TIM D. WHITE • PIETER A. FOLKENS

The HUMAN BONE MANUAL

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Tim D. White

Pieter A. Folkens

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ACADEMIC PRESS

Amsterdam • Boston • Heidelberg • London
New York • Oxford • Paris • San Diego
San Francisco • Singapore • Sydney • Tokyo

Acquisition Editor: Nancy Maragioglio
Project Manager: Brandy Lilly
Associate Acquisition Editor: Kelly Sonnack
Marketing Manager: Linda Beattie
Composition: A Higher Porpoise Design Group
Cover Printer: Phoenix Color
Interior Printer: The Maple-Vail Book Manufacturing Group

Elsevier Academic Press
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
525 B Street, Suite 1900, San Diego, California 92101-4495, USA
84 Theobald's Road, London WC1X 8RR, UK

This book is printed on acid-free paper. ∞

Library of Congress Cataloging-in-Publication Data
White, T. D. (Timothy D.)
The human bone manual / by Tim D. White, Pieter A. Folkens.
p. cm.
ISBN 0-12-088467-4 (casebound : alk. paper) 1. Human skeleton—Identification—Handbooks, manuals, etc. 2. Human skeleton—Analysis—Handbooks, manuals, etc. 3. Human skeleton— Classification—Handbooks, manuals, etc. 4. Human remains (Archaeology)—Handbooks, manuals, etc. 5. Forensic osteology—Handbooks, manuals, etc. 6. Forensic anthropology—Handbooks, manuals, etc. I. Folkens, Pieter A. II. Title.
GN70.W44 2005
599.9'47--dc22
2005010154

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 0-12-088467-4

For all information on all Elsevier Academic Press Publications
visit our Web site at www.books.elsevier.com

Printed in the United States of America
05 06 07 08 09 10 9 8 7 6 5 4 3 2 1

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Preface

Forensic scientists, law enforcement personnel, osteologists, paleontologists, and archeologists frequently encounter human remains in their work. These researchers can use skeletal remains to investigate both the recent and the ancient past. For them, an illustrated human osteology manual represents an important tool for identification and analysis, both in the field and in the laboratory.

In the field setting, professionals and students are often required to do fast, accurate identification without laboratory resources. This book is designed to be the primary resource in the field setting: a smaller, lighter, and more durable book for forensic scientists, law enforcement personnel, archeologists, osteologists, zooarcheologists, and paleoanthropologists.

The two-dimensional images in this manual are valuable tools in field identification, instruction, and learning involving human skeletal remains. They have been carefully crafted to show a maximum amount of anatomical information, and scaled to provide easy comparison. Organized for ease of use as a manual, this book emphasizes the basics while providing an introduction to the human skeleton and access to a wide range of modern work in human osteology.

Whatever success we have achieved in developing a useful manual we owe largely to the students and colleagues who have diligently used the first and second editions of our textbook, *Human Osteology*—the direct predecessor of *The Human Bone Manual*. Many colleagues made those volumes possible. Bill Woodcock at Academic Press first suggested the text. Bruce Latimer and Lyman Jellema of the Cleveland Museum of Natural History helped us to obtain the Hamann-Todd postcranial skeleton illustrated here. Mitchell Day assisted in providing specimens for illustrations from the University of the Pacific School of Dentistry's Atkinson Cranio-Osteological Collection of the A.W. Ward Museum. Thanks go to Bob Jones of Berkeley's Museum of Vertebrate Zoology for removing the grease from the illustrated skeleton. For forensic advice and consultation we thank Richard Thomas and Ellen Moore.

The manual illustrates human bones from additional institutions that are gratefully acknowledged here, particularly the Phoebe Apperson Hearst Museum of Anthropology at U.C. Berkeley (where TW is a Faculty Curator). We gratefully acknowledge the assistance of the U.S. Army Central Identification Laboratory, Hawaii; the FBI Laboratory Division; and the Armed Forces Institute of Pathology.

The following colleagues have graciously provided access to illustrative material in the manual: Suzanne Sundholm and Kent Lightfoot of the University of California Archaeological Research Facility, Larry Zimmerman of the University of South Dakota, Doug Ubelaker of the Smithsonian Institution, Jerry Fetterman of Woods Canyon Archaeological Consultants, George Gill of the University of Wyoming, Owen Lovejoy of Kent State University, and Steadman Upham of New Mexico State University kindly granted permission to reprint their photographs and drawings, and Scott Simpson provided much help in obtaining illustrative material. Requests for reuse of the photographs and artwork in this book should be made directly to the authors, or, in the case of credited illustrations, to the individual(s) or institution(s) identified in the appropriate figure caption.

The following colleagues and students contributed in their own ways to the manual, and they are all gratefully acknowledged: Elizabeth Agrilla, Michael Black, Jose Miguel Carretero, Susan Chin, Brianne Daniels, David DeGusta, Henry Gilbert, Eugene Hammel, Walter Hartwig, Bill Kimbel, Clark Larsen, Jeni McKeighen, Yoel Rak, Gary Richards, and Susan Standen. Chuck Crumley was responsible for moving this project from idea to reality, as were David Cella, Kelly Sonnack, Nancy Maragioglio, Brandy Lilly, and Cate Barr. We thank all of them. The Human Bone Manual was an idea of William Woodcock in the early 1980s. A quarter-century later, it is an idea whose time has come. Toss the manual in your trunk, suitcase, glove compartment, or backpack. Good hunting.

Tim D. White
Pieter A. Folkens

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Chapter 1

Introduction

Bones have been entombed for millions of years in sediments left by ancient lakes, swamps, and rivers that once dotted Ethiopia's Afar Depression. Today, as erosion cuts into these ancient layers, the fossils reach the barren Afar surface, often shattering into small, glistening, multicolored fragments of bone and teeth. Thinly scattered among the osseous and dental remains of thousands of crocodile, turtle, hippopotamus, giraffe, carnivore, baboon, pig, horse, antelope, and other animals found in the surface fossil assemblages are the remains of primitive human ancestors. While paleontologists search Afar outcrops for osteological clues about prehistoric human form, archeologists uncover the osteological remains of the inhabitants of Herculaneum who perished as Mount Vesuvius erupted, burying them with their possessions. On the other side of the globe, anthropologists probe into a recent grave containing skeletal parts that may be those of a Nazi war criminal.

1.1 Human Osteology

A thread that binds these and thousands of other investigations is **human osteology**, the study of human bones. The scientists performing the investigations employ their knowledge of the human skeleton in recovering and interpreting the bones. Outside of anatomical and medical science, there are three main areas in which knowledge of human osteology is often applied. First, osteological work is often aimed at identification of the relatively recently deceased and is usually done in a legal context. This work, which pertains to the public forum, most often a court of law, is called **forensic osteology**, a division of forensic anthropology. The other two contexts in which human osteological knowledge is commonly applied are historical. The context can be ancient and purely **paleontological**, as for the Pliocene pre-cultural hominids of Africa. Alternatively, the context can be relatively recent, part of an **archeological** record. For example, human bones recovered from the Aztec centers in Mexico were chronicled just a few hundred years ago by the Spanish during the "conquest" of Mexico. Osteological analysis of materials from such cultural contexts is routinely undertaken as part of archeological research. Archeologists concentrate on cultural residues of former human occupations, but they stand to gain a great deal of valuable information from the skeletal remains of the ancient inhabitants. It has recently become fashionable to refer to the study of human remains from archeological contexts as **bioarcheology**. However, human skeletal parts are only a small part of the biologi-

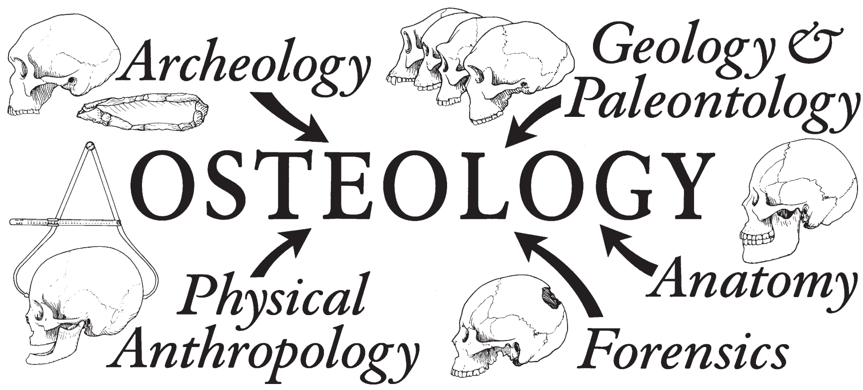


Figure 1.1 Osteology and associated scientific disciplines.

cal remains characterizing most archeological sites—indeed, most archeological sites lack human remains altogether!

The information that human or protohuman bones can provide makes the recovery of bones a critically important activity. Skeletal anatomy (including teeth) reflects the combined action of genes and environment. The skeleton forms the framework for the body, whereas the teeth form a direct interface between the organism and its environment. Bones carry in their shape, or **morphology**, the signature of soft tissues with which they were embedded during life—tissues including muscles, ligaments, tendons, arteries, nerves, veins, and organs. These soft tissues usually disappear soon after death. The skeleton, however, often preserves evidence of the former existence and nature of many of these other body parts.

Because the bones and teeth of the skeleton are resistant to many kinds of decay, they often form the most lasting record of an individual's existence. It is possible to estimate an individual's age, sex, and stature from the bones and teeth. Study of the skeleton often makes it possible to discern a variety of pathologies from which the individual may have suffered. Analysis of groups of individuals may offer insights into prehistoric population structure, biological affinities, cultural behaviors, and patterns of disease. The evolutionary history of humanity itself may be read from the fossil record—a record comprising mostly teeth and bones. Figure 1.1 illustrates the place of osteology in relation to other scientific disciplines.

1.2 A Guide to the Manual

The goal of forensic osteology often involves identification of an unknown individual. The process of personally identifying the remains of the recently dead individual is called **individuation**. To narrow the possibilities, the forensic osteologist first ascertains whether the remains are human and then begins to explore the individual characteristics, such as age, sex, and stature, comparing these variables in the hopes of obtaining an exclusive match with what is known about the missing individual. The human osteologist working in an archeological context usually cannot perform such personal identification. Rather, concerns are with characteristics of the individual and with the insights that skeletal remains of many individuals, representing biological populations, might provide on diet, health, biological affinity, and population history. The osteologist working in a paleontological context (and note that many fossils of Pliocene and Pleistocene age are found in archeological contexts) is also interested in using the normally rare fossil remains of human ancestors and other relatives to learn all these things and also to discern evolutionary relationships.

Skeletal remains can provide meaningful clues about the recent and the ancient past to all these investigators. To use these clues, one must master some fundamentals. The first two basic questions that any human osteologist must answer about a bone or collection of bones whether in a forensic, archeological, or paleontological context are:

- *Are the bones human?*
- *How many individuals are present?*

Whether the context is forensic, archeological, or paleontological, these questions usually must be answered before further analysis is possible. This manual, a guide to human osteology, emphasizes the anatomy of the human skeleton. The skeletal remains of some other animals, particularly when fragmentary, are often difficult to distinguish from human bones and teeth. Although there are no general differences that ensure effective sorting between human and nonhuman bones, the first step in answering the question of whether the bones are human is to become familiar with the human skeleton in all of its many variations in shape and size. Ubelaker (1989, Fig. 63) illustrates whole bones of mammals most often confused with humans, but this confusion rarely involves whole bones. Fragmentary nonhuman remains are more problematic and are encountered more frequently. Once a familiarity with the range, or envelope, of variation characterizing the modern human species is achieved, further work in comparative osteology of both extinct and extant mammals becomes a much easier task. With further comparative work comes more experience, and with that experience the osteologist is better able to make the basic identifications required.

Information on determining the age, sex, stature, and identity of skeletonized individuals is provided in later chapters of the manual. These second-level questions and many others, including those about biomechanical capability, phylogenetic relationships, and geographic affinities, however, can be answered accurately only after the elements and individuals have been identified correctly. Too often the first, basic identifications are overlooked or hastily performed, and thus any succeeding analyses are built on weak foundations.

Chapters 7–16 form the core of the book. In these chapters we consider one anatomical region at a time, beginning with the bones of the skull. A separate chapter and format are employed for the dentition. We introduce Chapters 7–16 with brief accounts of the phylogenetic history of the body segment(s) and osteological elements described in the chapter. This approach sets the osteological elements in a broad evolutionary framework. These introductory statements are mostly drawn from the excellent functional human anatomy text by Cartmill, Hylander, and Shafland (1987), and the interested reader may pursue further details there and in other comparative texts such as Jarvik (1980).

In the descriptive Chapters (7–16), each bone is shown individually, in various views, by means of photographs. For ease of comparison, the scale for all individual bones is natural size, while teeth are shown twice natural size. For paired bones, only the right side is shown unless otherwise indicated. Orientations for the articulated crania are standard, and other bones are illustrated in orientations showing the most anatomy. For example, the "anterior view" of the frontal is a photograph of the anterior surface of that bone. Details of the preparation and photography of these specimens are given in White and Folkens (2000).

Human osteology texts often depict human skeletons and their elements as if they were interchangeable. Sets of illustrations that provide little or no visual information on the relative sizes of different parts of the skeleton are standard. Furthermore, bones are often unscaled and/or derived from several individuals in such illustrations. This sacrifices additional information on proportionality and fosters typological thought. To remedy this situation, we chose the skeleton of a single individual to illustrate all the elements of the postcranial skeleton. All postcranial elements shown in the descriptive chapters of this manual are from a single modern human individual, Hamann-Todd specimen number 857, a twentyfour-year-old black male who stood 5' 7" tall (170 cm) and weighed 138 lb (62.6 kg). This skeleton was chosen for its relatively few unusual features (noted in the captions for each element), completeness, and excellent preservation. Articulated cranial and all dental specimens illustrated in Chapters 7 and 8 are of recent Mesoamerican origin, and the disarticulated bones of the cranium are all from a single modern individual from Southern Asia. Note that these disarticulated cranial bones are from a 16-year-old individual in which the bony elements could be disarticulated and shown intact. This young individual had not fully developed all the markers of cranial robusticity illustrated by the articulated skull.

