetic structure of extinct species and their relationship to contemporary species. A prime example, within the genus *Homo*, concerns the role of Neanderthals in the evolution of modern humans.

Neanderthals are a group of extinct hominids that inhabited Europe and the Middle East between about 230 000 and 30 000 years ago. Their proximity in time to anatomically modern humans has raised questions about the coexistence of these two hominid forms. It is controversial as to whether Neanderthals (1) should be regarded as direct ancestors of modern Europeans; (2) contributed, by hybridization, to the gene pool of modern humans before becoming extinct; or (3) evolved totally independently of *Homo sapiens*. The classical view emerging from anatomical and archeological studies has placed Neanderthals in a different species from *H. sapiens*. Furthermore, analyses of molecular genetic variation in the mitochondrial and nuclear genomes of contemporary human populations have generally supported the view that Neanderthals were not related to modern humans. Nevertheless, the relationship between Neanderthals and modern humans remains enigmatic, so the retrieval of Neander DNA is still one of the major goals of researchers in the field of ancient DNA.

The first successful extraction of a mtDNA sequence from a Neanderthal was performed on the 40 000-year-old Neanderthal type specimen found in a limestone quarry in the Neander Valley, Germany. A few years later, a second mtDNA sequence from a Neanderthal child (dating to about 30 000 years ago) found in Mezmaiskaya Cave in the northern Caucasus was determined and found to be similar to the type specimen. Phylogenetic analysis placed these two Neanderthals from Germany and the Caucasus together in a clade that is distinct from modern humans, suggesting that their mtDNA types have not contributed to the modern human mtDNA pool. Two new mtDNA sequences, subsequently obtained from a Neanderthal individual (about 42 000 years old) from Vindija, Croatia and from a second Neanderthal individual from the Neander Valley (about 40 000 years old), made it possible to estimate the mtDNA diversity among Neanderthal specimens. This genetic diversity was comparable to that of contemporary humans and lower than that of the great apes. The newly obtained mtDNA sequences also confirmed the hypothesis that Neanderthals were a separate hominid species (*H. neanderthalensis*) rather than a subspecies (*H. sapiens neanderthalensis*) that contributed some genes to modern human ancestry. This hypothesis was further supported by a work based on Southern blot hybridization technique. Nonetheless, for some authors a comparison of Neanderthal and living human mtDNA with mtDNA from ancient fossils of anatomically modern humans was a crucial step for solving this question. This has recently been achieved by the typing of mtDNA HV region of two anatomically modern *Homo sapiens sapiens* individuals of the Cro-Magnon type found in a southern Italian cave and dated at about 25 000–23 000 years ago. The Cro-Magnon sequences fall within a genetic category shared by people today but not by Neanderthals, bolstering the theory that modern *Homo sapiens* replaced Neanderthals in Europe rather than interbred with them.

Human Migrations

Up until the 1990s, the study of human migration patterns was primarily accomplished using macroscopic examination of ancient and fossil bone specimens and analysis of genetic polymorphism in living populations. Now analysis of DNA polymorphisms can reveal the relationships between populations and thus allow past migrations to be identified. Since it is maternally inherited and evolves quickly, mtDNA has been used extensively for unraveling the ancient human migrations. However, since gene flow through the maternal lineage is expressed, current attempts to understand prehistoric human migrations also include the use of Y chromosomal nuclear markers. Moreover, because direct analysis of ancient samples is the unique tool for checking the conclusions based on genetic analysis of modern populations, analysis of ancient DNA research has also been used when possible to establish the time and route of major migrations in human history. Ancient samples from Native American archeological sites have been used, for example, to shed light on the peopling of the New World. This example represents, indeed, one of the more debated topics in the study of human migrations. It is generally accepted that the ancestors of Native Americans came from Asia across the Bering Strait; however, the timing, place(s) of origin, and number of waves of migration are surrounded by controversy. Analyses of mtDNA diversity among Native Americans (both contemporary and ancient) have revealed that nearly all of them belong to one of five mtDNA haplogroups: A, B, C, D, or X. Initially, the presence of haplogroups A, B, C, and D in Siberian and Mongolian populations led scientists to propose these areas as potential geographic sources of ancestral Native American populations. Recently, this notion has been strengthened by the discovery of haplogroup X in Altaian populations from southern Siberia. Furthermore, several studies on Y chromosome DNA polymorphism were performed to investigate male migrations to the American continent. It has been proposed that populations occupying the area including Lake Baïkal, the Yenissey River Basin, and the Altai Mountains were the source for dispersals of New World Y-chromosome founders. Nevertheless, questions concerning the number and timing of migrations into the New World remain, to date, unresolved.