Each descriptive chapter is organized systematically. The element is first named and its articulations identified. Under the "Anatomy" section for each element, the major parts and osteologically significant features of each element are identified in **bold** typeface and described.

The function and soft tissue relations for most structures are identified in *italic* typeface. It is not our intention to give a complete listing of muscle origins and insertions. Instead, we provide data on soft tissue to make functional sense of bony features while constantly reinforcing the reality of bone as an integral part of the musculoskeletal system.

Ossification of each element is briefly considered in the descriptive chapters under a section called **Growth**. Further details on development of various elements are presented in Chapter 19. The **Possible Confusion** and **Siding** sections provide information to complement the illustrations and allow effective identification of isolated and fragmentary skeletal elements.

Measurements in this manual are expressed in the metric system as is standard in osteology. Carter (1980) provides a good history of the English and metric systems for students unfamiliar with metric terms or for those who remain unconvinced of the metric system's utility in modern scientific investigation.

1.3 Resources for the Osteologist

The most important single resource for the osteologist is a collection of skeletal remains. Ideally, the laboratory should have a growth series of skeletons of individuals of known age to accompany mounted skeletons of several individuals, as well as element collections in which many individuals of known sex, age, occupation, and pathology are represented. A collection of skeletal remains from a variety of modern nonhuman animals is also very important. Scheuer and Black's 2000 and 2004 volumes are excellent companions to this manual. They present extensive illustrations of immature human skeletal remains.

As you work with human bones and teeth, always respect them as objects of scientific inquiry. In some ways, skeletal resources are like books in a library. Bones and teeth have the potential, if read correctly, to inform about the living, breathing people to whom they once belonged. Treat these remains with care; some of them are fragile and all of them are irreplaceable.

Respect any system of organization in which you find skeletal material. Never mix bones and teeth of different individuals, even for a short time or with the best of intentions. Remember that mixing of bones results in a loss of contextual information—an action that is potentially even more devastating than physical breakage of an element. In the library, history books shelved incorrectly in the biology section become unavailable to any historian who wishes to consult them. Bones reshelved in the wrong place are almost impossible to retrieve.

Finally, respect the people who came before you by treating their bones with care. Respect the generations of students and professionals who will follow you by keeping the bones and their provenience intact.

Beyond the physical plant of the laboratory, key resources for the human osteologist have traditionally been equipment, specimens, and publications. The advent of electronic publishing and educational software and the explosion of resources on the World Wide Web has dramatically extended resources available to the osteologist. These media are rapidly growing, evolving, and volatile, but it is important that the osteologist be aware of them. The Appendix represents an attempt to identify and assess the most stable, important, and useful web sites pertaining to human osteology.

1.4 Identifying Bones

In bone identification it pays to remember that the osteologist always has an intact comparative skeleton close at hand, even in remote field situations. That skeleton is embedded in his or her own body. It is useful to visualize and even **palpate** (feel your own bones through the skin) the way in which an isolated skeletal element might "plug into" your own body. This is particularly true for identifying and siding teeth, which are conveniently exposed in the osteologist's mouth. Never ridicule an osteologist who holds a radius against the right forearm and then shifts it to the left forearm before identifying it; that osteologist will probably side the bone correctly. When identifying the side of any identified skeletal element, all the osteologist has to do is establish three axes in space: top to bottom, side to side, and front to back. Anatomical features of the bone will assist in this, thereby providing the clues necessary for correct identification and orientation.

A second tip for identifying skeletal remains involves hierarchies of decisions. Begin identifying a bone by deciding which elements it cannot be. For example, a radius fragment cannot be a cranial bone or tooth (which excludes hundreds of possibilities), a tibia or humerus (too small), a metatarsal (too big), or even a fibula (wrong shape). You will be surprised how soon you can exclude all but the correct choice if you approach identification in this way.

No matter how often you misidentify a bone or tooth, keep trying. Do not constantly use the articulated skeleton or intact skull as a crutch. There is great osteological truth to the idea that "with every mistake we must surely be learning." Try to learn from your mistakes. Try to identify the kinds of mistakes you are making. Are you most often misidentifying immature specimens? If so, set out a growth series for each skeletal element and see how the shape of the bone changes with growth. Are you having trouble with nonhuman skeletal parts? If so, look at a range of human variation to get a good idea of how much variation to expect. Are you simply confusing one part of the skeleton for another? If so, look at all the elements in the skeleton that might mimic each other when fragmentary and check the "Possible Confusion" sections in the descriptive chapters of this manual. Keep this manual nearby. It is much easier to carry than a skeleton, and the life-size photographs in many views should facilitate comparisons and identifications.

Chapter 2

Field Procedures for Skeletal Remains

Hundreds of studies about human osteology are published each year, ranging from initial announcements of fossil discoveries (White *et al*., 2003) to comprehensive treatments involving multiple populations (Larsen, 2001). All these studies begin with fieldwork. This chapter introduces procedures useful in recovering skeletal material. The chapter is organized in an approximately chronological manner. We first review aspects of discovery and techniques of retrieval and excavation. Then we discuss transport of skeletal material. Laboratory procedures and reporting are covered in Chapter 18.

In every aspect of osteological analysis—whether in the field or in the laboratory—common sense is critical. If there is any one overriding rule, it is to think before you act. There is no single formula, recipe, or procedure to apply in every field situation. There are simply too many different discovery contexts and too much preservational variation involving osteological remains. Cemetery excavation is different from isolated skeleton excavation, fossil bones are different from modern ones, forensic cases are different from archeological projects, and waterlogged burial conditions are different from mummified remains in the driest deserts. There are, however, some general principles that apply in most instances where skeletal remains are concerned.

In most forensic investigations involving osteological remains, there are official government protocols to be followed. For example, the Central Identification Laboratory Hawaii (U.S. Armed Forces; CILHI), the Armed Forces Medical Examiner (Armed Forces Institute of Pathology; AFIP), and the Federal Bureau of Investigation all have written guides for the handling of human remains. Often termed "SOPs," these are standard operating procedures that govern how osteological materials are treated by personnel. Usually these remains (often defined as human biological tissue) constitute evidence, and the purpose of many of the procedures is to ensure the integrity, maintenance, and security of that evidence. SOPs often include scene procedures, sampling procedures, laboratory procedures, reporting procedures, storage procedures, equipment procedures, and safety procedures. The osteologist should become familiar with these official protocols and procedures whenever involved in a forensic investigation. Skinner and colleagues (2003) provide very useful and comprehensive guidelines for osteological work in modern forensic settings, particularly those involving mass graves.

2.1 Search

Osteological remains may be discovered in forensic, archeological, or paleontological contexts either as a result of intentional professional or amateur survey or as a result of an accident. Intentional search methodologies vary widely, from paleontological expeditions to murder or disappearance investigations. Sometimes the search is large-scale, aimed at recovery of scattered hominid remains in large fossil fields. Other times, the search can be very localized, as in the charred rubble of the Branch Davidian Compound in Texas (Owsley *et al*., 1995), or on a larger scale, as in the search for military MIAs within decades-old craters created by high-speed military impact (Hoshower, 1998). The variety of remote-sensing applications to forensic investigations is reviewed by Davenport (2001) and Buck (2003), archeological survey methods are reviewed by Banning (2002), and Pearson (2001) gives a cross-cultural overview of the archeology of death and burial.

Sometimes remains from archeological or historical cemetery contexts may be brought to the attention of law enforcement agents or medical examiners as a result of vandalism or natural causes (Berryman *et al*., 1991). Other times, forensic osteologists are involved in the search for clandestine graves using methods ranging from aerial photographs to trained scent-detection dogs (France *et al*., 1992, Komar, 1999). Of course, not all searches result in discovery, and many a paleontologist returns empty-handed. Garrison (2003) provides a useful, broad overview of geoarcheological contexts in which virtually all osteological remains might be recovered, and Connor and Scott (2001), Haglund (2001), Crist (2001), and Owsley (2001) review the ways in which archeology can assist in forensic investigation. Steadman (2003) provides an overview of searching in forensic anthropology. Search methods will vary widely in osteology depending on the unique context of each case, but once discovery is made, a general series of steps is set in motion.

2.2 Discovery

Skeletal remains are often found by accident. For example, hikers and construction crews often find osteological material. When they do, they usually report it to local law-enforcement authorities. Because there are many more dog, horse, cow, and goat bones than human bones on the surface of most landscapes, these are often mistaken for human bones by laypersons and amateurs. A general rule for the practicing human osteologist is to assume that law-enforcement personnel who often first encounter such remains (including, in some cases, coroners) are not qualified to render accurate opinions on isolated, fragmentary skeletal remains. For example, pet rabbits that perished in trailer home fires have been identified by official coroners as human infants. Forensic human osteologists usually encounter situations in which morphological identification is easily accomplished (but see Ubelaker *et al*., 1991). However, a coordinated effort between physical anthropologists and law-enforcement specialists at a crime scene is absolutely essential for the recovery of all available clues (Wolf, 1986; Maples and Browning, 1994; Dirkmaat and Adovasio, 1997).

On being introduced to skeletal material, the human osteologist is faced with three critical questions:

- Is the material human?
- How many individuals are represented?
- Of what antiquity is the material?

Experience is the most valuable commodity in answering the first two questions. When in any doubt, consult comparative skeletal material or the illustrations in this manual.

The third question is usually more difficult to answer accurately, particularly if contextual information is not available. To give an accurate answer it is necessary to engage in a little detective work. The condition of bones themselves does not tell very much because the physical condition of the bones is largely controlled by the physical environment in which they were deposited. Bone weathering and deterioration are accelerated by direct sunlight, high heat, fluctuating temperature and humidity, biotic influences, and soil acidity. When these variables are held to a minimum, bone deterioration can progress very slowly. To assess the antiquity of skeletal remains (not individual age at death), it is necessary to give primary consideration to their context. Has the skeleton been recently disturbed? What kinds of artifacts appear with the remains? False teeth, dental fillings, coins, beads, pottery, coffin nails, and other evidence of material culture (if real association can be established with the skeletal remains) may be critical in determining the antiquity of the bones. Wear of the teeth can sometimes provide clues to the origin of the skeletal material; in many places, the teeth of recently dead individuals usually show far less wear than that seen under aboriginal conditions. Because contextual information is so critical to the accurate determination of the antiquity and origin of skeletal remains, the osteologist should always make every effort to visit the discovery site and make a firsthand assessment and record of the depositional history and associations of osteological material.

2.3 Excavation and Retrieval

Proper evaluation of any skeletal remains normally requires collection of the bones and subsequent laboratory analysis. Upon discovery, the osteologist's natural inclination (particularly when the remains were the object of a search and especially if they are hominid fossils) is to get the bones out—to collect them. This immediate separation of the specimen from its context is the worst strategy. The bones can no longer "walk away" on their own. Before disturbing the context, move away from the site and carefully develop a strategy for recording and recovery. If celebration of a paleontological discovery is called for, hold it off-site. Keep nonessential personnel off-site. On the site, it is advisable to show patience and restraint, while thoughtfully devising an appropriate strategy to extract the remains and all contextual information. Writing impressions down in the form of field notes is necessary and helps in this planning.

After the thrill and excitement of discovery have abated, it is time for serious, objective assessment of the situation. The following questions should be carefully considered:

- What are the political and legal constraints under which recovery must proceed? Goldstein (1995) provides an illuminating case study in this regard. Osteologists should confer with project management to ensure that all applicable laws are followed and all concerned parties are informed. In some archeological and some forensic investigation scenes, hazardous materials will play a role in conditioning how the excavation and retrieval proceeds.

- In what condition is the bone?
- What has happened to the bone as it has been exposed? How has natural or human-induced erosion uncovered and scattered the bone across the landscape?
- What contextual information is available?
- What options are there for recovering the bone? Consider the available time, labor, and equipment. As Hoshower (1998) notes, flexible excavation strategy is a key component of successful recovery.

Figures 2.1 through 2.12 illustrate some aspects of skeletal recovery in archeological situations. Mays (1998), Ubelaker (1989), and White and Folkens (2000) are sources of additional illustrations. Chapter 18 reviews special considerations involving preser-

Figure 2.1 A pioneer burial from near the historic Bordeaux Trading Post, southeastern Wyoming. The grave, which seemed to be associated with the trading post or the nearby Oregon Trail, was found in 1980 by a field archeology crew under the direction of George Gill. (*Left*) Oblique view of the grave, outlined by the perimeter of the darker in-filling soil. The right ulna is exposed near the upper end of the grave filling. Artifacts found with the skeleton include a wedding ring and adjacent black ring of mourning and three coins. (*Right*) The grave after excavation (from Gill *et al.*, 1984). Seen in this photograph are the remains of boots and a wide-brimmed black hat over the face. A displaced fragment of right radius is pedestaled next to the right patella.

Figure 2.2 Frontal view of the frontiersman's skull excavated from the grave shown in Figure 2.1. Note the cranial gunshot wound caused by a .44- or 45-caliber weapon. A second perimortem gunshot wound to the hip and at least three healing rib fractures were noted by the investigators. This individual, a male who probably lost his wife prior to his own death (indicated by the black ring next to the wedding band), most likely was shot in 1869 or 1870 (from Gill *et al*., 1984).

vatives, biomolecular sampling, and precautions.

The following general steps should be taken in the recovery of skeletal material:

- If skeletal parts have been scattered by erosion, mark each with a pin flag and assess the distribution to predict where more pieces might be found.
- The overriding concern in all work subsequent to the discovery of the specimen, in the field or the laboratory, is to allow no further damage to occur. Excavation and extraction damage to osteological remains is common but unnecessary. Steps should be taken to consolidate fragile bone ***in situ*** (in place) with preservatives, if practical.
- Lose as little information as possible, especially concerning **context**. The remains, whether in a forensic or an archeological context, are one-of-a-kind. They are nonrenewable resources. There is only one such bone, individual, burial, or cemetery, which means that there is only one chance to extract the remains completely and correctly. Actions taken during recovery have consequences that long outlive any investigator, rendering the osteologist's responsibility a weighty one.
- Obtain proper equipment for recovery. Table 2.1 is a supply and equipment checklist that osteologists may find useful to consult before heading into the field. Provided that the bones and their context are not immediately jeopardized, recovery should be delayed until the proper tools are available. Use your judgement on how precarious the situation is.
- Before disturbing the scene make written and photographic records of everything important. Never rely on memory. It is often useful to establish a datum point

Table 2.1 Equipment and Supplies for Osteological Fieldwork

TEAM EQUIPMENT	TEAM SUPPLIES
Compass	Film and protective film bags
Tape measures	Compact flash cards (digital media)
Hammers (carpenter's and geological)	Video tapes
Nails or stakes	Audio tapes
Twine (yellow or white)	Glue
Line levels	Tape (masking, gaffer's, transparent)
Shovels and picks, axes and saws	Pin Flags
Trowels, buckets	Preservative
Digging probes (dental and bamboo)	Solvent for preservative
Brushes (various sizes and stiffnesses)	Packing material
Screens	Containers (boxes, bags, vials)
Metal detector (forensic cases)	Aluminum foil
Step ladder	Tissue paper
Camera tripod	Newspaper for wrapping
Cameras (video, digital, Polaroid®, film)	Notebooks
Camera flash attachment and cable release	Writing utensils (waterproof writing utensils)
Photo scale, 18% gray card, directional arrow	Labeling pens and ink
Photo information board (dry erase board)	Batteries (flashlight and camera)
Pliers, wrenches, cutters, files	Wire
Ropes, tarpaulins, field umbrellas	Jacketing supplies
Aerial photographs, stereo photo viewer	Plaster
Travel and excavation permits	Gauze
Tape recorder	Water
Portable tables and chairs	Acetate sheets
Bush clippers	Nail polish
Global positioning instrument	Syringes
Laptop computer(s)	

PERSONAL EQUIPMENT	PERSONAL SUPPLIES
Digging instruments	Money
Pocket knife, scissors	Writing utensils, notebook, calculator
Radio	Lens cleaning fluid and papers
Hand lens	Film
Flashlight, extra bulbs and batteries	Institutional letterhead and envelopes
Camera, film, batteries, flash, lenses	Gaffer's tape
Measuring tape, calipers	Medicines, water purifier
Photo background, cable release, scale, strap	Plastic bags
Small photo mirrors	Permanent ink
Travel documents (passport, tickets, health certificate, insurance forms, permission letters)	Marking pens
Hat and bandanas, gloves	Rubber bands, paper clips
Tent	Toiletries
Sunshower, towel	Soap and shampoo
Plate, cup, utensils, canteen	Toothbrush and paste
Sleeping bag and pad	Sunscreen, lip balm
Needle and thread	Insect repellent
Small preparation kit	
Sunglasses, extra glasses or lenses	

Figure 2.3 Prehistoric archeological site in northern California, before and after excavation. (*Top*) The outlines and darker infillings of circular grave pits can be seen on the floor of the excavation trench. The scales are in inches. (*Left*) Flexed burials were revealed within the slightly superimposed grave pits of burial 2. Here, the two individuals in this burial are shown, both flexed. The same large stone appears in the lower left corners of the two photographs.

Figure 2.4 Flexed burial of an adult accompanied by grave goods. Shell beads adhere to the cranium, stones are in the mouth, and other beads and pendants are seen around the postcranial skeleton. Prehistoric, northern California. The scale is in inches.

on the site to control a grid laid out with stakes and cord across the surface. All recovered objects can be related to the grid. Wolf's (1986) advice on approaching a crime scene with scattered material as if you were clearing a minefield is appropriate in this regard. In the past, a Polaroid® camera and 35-mm black-and-white film were practical and common solutions. However, digital imaging has largely replaced film in such situations (see Section 18.9). Whether using film or digital photography, or tape or digital recording, always create a backup in case of equipment failure or operator mistake. A scale and directional arrow should be included in all drawings and photographs. Subsequent stages of the excavation should be photographed from as many angles as appropriate. Remove all tools, obscuring roots, and lumps of earth before photographing. If lighting is a problem, particularly in an excavation, use a white sheet or aluminum foil on cardboard, or a flash attachment, to illuminate the specimen. The key to successful photography is the control of light. If a specimen is of critical importance, it is good to make a video record of it for teaching, lecturing, curatorial, and forensic purposes.

- Begin preservation measures if necessary (for hardeners and other preservatives, see Chapter 18).

Figure 2.5 Prehistoric cremation exposed by an archeological excavation. Associated with the cremation are obsidian artifacts. The cremated bone fragments are seen in the area above the LAS. 7 indicator. Prehistoric, northern California. The scale is in inches.

- Collect all bone exposed on the surface, even fragments that do not seem to be hominid. Remove your shoes if necessary and get down on your belly for a close look. Make sure the light is adequate before doing this. It is to your advantage that rains have washed the bone surface clean; as you disturb the soil it becomes more difficult to recognize small bone fragments. Move slowly and carefully, not trampling remains or artifacts underfoot.
- Screen earth from the abdominal region of all skeletons to recover dietary or fetal skeletal remains. Screen all of the loose surface earth left over from each skeleton. A 1.0-mm mesh size (window screen) will recover most important fragments. Water wash excavated material through a screen to make the small fragments more visible and easy to recover.
- For burials, or other articulated *in situ* material, expose the bones one at a time. In an archeological context it is important to recognize that there is a very large culturally determined and ethnographically observed range of variation in human mortuary practice. For most applications, however, there are some general kinds of burials to which the osteologist should be alert: A **primary interment** is a burial in which all of the bones are in an anatomically "natural" arrangement. Such burials are sometimes classified according to whether the extremities are extended or flexed. There are no neat categorizations here, and one photograph is

worth many words of description. A **secondary interment** is a burial in which the bones of a skeleton are not in a "natural" anatomical relationship but have been gathered together some time after complete or partial disarticulation of the skeleton and then buried. Sometimes this burial comprises a bundle of bones. A **multiple interment** is a burial in which more than one individual is present. These burials include ossuaries, burial urns containing more than one individual, and a variety of other possibilities. **Cremation** is a mortuary practice involving the intentional burning of the body. Cremations can often be informative—the less efficient the fire, the more informative the specimen. Micozzi (1991) reviews mortuary practices worldwide.

- In exposing burials, use appropriate tools and use them carefully. Dental picks are sharp and efficient, but they can easily damage the bone. Wooden or bamboo tools may sometimes be suitable, and a range of brushes of various sizes and stiffness is indispensable. Work from the rib cage outward where possible. Do not use the trowel in a sweeping motion unless you are doing exploratory work. Try to leave bones supported as you clean, exposing the foot and hand bones last. Watch for soil color and texture changes, rodent and root disturbance, mat impressions, rotted vegetation, wood, insect remains, charcoal, and associated artifacts such as lip plugs or beads. Be alert to all soft tissue that might remain, including hair, skin, fingerprints, and ligaments. Write orotherwise record your notes; memory will not suffice. Record angles of flexion, the orientation of the body and head, the depth of the bones from the surface or the datum, and any other contextual details. Take soil samples where appropriate. Remember that all details of context should be retained in an archeological or forensic excavation. In archeological situations, context often yields the greatest amount of behavioral information. Excavation of a site destroys it, and contextual data left unrecorded are lost forever.

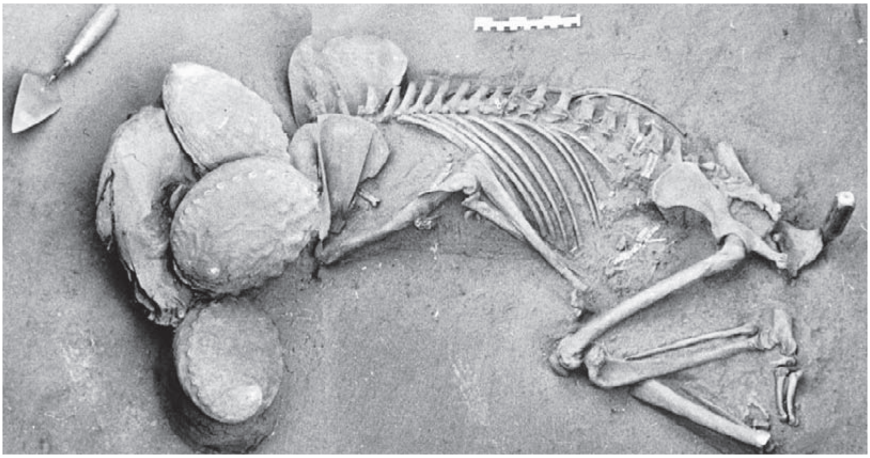


Figure 2.6 Ceremonial bear burial. Three large abalone shells cover the skull of the bear. Because the bones of large mammals were usually exploited for their nutritive value, large mammal bones from archeological refuse deposits are usually very fragmentary; this case is an obvious exception. Prehistoric, northern California.

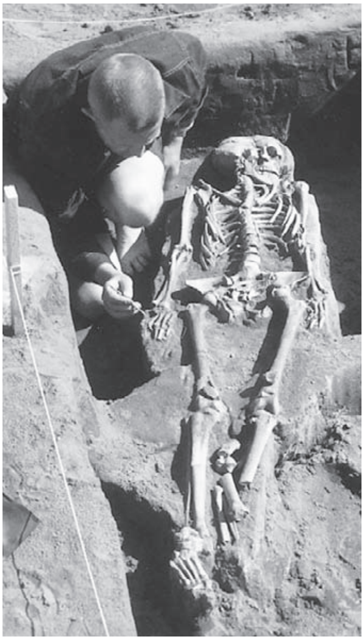


Figure 2.7 and 2.8 An extended burial from the prehistoric Libben site in Ohio. The excavator (*left*), having cleared the central part of this burial, carefully exposes the hand phalanges with a dental probe. After full recording, the archeologist (*above*) carefully removes the ulna and humerus. The ribs have been exposed for photographic recording and drawing, but they were not endangered by undercutting during excavation.

- Samples for biochemical analyses and histology (see Chapter 18) should be taken at the earliest time, with clean tools and gloves, in sterile containers, to avoid contamination. See Nielsen-Marsh *et al.* (2000) for a review of how bone degrades chemically.

The actual removal of the bones themselves is one of the last steps of recovery, after exposure, photography, and drawing. To aid in their hardening, let the exposed bones dry completely in an area shaded from the sun. Free each bone gently—do not use force. Earth (matrix) may be left on the thin parts (scapula, pelvis) to avoid damage during transport. Do not attempt fine cleaning in the field; this should be performed in situations where light, tools, water, comfort, advice, comparative material, and time are in greater supply—in other words, in the laboratory. Take each bone out individually and label as you go along, particularly the ribs and vertebrae. Keep right and left hands, feet, and rib bones in separate containers. Keep unfused epiphyses with their associated bones. Be observant as you remove the elements, watching for fetal bones, sesamoids, kidney and gall bladder stones, and small artifacts. Save everything, even if you think that it might not be human. It is easier to do accurate identification in the laboratory. Do not disregard immature skeletal parts or disturbed burials; such disregard will skew the cemetery representations and ultimately have an adverse effect on any demographic reconstruction.

After removal, if the bone is still wet, let it dry completely in the shade. Never mix the specimens during washing or packing at the site. Screen all earth that remains at the spot of the burial, watching for beads, teeth, and other items that may have been missed as the larger bones were removed.

Decisions about washing of material at the recovery site are best left to the judgement of the investigator. As Brothwell (1981) notes, there is generally no problem in deciding about bone strength; bones are not generally deceptive in this regard. It is usually evident during recovery whether they are likely to disintegrate when handled. If water is available and the bone is well preserved, it may be convenient to wash parts of each skeleton in the field camp. It is often best to remove the earth from the cranial cavity and orbits while the soil is still damp. Do not try to reconstruct bones in the field—just keep them together.

Decisions about the application of preservatives (Section 18.2) must be made during exposure, and this application will often be necessary before removal is possible.

Aluminum foil is an inexpensive but very effective material that can be used to stabilize, protect, and keep bones and their parts in place during lifting and transport. Press the foil firmly around all the bone and matrix irregularities.

Some investigators use burial recording forms. These can be useful, provided that caution is used in determining sex, age, and other features often prompted by such forms. Be sure to mark these determinations of identity as preliminary when they are made under field conditions.

Figure 2.9 Mass grave at the prehistoric Libben site containing the skeletal remains of four children and an adult. The legs and feet of a later extended adult burial protrude into the excavation from the bottom of the photograph. Such superimposition of different burial events is commonly encountered in aboriginal cemeteries, usually because graves were not marked with permanent surface monuments.

Figure 2.10 Extended burial of an immature individual from the prehistoric Libben site. Great care must be taken with such young individuals to recover the many unfused bones.

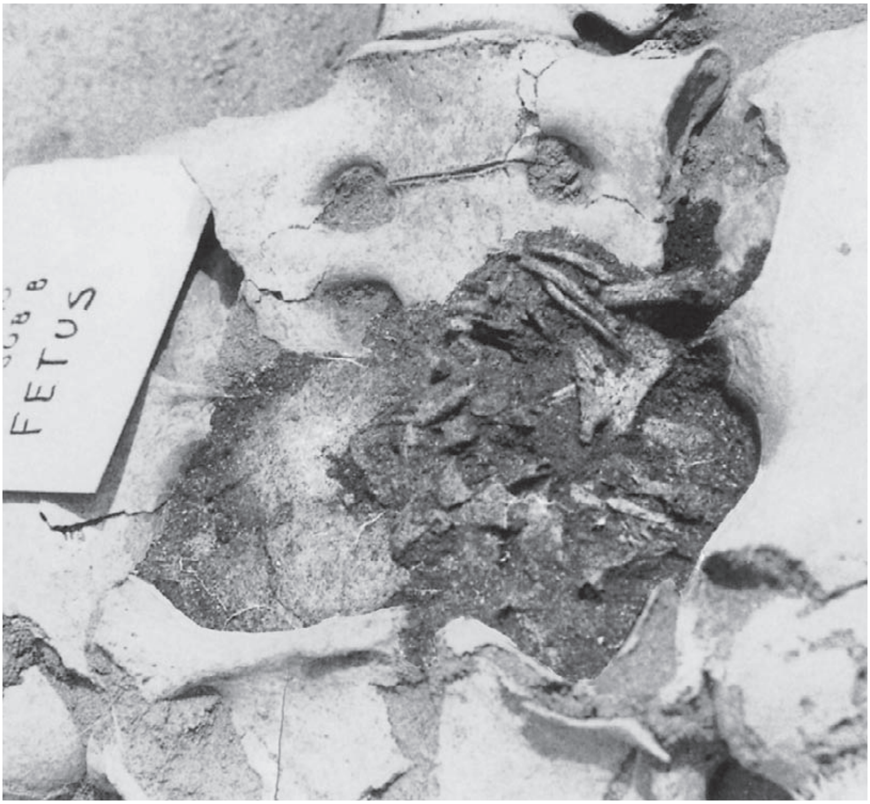


Figure 2.11 Bones of a fetus were found within the pelvic cavity of this female skeleton from the prehistoric Libben site. The humerus, ribs, and scapula of the fetus are just anterior to the sacroiliac articulation.