Other issues, such as the expansion of Neolithic farmers into Europe or the role of male and female migrations in human history, have also been investigated through DNA analyses. By using autosomal, mitochondrial, and Y chromosome polymorphisms, it has been shown, for example, that Y chromosome variants tend to be more localized geographically than those of mtDNA and the autosomes. In other words, it seems that females have had a much higher migration rate than males. Patrilocality could be a good explanation: women moved much more frequently between groups than did men, leading to greater between-population differences for the Y chromosome.

Contamination, Interpretation Difficulties and Validation of Results

The importance of fossils in the field of anthropology has been somewhat reduced as it has became possible to study human history through the distribution and frequency of DNA sequences from present-day populations worldwide. A reconciliation of both approaches (paleontological and genetic) has come with the extraction and amplification of DNA from ancient specimens. However, technical pitfalls make ancient DNA studies liable to yield dubious results, particularly when human remains are studied.

Ancient DNA molecules tend to be damaged and consequently are refractory to most of the current procedures for nucleic acid analysis. Water and oxygen, which cause hydrolysis and oxidation of DNA, respectively, reduce the number and the size of the fragments that can be amplified. Under these circumstances, it is possible that DNA polymerase errors, as well as miscoding lesions in the template DNA sequences occur.

The difficulty in amplifying DNA in archeological samples may also result from the presence of inhibitors that interfere with the PCR reaction. Indeed, archeological specimens may contain low-molecular-weight compounds, most likely to be derived from the burial environment, which copurify with DNA and potently inhibit the activity of Taq polymerase employed in PCR.

Nevertheless, the main problem encountered in the analysis of ancient DNA is contamination of samples by modern DNA molecules. Because of the efficiency of PCR, even low levels of contamination with contemporary DNA will lead to erroneous results. Human remains are particularly difficult to work with, owing to the difficulty of identifying contaminating human sequences. Such contaminations may stem from a variety of sources, such as handling during excavation or removal of samples or contamination of reagents and glassware used during the extraction and analysis procedures.

All these problems can be overcome by the implementation of specific precautions in the preparation and handling of samples and solutions as well as experimental controls at the DNA extraction and amplification stages. To avoid contamination, all DNA extractions and PCR preparations involving ancient DNA samples should be performed in a laboratory room exclusively dedicated to ancient DNA analysis and physically separated from the main genetics laboratory. In each extraction and amplification step, a control sample (a sample with no tissue, bone, or extracted DNA sample) should be included and processed similarly. A strong inverse correlation between amplification efficiency and length of the ancient DNA to be amplified should be noted. Multiple extracts must be performed, preferably from different tissues of the same individual, and the results should be identical. The amount of damage likely to have been suffered by the ancient DNA should be determined. An estimation of the number of ancient template DNA molecules from which the PCR starts should be made to ensure the quality of ancient DNA sequences. The cloning of the PCR product and sequencing of several clones should be used to detect problems and to obtain a consensus sequence for the target. DNA extraction and amplification should be independently repeated in a different laboratory, and the results should be consistent across laboratories.

In addition to contamination, ancient DNA studies face other problems. Since the archeological and paleontological specimens used are valuable and available in limited quantity, the small amounts of DNA that could be extracted allowed typing of only a limited number of markers for each sample and the data obtained are not always highly informative. Moreover, only the remains that are discovered can be analyzed; this means many questions may never be addressed by ancient DNA methods. Finally, another drawback to using archeological materials is that it is often difficult to obtain anything resembling a population of individuals who lived together at the same time.

Conclusion

Molecular anthropology intertwines with a variety of disciplines, such as forensic genetics, anthropology, archeology, evolutionary studies, and paleopathology. From human remains, the molecular biologist attempts to understand issues such as the nature of societies that existed in the past, their cultural and ritual customs, their evolutionary histories, their migrations and interactions with other societies through trade, warfare, and acculturation, their impacts on the environment, their means of subsistence, and their diseases. However, technical pitfalls make the field liable to give dubious results unless many precautions and experimental controls are implemented. Future developments such as the possibility of removing or repairing chemical damage in the ancient DNA would be welcome additions to this field.

See Also

Anthropology: Sex Determination; Determination of Racial Affinity; **DNA:** Basic Principles; Risk of Contamination; Mitochondrial

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