2.4 Transport

When exposure, photography, and drawing are complete, the skeletal remains can be removed from the archeological context. In the forensic context the decision to remove is made by the chief of the crime scene. This begins a "chain of custody" in which the osteologist must participate and document in writing (Melbye and Jimenez, 1997). If the bone is well-preserved, the elements can be lifted individually. Once bones have been extracted and field-cleaned, they are ready for packing and transport to the laboratory. Available vehicles and packing materials for transport vary greatly. Transport thus depends on what is available. However, under all conditions, one primary rule should always be observed: Do not let any more damage, contamination, or mixing occur.

Occasionally it is necessary to remove the burial or its parts as a unit, in a supporting block of matrix, for study or display. To remove an entire burial, employ the paleontological technique of jacketing. To do this, first isolate the specimen on a pedestal of earth. Cover it with several layers of wet tissue paper where the bone is exposed. Next, use burlap bandages soaked in plaster to form a cast or jacket around the specimen. Reinforce this jacket as necessary with strengthening rods of metal or wood. After the plaster has hardened, undercut the specimen and lift it out. This is an expensive operation in terms of material, time, and personnel. It requires experience and should be used only when necessary.

Once the burial has been removed, washed, and dried, the hands, feet, and ribs should be bagged by side and the vertebrae by type. Labeling these elements at the time of removal greatly facilitates later sorting in the laboratory. Fine cleaning and gluing should be left for the laboratory. Label all bags and boxes used for collection with waterproof ink. Paper bags are prone to deterioration if used for long-term storage, but they breathe moisture and are therefore better than plastic bags for post-excavation sorting and transport of skeletal material that retain residual moisture. In transport, keep the bones away from water. It is very important to carefully label and maintain organization when the bones are extracted from their context and moved to the laboratory.

When packing bones, pack tightly with lots of padding (plastic bags or newspaper) to avoid movement in the container. Pack heavier, denser bones at the bottom of containers and the more fragile bones such as scapula, pelvis, and crania at the top. Be sure that all bones stay in their assigned containers during the jostling that inevitably accompanies transport. Be particularly careful with the cranium, whose face is fragile. The cranium and mandible should each be packed separately, and care should be taken to ensure that teeth do not dislodge from their sockets during transport.

Figure 2.12 This fetal skeletal material from the prehistoric Libben site represents one of the smallest burials ever recovered. Good preservation combined with great concern for detail during excavation made the skeletal collection from this archeological site one of the best available for the study of prehistoric demography (see Chapter 19). Natural size.

Chapter 3

Ethics in Osteology

Ethics is the study of standards of conduct and moral judgment. Ethics can be seen as a system of values that specify a code of conduct. There are multiple value systems, each with definitions of what is considered right and wrong. These definitions are cultural, so what might be ethical for one scientist, for example, might be unethical for a religious leader. Different ethical systems collide across the spectrum of osteological endeavors—from the forensic, to the archeological, to the paleontological. Excellent historical perspectives on the subject of ethics in human osteology are provided by Walker (2000) and Ubelaker (2000).

Professionals who study human skeletal remains are frequently called on to make ethical judgements. This chapter examines some of the ethical standards peculiar to osteology and universally practiced by osteologists. For some osteological issues there are no easy answers and no prescribed codes of conduct to guide the practitioner (Figure 3.1).

Human osteologists are routinely called on to practice in the glare of the media spotlight and within legal, political, social, and economic arenas where science may be misconstrued and misrepresented. Whether the issue is the number of perished individuals in the Branch Davidian compound at Waco (Owsley *et al*., 1995), the nature of trauma to the soldiers who died with Custer at the Little Big Horn (Scott *et al*., 2002), or the affinities of an individual who died thousands of years ago at Kennewick (Morell, 1998), the human osteologist is obliged to be guided by facts and the scientific approach rather than by speculation, superstition, economics, preconception, or political expediency.

3.1 Ethics in Forensic Osteology

Human skeletal remains often figure prominently in legal matters. Osteologists are routinely asked to identify skeletal remains—to determine whether they are human and, if they are, to determine the age, sex, identity, and antiquity of the remains. Information is provided on how these determinations may be made for bony remains in Chapter 19. Sometimes the osteologist is asked by law-enforcement representatives to make identifications, a report is filed (see Chapter 18), and the matter ends there. On occasion, however, the osteologist becomes more deeply enmeshed in the legal system.

In many countries, law is practiced in an adversarial system in which prosecuting and defense attorneys and their teams square off in courts of law. There are often seri-

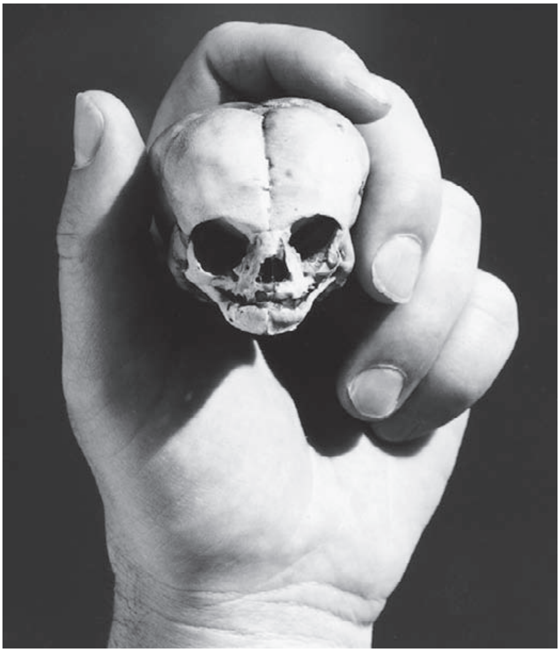


Figure 3.1 **A human fetal skull.** Is it right or wrong for this unborn individual's remains to be curated in a museum? Different people give different answers to this question depending on what ethical perspective they bring to the issue.

ous questions of criminality or inheritance involving identification of the deceased. The stakes may be high. In such legal affairs, osteologists may be retained for their expertise and testimony by either side. For these and other reasons, the American Academy of Forensic Sciences has formally incorporated physical anthropology as one of its disciplines.

3.1.1 Boundaries of Evidence

In all osteological work, but particularly in forensic osteology, it is important for the analyst to keep two things clearly in mind at all times. First, any conclusion drawn in an osteological report must be defensible. In other words, the osteologist must prepare for a challenge by employing the most sound and up-to-date analytical methods available. Second, the osteologist should always avoid stepping beyond the boundaries set by the osteological evidence itself. In other words, he or she is an expert in osteology and not necessarily an expert in criminalistics, pathology, toxicology, engineering, or detective work.

The forensic osteologist must always report and testify within the bounds of the bony evidence and according to the principles of the scientific discipline that he or she represents. The osteologist should explicitly draw the attention of all concerned parties to limitations of the evidence itself and to uncertainties associated with the identifications that have been performed.

One example suffices to show the tragic toll that can be taken by a failure to observe these basic rules. The Vietnam War and associated conflict in Southeast Asia resulted in the deaths of hundreds of thousands of people, among whom were American military personnel. The Americans who never returned, and whose bodies were not accounted for, were listed as MIA (missing in action). Thirteen men aboard an American AC-130 gunship shot down over Laos in 1972 were counted among the MIAs. Over ten years later an excavation at the crash site recovered 50,000 pieces of bone; the largest bone was 13 cm long, and most fragments had a maximum dimension of around 1 cm. After analysis by the U.S. Army, it was announced that positive identifications had been made on anatomy alone, and that all thirteen men had been accounted for by these bone fragments. The skeletal remains were then forwarded to the families for burial. Relatives of the crew members pressed the issue of identification, and an independent investigation of these bones was made. It became clear that the analysis, although done by professional osteologists, had made conclusions about age, sex, race, and individuation that went far beyond the evidence (Getlin, 1986).

Science, fortunately, is self-correcting. In cases like this one the evidence can be examined by several investigators and faulty analysis is thereby exposed. In the meantime, however, the lives of many people can be deeply affected by the conclusions of the osteologist, who clearly has a responsibility to respect the limits of the hard evidence.

3.1.2 The Expert Witness

Witnesses in court proceedings are sworn to tell the truth, the whole truth, and nothing but the truth. The expert witness in forensic osteology must also, of course, adhere to these rules. See Kogan (1978), Stewart (1979), Feder (1991), and Steadman (2003; Section I, Personal Identification and Legal Considerations of Forensic Anthropology Casework in the United States) for further details on expert testimony, and Haack (2003) for an overview of science in the courts. Testimony by expert witness scientists is on the increase in courts of law throughout the world, although different judicial systems handle experts in different ways. For example, in Germany the expert witness is called by the court, whereas in the United States experts are often retained by lawyers on either side of a case. Testimony by scientists may have dramatic impact on the outcome of a judicial proceeding, particularly when the testimony is seen as ethical and articulate and comes from a person expert in his or her discipline. Hollien (1990) observes that several major problems surround scientists serving as expert witnesses. Among the most important are the lack of training of most scientists for the courtroom setting, the great variance in the qualifications of "experts" admitted into the courtroom, and the pressures upon the scientist, both overt and subtle, to adopt an advocacy position for the side paying the bills.

For individual osteological expert witnesses who are ethical, well-trained, experienced, and who stay within the boundaries imposed by the evidence, any of these problems are insignificant. Unfortunately, history has shown that not all experts have demonstrated these attributes. Courts have different standards for admitting scientific evidence. State and U.S. courts traditionally followed the "Frye rule," named after a landmark 1923 decision. This held that expert testimony must be based on a well-recognized scientific principle or discovery that is "sufficiently established to have gained general acceptance in the particular field in which it belongs." The general acceptance test is only one of several questions that can help the court in evaluating expert testimony. The 1993 Daubert U.S. Supreme Court decision suggests that other factors to consider are whether a method or technique can be (and has been) tested, whether it has been subjected to peer review and publication, and what the error rates are.

The late American physical anthropologist and "expert witness" Dr. Louise Robbins (Hansen, 1993) may serve as an example. Robbins was a self-appointed expert in footprint identification who testified at numerous trials about her abilities to individuate people based on impressions left by their shoes, socks, or bare feet. She claimed that her techniques allowed her to tell whether a person made a particular print by examining any other shoes belonging to that individual. She stated that footprints were better indicators for identifying people than fingerprints. Other expert witnesses testified on her behalf, and against her, during a forensic career that spanned a decade and saw many convictions. Only years later, after her death, were her techniques and conclusions exposed. Physical anthropologist Owen Lovejoy of Kent State University noted, "She may well have believed what she was saying, but the scientific basis of her conclusions was completely fraudulent" (p. 66 in Hansen, 1993).

To her own eyes, and to the eyes of the attorneys who retained her, Dr. Robbins was acting in a professional and ethical manner. In the eyes of other scientists, she was unethical. In the end, her conclusions were shown to be unreliable, but years of litigation were involved, and years of incarceration resulted from convictions aided by her interpretations.

Forensic experts often disagree, and not always because one of them is unethical or untrained. Nordby (1992, p. 1116) asks, "How can we understand the grounds for genuine disagreement between two honest, qualified forensic experts?" He argues that we must distinguish between seeing and observing. We all see, but we observe different things based on the contexts of our knowledge, beliefs, values, and goals. Nordby argues convincingly that it is the role of the expert witness to refine the context of observation based on expert understanding, always examining hidden observational expectations that may influence supplied interpretations. The expert must always be self-critical and always ready to defend what may turn out to be the only supportable conclusion —the conclusion of "I don't know." The expert supplies good reasons to support that opinion. Nordby (p. 1124) concludes: "Both knowing and not knowing are informed positions reached by careful application of scientifically defensible methods. When the results of those methods do not allow us to rationally prefer one conclusion over an alternative, we must settle for knowing *why* we do not know."

3.2 Ethics in Archeological Osteology

There is a stark contrast between the widely accepted and easily delineated ethical and legal guidelines for the osteologist working in a forensic setting and the ambiguities of ethics and law that haunt the osteologist working in an archeological setting. Evidence, logic, reason, and the scientific method are all held in high esteem in the forensic realm. When claims of entitlement enter the legal system, for example, there is rarely an attempt to "balance" scientific and spiritual evidence—the former takes precedence. This was traditionally the case in the realm of scientific archeology. Now, however, the situation involving bones from archeological contexts throughout the world has become complex, fluid, ambiguous, politicized, and confusing due to the promulgation of laws that aim to redress what are seen as religious injustices undertaken in the name of science. It is necessary to examine the causes for this situation and to consider some of its implications for osteological research involving human remains.

3.2.1 Ethics in Collision

Research in human osteology necessarily involves the study of hard tissues that represent people. A variety of living people have objected to osteological excavation and research. Anatomical study of the deceased has been controversial from its very inception. Early anatomists were forced to retrieve and dissect their cadavers in secrecy. Today, as every first-year medical student knows, remains of the dead are vital resources for teaching the living. So it is in osteology.

Death has a high emotional value, as indicated by the fact that both modern and prehistoric humans have developed a wide range of customs and rituals for dealing with it—customs and rituals that change through time. Archeologists and physical anthropologists have learned, and continue to learn, about past human mortuary practices by excavating skeletal remains. As outlined elsewhere in this book, careful analysis of the bones themselves has led to insights into the diet, living conditions, population structure, genetic relationships, health, and evolution of hominids in both the recent and remote past. The emotive value of death has combined with the information content of human bones to form a combustible mix in the modern world. The debate over human skeletal remains poses ethical dilemmas for practicing osteologists and archeologists.

In North America and Australia, large populations of indigenous people met European explorers several hundred years ago. Subsequent to this contact both continents saw the decline and sometimes the extinction of native peoples and their cultural heritage as European colonization proceeded. Native Australian and American survivors of these invasions suffered and continue to suffer great injustices. A callous disregard for surviving native people has sometimes been demonstrated by developers, museologists, governments, and anthropologists in the recovery and disposition of aboriginal skeletal remains. A double standard has sometimes been applied in the disturbance and subsequent treatment and disposition of European versus indigenous skeletal remains (McGuire, 1989; Hubert, 1989).

In Israel, ultraorthodox Jews have sought to restrict archeological research. In New York, African-Americans have insisted that skeletal remains of slaves only be studied by African-American osteologists. Archeological excavation and analysis of skeletal remains have been seriously curtailed and even stopped at the insistence of some native North American and Australian groups who have used the issue as a forum from which to express their grievances. The question of excavation and post-excavation handling and disposition of osteological remains has rapidly gathered considerable symbolic importance to many people. In some regions, research into prehistory has suffered setbacks, with excavations being halted while cultural and skeletal material is reburied. There is no better way to illustrate and explore the ethical issues of excavation, analysis, and reburial of human skeletal remains than to present a case history (for additional views, see Meighan, 1992; Klesert and Powell, 1993; Goldstein and Kintigh, 1990; Jones and Harris, 1998; Webb, 1987; Williams, 2001; and Zimmerman, 1987a, b, 1989, 1997).

Just over six hundred years ago, long before Columbus explored the "New World," a fortified village site at Crow Creek, on what is now the Sioux Indian Reservation in South Dakota, was inhabited by nearly one thousand Native Americans. This prehistoric, probably Arikara, village was attacked and nearly five hundred of the inhabitants killed. Although there is no historic record of this event, human skeletal remains documenting the massacre were discovered eroding out of the site in 1978 (Figure 3.2) (Willey and Emerson, 1993). An agreement was reached among the Sioux (Lakota, Dakota, and Nakota Tribes on whose land the site was located), the U.S. Army Corps of Engineers, and the project archeologists.

Analysis of the huge skeletal sample excavated at Crow Creek was limited by the amount of time available before it was placed in gold-painted, concrete coffins and reburied. The alternative to study and reburial was no excavation at all. The project osteologist, P. Willey of the University of Tennessee, summarized the situation as follows:

> Only five months were permitted for the analysis, and I and the other physical anthropologists did as complete a job as we could. As the analysis proceeded, however, research questions came up which we could not pursue answers to within the period of time designated . . . Indians living today stand to benefit from our conclusions. Additional study of the remains might aid Native Americans further. Examples of the applications of our analyses include determinations of biological relationships which support Indian land claims and understandings of prehistoric disease which could alleviate suffering among present-day Native Americans. If our studies of disease could result in understandings which saved just one child's life, then surely retaining skeletons for complete study is warranted. When we

Figure 3.2 The Crow Creek massacre bone bed.

> all stand to benefit, the interests of one ethnic group should not be permitted to stand in the way. We must be able to do the most complete and comprehensive study of all human skeletons of all human groups.
> (Willey, 1981, p. 26)

The issue of excavation, analysis, and reburial stands out clearly at Crow Creek, but it goes far beyond this one occurrence. Some Native Americans have claimed that all archeological research is racist and in violation of the sacred nature of prehistoric sites. Some archeologists have responded by reburying excavated remains, or not excavating at all, as a means of lessening tensions or securing contracts. Several archeologists and physical anthropologists have gone so far as to sign binding legal agreements to rebury any bone material (including nonhuman bone) on the spot without analysis, to bury all photographs and negatives made during the research, and to rebury any artifacts found in the vicinity of the skeletal remains. Skeletal samples have been taken from museum collections and reburied, a phenomenon some physical anthropologists have likened to the destruction of single-copy manuscripts.

The American Committee for Preservation of Archeological Collections considers the maintenance of archeological collections, including skeletal remains, to be part of the professional and ethical duty of scholars in archeology. This group urges archeologists to abstain from participation in any field project, contract, or other program in which collections obtained from research will be given up for destruction. They recommend that scholarly organizations in archeology treat knowing acts of destruction of archeological materials, or complicity in such acts, as grounds for expulsion from the profession of archeology.

Many physical anthropologists have actively opposed efforts to rebury skeletal material, probably because these scientists are most aware of the potential information in these remains and are most sensitive to how this information is lost through reburial. Jane Buikstra, a physical anthropologist, has addressed several misconceptions that have characterized the issue (Buikstra, 1981a, 1983). White archeologists have been accused of "never digging up their own ancestors," in effect practicing a kind of archeological apartheid. As Buikstra notes, the fact that a mostly white set of professional archeologists study a set of mostly aboriginal bones in North America and Australia is not a manifestation of racism. From the excavation of remains of white frontiersmen in Wyoming (Gill *et al.*, 1984; see Chapter 2) to analysis of remains from 17th- and 18th-century graves of European whalers on Spitsbergen (Maat, 1981, 1987), archeologists and physical anthropologists routinely work on skeletal remains associated with recent Western culture. In fact, the largest and best-studied skeletal series in use by physical anthropologists is composed of mostly white and black individuals from medical school dissections at Case Western Reserve University. Many of these skeletons come from known, named, specific individuals whose religion is often recorded. Furthermore, some of the skeletal sexing and aging techniques used most widely by osteologists were developed, in part, from analysis of the remains of white Americans killed in the Korean War (see Chapter 19). The misconception that continued curation of remains does not help living people has been addressed repeatedly. For example, Ubelaker's (1990) success in positively identifying Native American murder victims from the Pine Ridge Reservation was a direct result of his use of comparative collections of Native Americans.

3.2.2 NAGPRA and Its Effects

In North America, some Native Americans argued during the 1970s and 1980s that because some contemporary Indian people have descendant relationships to some skeletal remains housed in museum collections, the disposition of these remains should be controlled exclusively by modern Native Americans. Numerous state laws addressed the issue, and on November 16, 1990, President Bush approved Public Law 101–601, the Native American Graves Protection and Repatriation Act (NAGPRA), an act of Congress that directed all museums and laboratories within the United States (which receive federal funding) to inventory all human remains and associated funerary items, to determine which among them can be linked ancestrally to existing federally recognized tribes, to consult with those affected tribes, and to follow the wishes of the tribes regarding those collections. Contrary to popular assumption, NAGPRA does not require reburial but rather gives control over the final disposition of remains to the most appropriate, federally recognized Native American or Hawaiian claimant. Groups are free to choose long-term curation, and the law attempted to set up a process of consultation whereupon this option might be considered, among others.

The NAGPRA legislation came at a time when large numbers of American anthropologists were questioning the rationalist and empiricist roots of their discipline. As Zimmerman (1994, p. 65) notes, "Part of the rift between archeologists and Native Americans stems from a fundamentally different conception of the past. To Native Americans, the idea that discovery is the only way to know the past is absurd." Many anthropologists are sympathetic to the more "spiritually oriented," culturally relativist, antiscientific viewpoint. Indeed, some anthropologists are sympathetic to the notion that there is no objective reality at all. The NAGPRA statute is based on something known as "cultural affiliation." The law instructs institutions and potential claimants for "repatriation" to assess "cultural affiliation" by a "preponderance of the evidence," evidence that includes everything from biology to geography to folklore and oral tradition. How are these weighed? Remains may only be returned after such "cultural affiliation" is established. Thus, the NAGPRA legislation has opened institutional skeletal collections up to potential claims by individuals who feel spiritual connections to the remains in question.

The debate concerning excavation, study, and reburial of human skeletal remains will continue to be heard in the courts, as was the Kennewick case (Gould, 2004). One hopes that the ethical concerns of all the various sides to the debate are reflected in the laws that will continue to be written and tested in such settings. Communication, however, is most effective outside the legal system. Professional archeologists and osteologists bear a great responsibility in education. All groups involved in the debate should be engaged in an ongoing dialogue, people talking with each other instead of past each other. These issues will only be defused through public education and through the long-overdue graduate-level education of Native Americans and Aboriginal Australians in physical anthropology.

3.2.3 The Future

Any group of people, from the smallest family to the human species, is best equipped to deal with its present and future when it most fully understands and appreciates its heritage. Prehistoric research, including osteological study, is one way that heritage can be fully revealed. The great tragedy in the debate over skeletal remains from archeological contexts is that the issue has sometimes pitted archeologists against descendants and relatives of the people they wish to study. This has occurred at a time when the very archeological resources in North America and Australia (which both parties seek to preserve) are disappearing at an unprecedented rate at the hands of the developer and the looter (Figure 3.3). In the face of this catastrophic and irreversible destruction of the past's only record, the reburial issue constitutes a costly diversion for all parties. The scientific community and native groups need to redirect their energies in a concerted effort to save and protect the heritage of the past before it disappears.

What is true for upper Pleistocene and Holocene osteological remains is also true for hominid fossils. In many parts of the world where the most important hominid fossils are being found, the academic and scientific infrastructures remain little developed. As a result, fossils have often been exported to the nations that had "colonized" these lands, to be studied by foreign experts, and often displayed and curated indefinitely in foreign museums and universities. The demise of colonial rule across Africa and Asia ended this situation, but attention to the development of facilities and personnel to support ongoing human paleontological research in these areas was slow in coming. Today, particularly in Africa, a first generation of scholars is taking important

Figure 3.3 (*above* and *following page*) Vandalism of osteological remains in an archeological context. Evidence of looting is seen in these two photographs taken at the site of Nuvakwewtaqa, a large (1000+ room) pueblo in central Arizona occupied between AD 1280 and 1425. Vandals have haphazardly discarded the human skeletal remains encountered in their search for grave goods, damaging the bones and forever losing their context. The nonrenewable archeological record is rapidly disappearing due to such plunder. Photos courtesy of Peter Pilles and the Coconino National Forest.

Figure 3.3 (*continued*)

steps toward developing the necessary platform from which to conduct world-class research into human paleontology. There are continued instances of exploitative relationships and hit-and-run fossil hunting by foreigners from the developed world, but there are also several models of international collaboration between local and foreign scholars, in both Africa and Asia.

It is essential for osteologists interested in conducting laboratory and field research in foreign countries to make early and open contact with the governmental administrators and local scholars in any country in which they intend to work. Research must go hand-in-hand with development in these situations, ensuring meaningful, uninterrupted progress and productive science.

Chapter 4

Bone Biology & Variation

Bone as a connective tissue and bones as elements may be studied on several hierarchical levels. Information derived from many skeletons may be used in reconstructing **population biology** (Chapter 19). Study of the various elements of a single skeleton may be used to elucidate the biological aspects of an individual (Chapters 17 and 19). Such assessments are built on a foundation that emphasizes the identification of the bony **elements** that constitute each human skeleton (Chapters 7–16). Before embarking on a systematic consideration of human skeletal elements, it is useful to consider bone biology. This chapter should therefore be considered an essential stepping stone to the descriptive and interpretive chapters to follow.

It is important to note the multiple functions of bone as a tissue and of bones as organs. Bones act as essential mechanical components of the **musculoskeletal system**. They serve to protect and support soft tissues; to anchor muscles, tendons, and ligaments; and as the rigid levers that muscles operate to produce movement. Bones also function as physiologically critical centers for the production of blood cells, as storage facilities for fat, and as reservoirs of important elements such as calcium (essential for blood clotting and muscle contraction). Bone as a tissue is adapted to these functions. The varied mechanical and physiological functions of bones as organs are intimately related to the gross and microscopic (including molecular) structure of bone tissue, which we review in this chapter.

Bone is a dynamic tissue that allows for growth during ontogeny (development) of the individual. It is shaped and reshaped by cells that reside within it. Because of this, the gross shape, or **morphology**, of bones can be altered during life. The shape and size of bones and teeth can also vary dramatically between individuals. Before introducing bone biology at the level of the molecule, the cell, and the gross element, it is critical that we examine a property of all biological structures, the property of variation. Understanding and appreciating variation in bony and dental gross anatomy is critically important in any work with the human skeleton.

4.1 Variation

For a random living sample of fifty male and fifty female individuals from various human populations, it would be easy to establish physical characteristics that would allow each person to be recognized individually. Variation would be employed in sorting the population, and only in the rare instance of identical twins would there be much difficulty in distinguishing different people. This is because the human species, like other species, exhibits variation. This variation extends to the teeth and bones of the skeleton.

In identifying our friends and acquaintances, we make use of our ability to recognize variation. Without variation in physical features it would be impossible for us to identify one another at the group and individual levels. In fact, our use of soft tissue variation seems so natural that we take it for granted. Oddly enough, however, the amount of variation in the hard tissues of the body is often not anticipated by students of osteology. Shape and size in human bones and teeth vary widely, and analysis of this variation makes human osteology simultaneously challenging for the beginner and useful for the professional.

There are four major factors leading to variation in human skeletal anatomy. One source of this variation is **ontogeny**, or growth. A great deal of skeletal variation in size and shape is observed along the continuum of growth between fetus and adult. This variation can be used by the osteologist in determining the age at death from skeletal remains.

A second source of skeletal variation in humans is the sex of the individual. Humans are moderately **sexually dimorphic** in body size, and in any given skeletal population this dimorphism is manifested in the relatively smaller size of female bones and teeth. This size variation is accompanied by shape variation, which allows certain skeletal elements to be used in determining the sexual identity of prehistoric remains (Chapter 19).

A third type of variation is **geographic**, or **population-based**. Different human groups vary in many skeletal and dental characteristics. This geographic variation can be employed to assess the geographic (sometimes called racial) affinity of skeletal remains (Chapter 19).

Finally, even individuals of the same age, sex, and population differ in anatomy; apart from most identical twins, no two people are identical in their external size and shape. Skeletal elements are not exceptions to this rule. Normal variation between different individuals of the same age, sex, and population is called **individual**, or **idiosyncratic**, **variation**. This variation can be substantial, but it is too often overlooked. Figure 4.1 illustrates the influences of ontogeny, sex, and idiosyncrasy on variation in the talus, one of the bones of the ankle.

A profusion of classifications of fossils has been created by the failure to appreciate normal skeletal variation in modern species and the failure to understand the principles and goals of taxonomy. In the resulting forest of family trees, ill-conceived species and genera are hung like ornaments. Normal variation within closely related **extant** (modern) species must guide our expectations of variation in species whose members lived in the past. For this reason, osteologists unfamiliar with normal variation in the present are inclined to misinterpret similar variation in the past as indicating multiple species. To help avoid such misinterpretation, the paleontologist must become familiar with variation in modern humans and their closest relatives, the great apes, by studying large skeletal collections. In assessing any skeletal element, note ontogenetic changes in shape and size by studying different individuals who died at different ages. To assess normal variation in the adult skeleton arising from the other sources identified previously, try to examine a large, mixed-sex sample of individuals. Figures 4.1, 4.2, 4.3, and 4.4 illustrate variation in size and shape in a single-site, balanced-sex sample from a prehistoric Californian skeletal population.

The reality of dimensional and morphological variation in the hard tissues of individuals makes **typology**, the practice of choosing one individual to characterize a species, a particularly unsuitable approach to the study and understanding of human osteology and evolution. Yet, to illustrate basic points of anatomy and identification it is necessary to begin somewhere. In using this book's chapters on identification (Chapters 7–16), the reader should think of the skeletal elements chosen for illustration as representative, but never as typical. There is no "typical" individual. We illustrate variation in skeletal size and shape in this book to reinforce the fact that such variation in biological structures is normal and to be expected.

4.2 A Few Facts about Bone

Bone—one of the strongest biological materials in existence, particularly in terms of bearing weight—is the main supporting tissue of the body. During running, a human loads the bones at the knee joint with a force in excess of five times the weight of the entire body. Yet, despite its great strength, bone is a very lightweight material. The skeleton itself constitutes less than 20% of the weight of the entire body, whereas a framework of steel bars performing the same mechanical functions as the human skeleton would weigh four to five times more. Unlike steel, bone is a **composite** material, formed of protein (collagen) and mineral (hydroxyapatite). Bone differs from steel in yet another sense: it is a living tissue that can repair and reshape itself in response to external stresses. More detailed reviews of the physical, geometric, and mechanical properties of bone as a tissue, and bones as organs, are provided by Burr (1980) and Currey (1984, 2002).

4.3 Bones as Elements of the Musculoskeletal System

In the most basic terms, the musculoskeletal system is a system of bony levers operated by **muscles**. Any connection between different skeletal elements is called a joint. Bones in the skeleton **articulate** at joints and are connected to one another by means of **ligaments** and **cartilage**. Cartilage is a tough and dense but elastic and compressible connective tissue. Bones are moved by muscles acting directly on the bones or via **tendons**, closely packed parallel bundles of collagen fibers. Movement at the joints is controlled and limited by the shapes of the articular surfaces and by ligaments that bind the joints together and prevent dislocation (Figure 4.5).

The hip, elbow, knee, and thumb joints are all examples of freely moving joints called **synovial joints**. The surfaces of the bones participating in synovial joints are coated with a thin (usually 1–5 mm) layer of slick, articular cartilage called **hyaline cartilage**. The area between the adjacent bones is the **joint cavity**, a space lined by a membrane that secretes a lubricant called **synovial fluid**, which resembles egg white in consistency. This fluid nourishes cartilage cells of the joint and is confined to the joint by the fibrous **joint capsule**, a sac made of connective tissue and reinforced by ligaments connecting to the periosteum of the articulating bones (see Section 4.4). The combination of hyaline cartilage coating the bone surfaces and synovial fluid lubricating these surfaces gives synovial joints durability with smooth movement and low friction.

Synovial joints are often classified according to the geometric properties of the articulation. The hip joint is a **spheroidal**, or **ball-and-socket** joint, with the hemispherical femur head fitting into the acetabulum, a cavity in the pelvis. This joint structure allows movement in many directions. The elbow and knee joints are called **hinge** joints because they allow a hinge-like movement limited mostly to one plane. The joint at the base of the thumb is called a **saddle-shaped**, or **sellar**, joint because

Figure 4.1 (*below* and *opposite*) Normal variation in a bone of the ankle, the talus (viewed from the inferior, or lower, aspect; the anterior, or front, surface of each bone is toward the top of the page). All of the tali shown here were selected from a single-site skeletal sample of prehistoric Californians to illustrate skeletal variation attributable to age, sex, and idiosyncrasy. All specimens are from the left side except for the specimen in the upper right corner. One-half natural size.

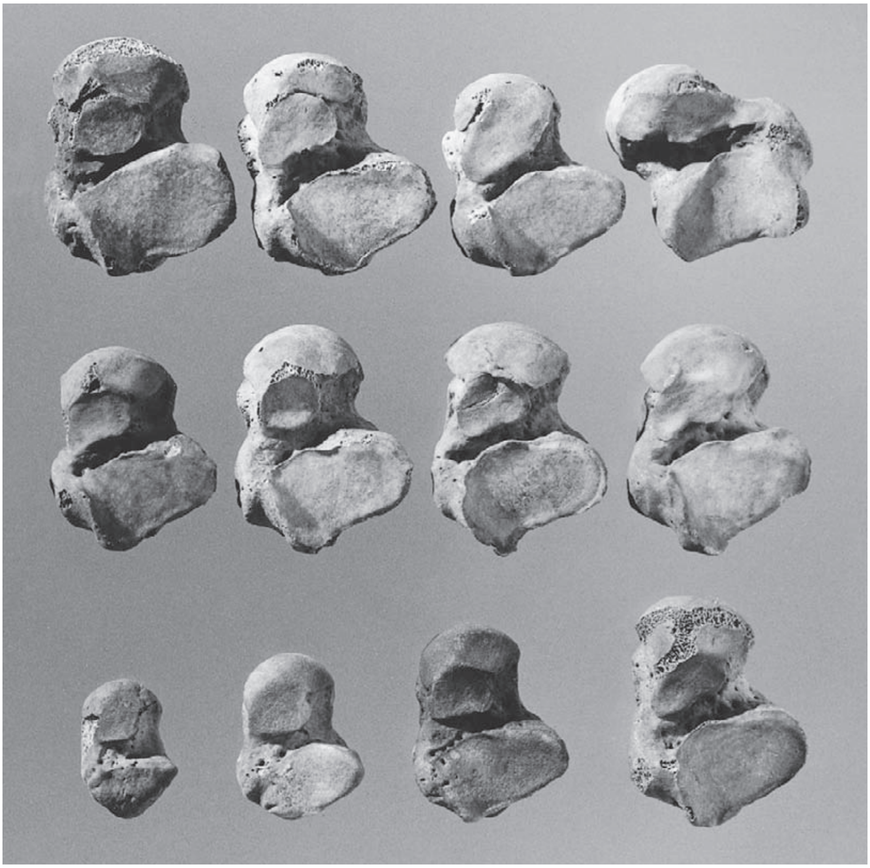
(*Top*) **Idiosyncratic variation.** Six adult male tali chosen from a sex-balanced sample of fifty adult individuals. Variation in this series is seen in the size and shape of the overall bone outline as well as in the proportions of the parts of the bone and in the topography of the various surfaces. Such variation is common in human skeletal remains.

(*Middle*) **Sex variation.** Three adult female (left) and three adult male (right) specimens chosen at random from a sex-balanced sample of fifty adult skeletons. *Homo sapiens* is a primate species whose sexual dimorphism in body size is moderate by primate standards, less than the gorilla, but more than the common chimpanzee. Chapter 19 considers sexual dimorphism in the human skeleton.

(*Bottom*) **Ontogenetic variation.** The specimen at the far left is a talus from a newborn child. Tali from individuals at ages 1.5, 6, 10, 12, and 18 years show ontogenetic changes in size and shape of this skeletal element.

of its shape. It allows movement in two basic directions. **Planar** joints allow two bones to slide across one another, examples of which can be found in the wrist and the arch of the foot.

Because of their mobility, synovial joints are the most obvious joints in the musculoskeletal system, but there are two other important joint types in the body: cartilaginous joints and fibrous joints. In **cartilaginous joints** (**synchondroses**) the articulating bones are united by means of cartilage, and very little movement is allowed. The temporary joints between growth centers (described later) in a single growing bone are cartilaginous. Some of these joints persist in adulthood, such as the cartilaginous connections between the ribs and the breastbone (sternum). A **symphysis** is a variety of cartilaginous joints in which the fibrocartilage between the bone surfaces is covered by a thin layer of hyaline cartilage. **Syndesmoses** are tight, inflexible fibrous joints between bones that are united by bands of dense fibrous tissue in the form of membranes or ligaments; an example is the joint at which the two lower leg bones (tibia and fibula) articulate above the ankle (the distal tibiofibular articulation). **Cranial sutures** are fibrous joints of the skull; these are interlocking, usually tortuous joints in which the



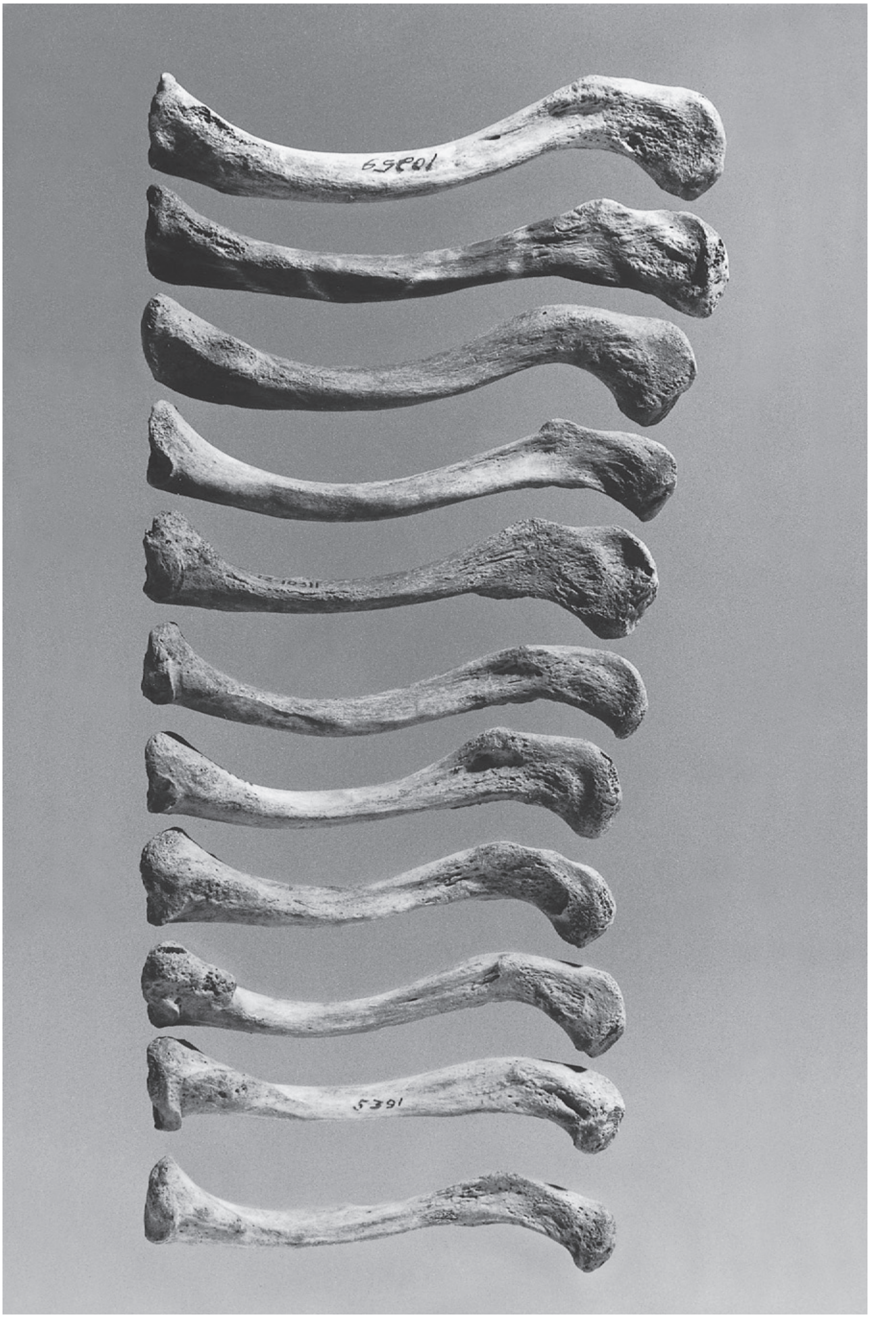


Figure 4.2 Adult human clavicles (collarbones) selected to illustrate the total range of variation in size, outline, and topography in a single-site, sex-balanced sample of eighty normal prehistoric Californians. Note the variation in overall size, in the shape of the bone, and in the topography of the surface. This kind and amount of variation should be expected in any normal sample of similar age and sex composition. These right-side specimens are shown in inferior view, with the lateral (arm end) toward the right side of the page. One-half natural size.

bones are close together and the fibrous tissue between them is thin. A **gomphosis** is the joint between the roots of the teeth and the bone of the jaws. When any two bony elements fuse together, the result is called a **synostosis**.

Movement of the skeleton takes place, for the most part, at synovial joints. This movement is caused by the muscles, which work by contracting across joints between bones. Muscles usually attach to two different bones, but they may attach to several. Most muscles are connected to bones via **tendons**. **Ligaments** are cords, bands, or sheets of collagenous bundles that extend between the bones forming a joint. Liga-

Figure 4.3 Adult human femora (upper leg bones) selected to illustrate the size and shape variation encountered in a single-site, sex-balanced sample of 100 normal prehistoric Californians. There is considerable variation between specimens shown here in size, robusticity, markings of muscle attachments, and proportions and angles of the different parts of each femur. These left-side specimens are shown in posterior view, with the superior (top) end of the bone toward the top of the page. One-third natural size.

ments resist tension, thereby strengthening the joint and permitting only movements compatible with the function of the joint.

Muscle attachment sites are conventionally identified in relative terms. The site that stays relatively stable during contraction of the muscle is called the **origin**. For the appendages, this is usually the attachment site closest to the trunk. The site that is moved by the contraction of a muscle is termed the **insertion**. For example, the muscles that flex the fingers originate in the anterior compartment of the forearm and insert on the fingerprint side of the finger bones (phalanges). Actions caused by

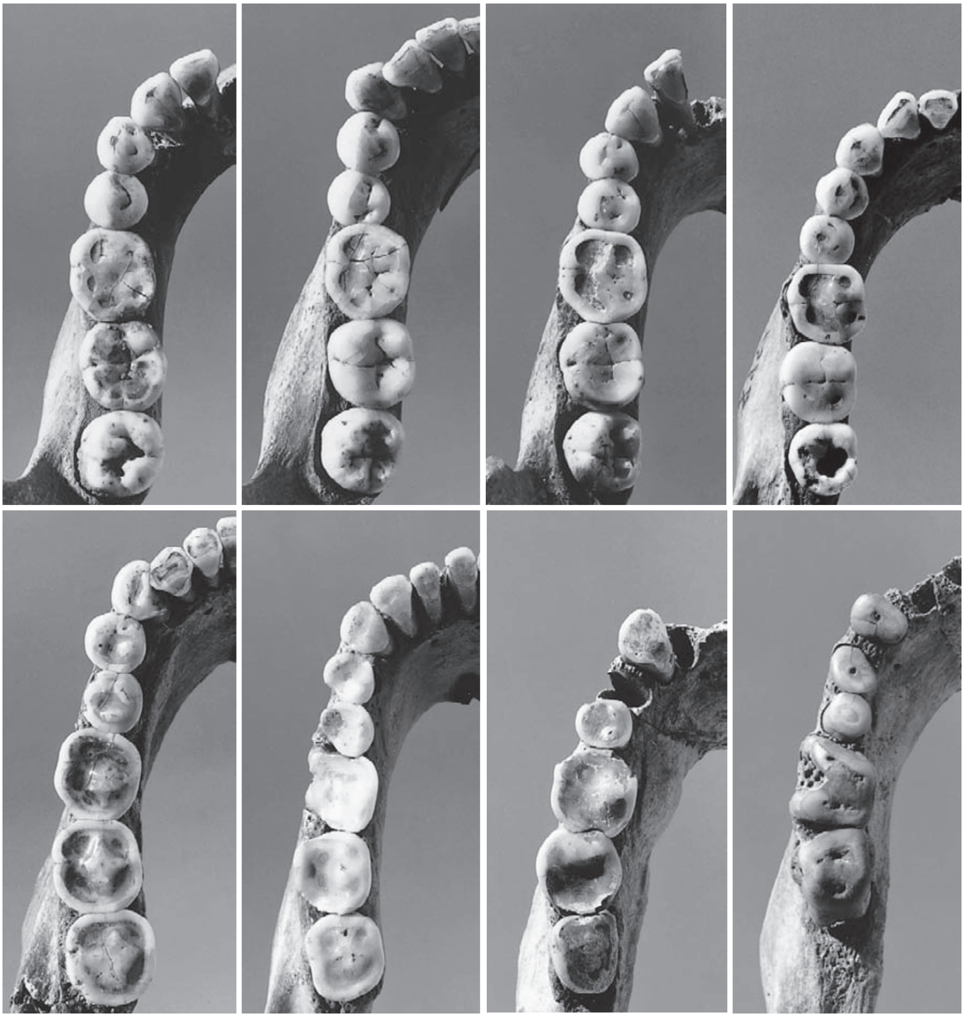


Figure 4.4 Dental variation due to age (reflected in wear), sex, and idiosyncrasy. The tooth rows shown here were selected from a single-site, sex-balanced skeletal sample of sixty prehistoric (Late Horizon) Californians. Note the differences in wear, size, and shape of the teeth as well as the variation in tooth row curvature and length.

Figure 4.5 Dorsal view of a human right wrist and hand. This composite illustration combines the techniques of cross-sectioning (little finger), dissection (ring and middle fingers), and radiography (thumb). The bones are embedded in a matrix of soft tissues including skin, nerves, arteries, veins, muscles, ligaments, tendons, and joint cartilage. In the assessment of external bone morphology, neither the soft tissue matrix nor the internal structure should be forgotten.

muscles are usually reciprocal. At the elbow joint, different muscles cause opposite motions such as **extension** (straightening the arm) and **flexion** (bending the arm). Such muscles are called **antagonists**. Muscles are often identified by the primary action that their contraction causes. Chapters 7–16 introduce some of the major muscles that move the human skeleton and leave traces of their origins and insertions on the bones. For now, we can easily illustrate several basics of the musculoskeletal system with the human hand and arm. Muscles in the forearm are easily palpated as the hand is clenched and opened. These muscles act via tendons, which become very visible across the front and back of the wrist when it is flexed and extended. For example, the *extensor digitorum* muscle, a resident of the forearm, functions in extending the four fingers as it operates via four tendons that cross the wrist.

4.4 Gross Anatomy of Bones

The wide range of element shapes in the human skeleton may seem to defy classification. The bones in the body may, however, be partitioned into a few basic but overlapping shapes. The limb bones and many of the hand and foot bones, usually called long bones, are tubular in shape, with expanded ends (Figure 4.6). The bones of the cranial vault, shoulder, pelvis, and rib cage tend to be flat and tabular. The bones of the ankle, wrist, and spine are blocky and irregular. Despite this variety of external form, the makeup of bones at both the gross and microscopic levels is remarkably constant.

At the gross level, all of the bones in the adult skeleton have two basic structural components: **compact** and **spongy** bone. The solid, dense bone that is found in the walls of bone shafts and on external bone surfaces is called compact, or **cortical**, bone. At joints, compact bone covered by cartilage during life is called **subchondral bone**. This is recognized as smoother and shinier than nonarticular compact bone and lacks the haversian systems described later.

The second kind of bone has a more spongy, porous, lightweight, honeycomb structure. This bone is found under protuberances where tendons attach, in the vertebral bodies, in the ends of long bones, in short bones, and sandwiched within flat bones. This **cancellous**, or **trabecular**, bone is named after the thin bony spicules (**trabeculae**) that form it. The molecular and cellular compositions of compact and trabecular bone tissue are identical; it is only the difference in porosity that separates these gross anatomical bone types.

Areas of trabecular bone in the growing skeleton constitute sites of the **red marrow**, a blood-forming, or **hematopoietic**, tissue that produces red and white blood cells and platelets. The **yellow marrow**, mainly a reserve of fat cells found in the **medullary cavity** (hollow inside the shaft) of tubular bones, is surrounded by compact bone. During growth, the red marrow is progressively replaced by yellow marrow in most of the long bones. As noted previously, in addition to their role in blood cell production and fat storage, bones function as organs in yet another way: bone tissue represents a calcium reservoir for the body.

Parts of tubular, or long, bones are often described according to the centers of ossification (see Section 4.7) that appear during the growth process. The ends of long bones are called the **epiphyses** because they develop from secondary ossification centers of the bone (the articular surfaces of the epiphyses are parts of joints). The shaft of a long

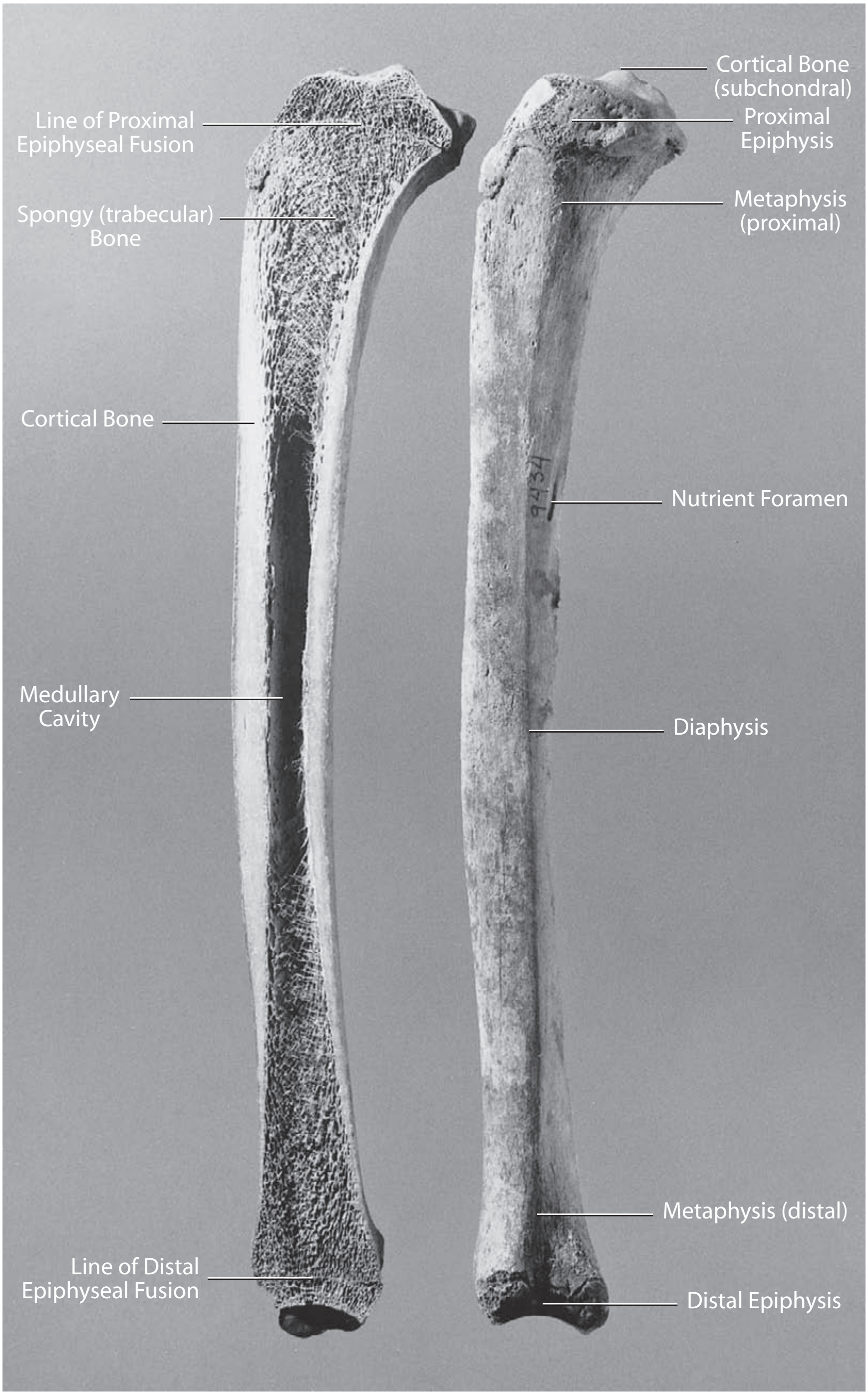


Figure 4.6 A left tibia (shin bone) sectioned (cut) to show key elements of the gross anatomy of a human long bone. Note the disposition of the compact and spongy bone. One-half natural size.

bone is called its **diaphysis** because it is the result of the primary ossification center of the bone. The expanded, flared ends of the shaft are called **metaphyses**. A good example of these parts is the knee, where the epiphysis at the knee end of the femur fuses to the metaphysis of the shaft when growth is complete.

During life, the outer surface of bones is usually covered with a thin tissue called the **periosteum**. This tissue is missing in dry bones, but in life it coats all bone surfaces not covered by cartilage. The periosteum is a tough, vascularized membrane that nourishes bone. Some of the thin fibers of the periosteum penetrate the surface of bone, whereas others intertwine with tendons to anchor muscles to the bone. The inner surface of bones is lined with an ill-defined and largely cellular membrane called the **endosteum**. Both periosteum and endosteum are **osteogenic** tissues—they contain bone-forming cells that are numerous and active during youth. These cells are reduced in number, but remain potentially active in adulthood. They may be stimulated to deposit bone when the periosteum is traumatized.

4.5 Molecular Structure of Bone

We now turn to an assessment of bones at more basic molecular and cellular levels. No matter what shape a bone takes at the molecular level, its tissue is basically the same in all mammals. Bone tissue, like fiberglass, is a composite of two kinds of materials. The first component is a large protein molecule known as **collagen**, which constitutes about 90% of the organic content of bone. Collagen is the most common protein in the body. Collagen molecules intertwine to form flexible, slightly elastic fibers in bone. The collagen of mature bones is stiffened by a dense inorganic filling of the second component, **hydroxyapatite**. In bone, crystals of this mineral, a form of calcium phosphate, impregnate the collagen matrix. This weave of protein and minerals gives bone its amazing properties. The combination of materials is illustrated by two simple experiments. The mineral component gives bone its hardness and rigidity. When soaked in acid to dissolve these minerals, a bone becomes a rubber-like, flexible structure. However, when a bone is heated to combust the organic collagen, or leached out in some archeological contexts, it becomes extremely brittle and crumbles.

Characterizations of bone at the molecular level give some clues about its physical properties, but it is important to consider that bone as a tissue must be made and maintained by cells, it must be responsive to stress, and it must be capable of growth. A look at the structure of bone above the level of the collagen fibril and associated mineral provides insight into these dimensions of bone function.

4.6 Histology and Metabolism of Bone

Histology is the study of tissues, usually at the microscopic level. There are two histological types of mammalian bone: **immature** and **mature**. Immature bone (**coarsely bundled bone** and **woven bone**) is the first kind of bone to develop in prenatal life. Its existence is usually temporary, as it is replaced with mature bone as growth continues. Immature bone is usually formed rapidly and characterizes the embryonic skeleton, sites of fracture repair, and a variety of bone tumors. It has a relatively higher proportion of osteocytes (see later) than mature bone. Woven bone is the more phylogenetically primitive bone type in evolutionary terms. It is coarse and fibrous in microscopic appearance, with bundles of collagen fibers arranged in a nonoriented, random pattern.

Both compact and trabecular portions of adult bones are made of mature, or **lamellar**, bone tissue, named for the orderly, organized structure produced by the repeated addition of uniform lamellae to bone surfaces during appositional growth. Compact bone is composed of dense bone that cannot be nourished by diffusion from surface blood vessels. **Haversian systems**, with their canals and canaliculi (described in this section), are the solution to this problem. In contrast, the more porous trabecular bone receives nutrition from blood vessels in surrounding marrow spaces and lacks haversian systems. Normal adult bone, both compact and trabecular, is histologically lamellar bone. Lamellar bone is usually laid down more slowly than woven bone, which it usually replaces.

Microscopic examination of a transverse section of compact bone in, for example, the tibial shaft reveals the internal structure of haversian bone (Figure 4.8). Such a section resembles an end view of a pile of sawed-off tree trunks. The cross section of each "trunk" often shows approximately four to eight concentric rings, known as **haversian lamellae**. A close examination of each lamella would reveal a bed of parallel collagen fibers. Fibers in successive lamellae, however, are oriented in different directions. This alternation of fiber direction adds strength to the structure.

Each "trunk" in the cross section of compact lamellar bone is known as a **haversian system**, or **secondary osteon**. See Figure 4.7a–4.7c for illustrations and descriptions of osteons. These haversian systems measure about 300 μm (0.3 mm) in diameter and are about 3–5 mm in length. They represent the basic structural unit of compact bone, and their long axes parallel that of the long bone of which they are part. Passing through the core of each haversian system is a hollow **haversian canal**, through which blood, lymph, and nerve fibers pass. Additional smaller canals, the **Volkmann's canals**, pierce the bone tissue obliquely and at right angles from the periosteal and endosteal surfaces to link the haversian canals, creating a network that supplies blood and lymph to the cells of long bones.

Small cavities found within each lamella are called **lacunae**. Each lacuna harbors an **osteocyte**, a living bone cell. Nutrients are transported to these cells through **canaliculi**, minute fluid-filled channels that radiate from the centrally placed haversian canal to lacunae in succeeding lamellae or from one lacuna to others. These channels in bone tissue enable the living cells to survive in a heavily mineralized environment.

Three primary cell types are involved in forming and maintaining bone tissue. **Osteoblasts** are bone-forming cells responsible for synthesizing and depositing bone material. Osteoblasts are often concentrated just beneath the periosteum. They make large quantities of a material known as **osteoid** (prebone tissue), an uncalcified organic matrix rich in collagen. Calcification of bone takes place as crystals of hydroxyapatite, the inorganic component of bone, are deposited into the osteoid matrix. Once surrounded by bony matrix, the osteoblasts are called osteocytes, cells that reside in lacunae and are responsible for maintaining bone tissue. **Osteoclasts** are responsible for the **resorption** (removal) of bone tissue. All skeletal elements change dramatically during ontogeny and continue to be capable of change in adulthood. Bone formation takes place throughout life. The reshaping, or **remodeling**, of bone takes place at the cellular level as osteoclasts remove bone tissue and osteoblasts build bone tissue.

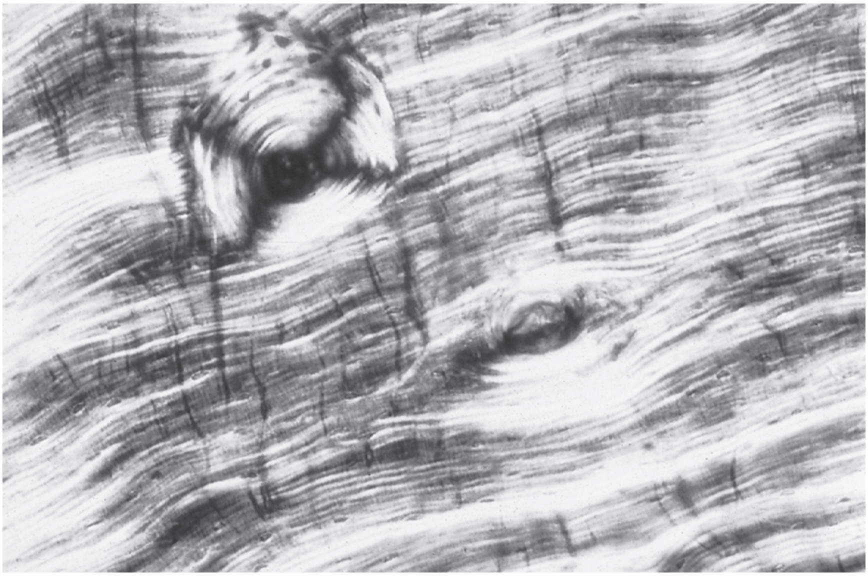


Figure 4.7a Bone histology. A comparison of primary and secondary osteons (from Paine and Godfrey, 1997). Polarized lighting, 200X. The primary osteon is an island with lamellar bone streaming around it; the larger secondary osteon intersects the lamellae of primary cortical bone. A primary osteon is composed of a vascular canal without a cement line (because it does not replace preexisting bone). The cement line (sheath) and lamellar bone organized around the central canal characterize the secondary osteon, which fills a space left by the disappearance of preexisting bone.

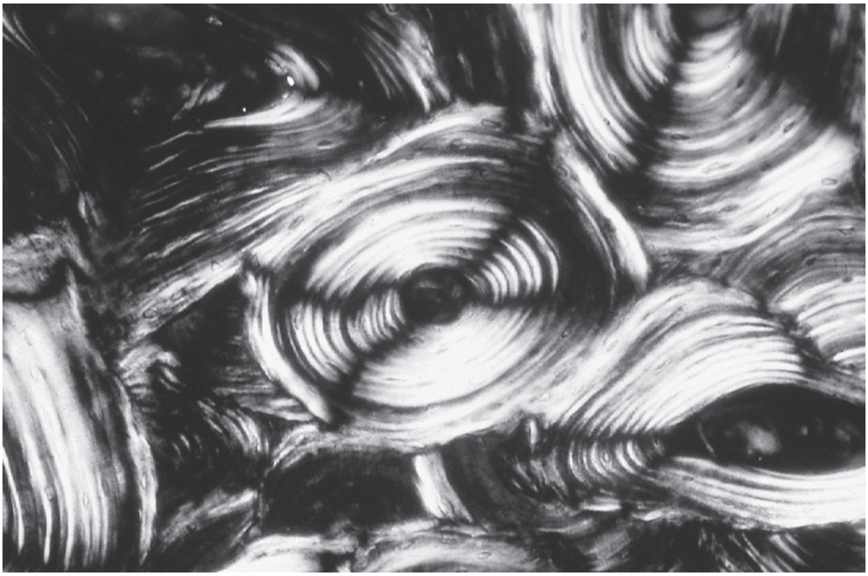


Figure 4.7b Bone histology. An intact secondary osteon with several fragmentary osteons. Secondary osteons are products of bone remodeling. Polarized lighting, 200X.

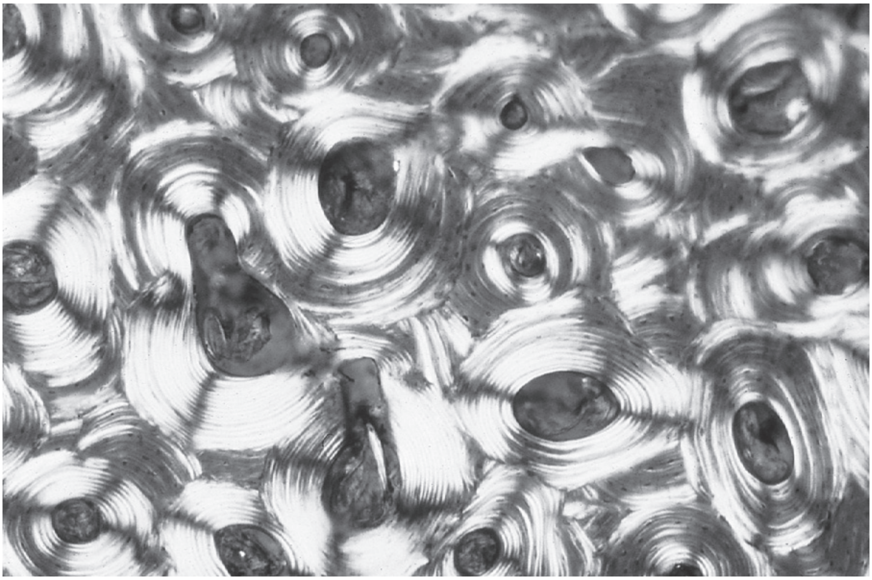


Figure 4.7c Bone histology. A crowded field of secondary osteons. The large haversian canals indicate incomplete formation of several osteons. Polarized lighting, 100X. See Chapter 19 for a discussion of how analyses of these microscopic histological structures in bone have been employed in individual age assessment. Courtesy of Robert Paine.

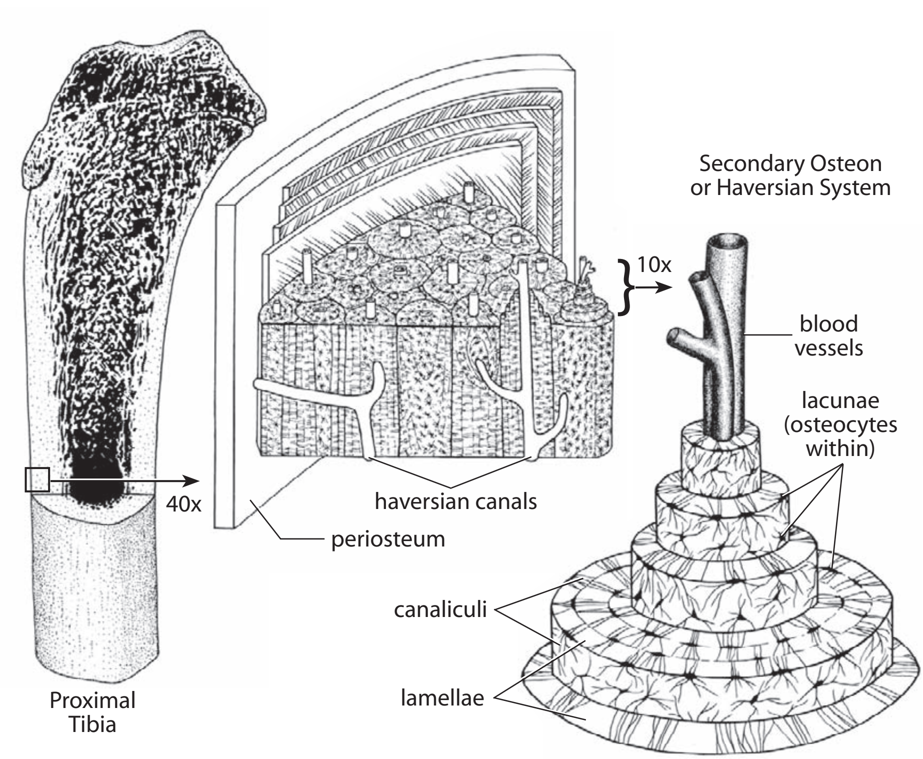


Figure 4.8 Gross and microscopic structure of bone.

The opposing processes of bone formation and resorption allow bones to maintain or change their shape and size during growth. Some osteologists distinguish between "modeling" as bone sculpting during growth and "remodeling" as the process of continuous removal and replacement of bone during life.

4.7 Bone Growth

The histological situation described in Section 4.6 accounts for the metabolism of bone and the plasticity of bone in the adult. During ontogeny, however, the skeleton undergoes tremendous growth. Osteocytes do not divide, and, because bone matrix calcifies soon after being produced, the tissue cannot undergo further expansion from within. As a consequence, all bone growth is the result of bone deposition on a preexisting surface. Indeed, bone always develops by replacement of a preexisting connective tissue. Embryologically, bone development (**osteogenesis**, or ossification) occurs in two general sites. In **intramembranous ossification**, bones, particularly the frontal and parietal bones of the cranial vault, ossify by apposition on tissue within an embryonic connective tissue membrane. Most bones in the skeleton, however, grow through a process known as **endochondral ossification**, in which bones are preceded by cartilage precursors called cartilage models. Early in its development, *in utero*, the skeleton is flexible, but ossification is initiated before birth. Visible elements of the early skeleton are mostly composed of cartilage, a material that is good for rapid growth in a medium where the functions of support are not yet necessary. Cartilage is composed mostly of collagen and, unlike bone, it is flexible and avascular in the adult. The only difference between the two distinct mechanisms of ossification is the environment in which ossification occurs. There is no difference between the kind of bone produced.

Fetal ribs, vertebrae, basicranium, and limb bones begin as cartilage models. Ossification occurs within the cartilage model as it is penetrated by blood vessels. Growth radiates from the location of the initial penetration, which becomes the **nutrient foramen**. A thin membrane called the **perichondrium** surrounds the cartilage model of the long bone. Osteoblasts just beneath the perichondrium in the fetal long bone begin to deposit bone around the outside of the cartilage shaft. Once this occurs, this membrane is called the **periosteum**, a fibrous connective tissue, which in turn deposits more bone, layer by layer. As the diameter of the growing long bone shaft increases, osteoclasts on the endosteal surface remove bone and osteoblasts in the periosteum deposit bone. Thus, **appositional growth** allows shaft diameters to enlarge during development. The compact bone of an adult limb bone shaft is periosteal in origin, the original immature shaft having been removed by osteoclasts to form an enlarged medullary cavity. Slow subperiosteal apposition continues throughout life after an adolescent "growth spurt" (Garn, 1972).

Meanwhile, the developing long bone must also grow in length. During growth, the roughened, porous, usually irregular end of an immature long bone's metaphysis marks the region at which most longitudinal growth occurs. Sandwiched between the metaphysis (the primary center of ossification) and the epiphysis (the secondary center of ossification) during development is a cartilaginous center known as the **growth plate** (**epiphyseal plate**), a tissue layer responsible for bone formation. This plate, a

Figure 4.9 Growth series for the left human tibia (lower leg bone). The tibia on the far left is that of a newborn child. Larger specimens to the right are from individuals of ages 1.6, 6, 10, 12, and 18 years. Specimens are shown in anterior view, with the proximal (top) end of the bone toward the top of the page. One-fourth natural size.

layer of cartilage, "grows" away from the shaft center. The growing cartilage is replaced by bone on the diaphyseal side of the plate. As the individual grows, the epiphyseal plate is pushed farther from the primary growth center of the bone (the shaft), lengthening the bone. Ossification and growth of the bone come to a halt when cells at the growth plate stop dividing, and the epiphysis fuses with the metaphysis of the shaft. Because the ends of the long bone flare, substantial remodeling occurs as the bone lengthens during this process (Figure 4.9).

At eleven weeks before birth there are usually about 800 ossification centers, the "bony pieces" of the skeleton. At birth there are about 450 centers. As a rule, "primary" centers appear before birth, and "secondary" centers appear after birth. The secondary center at the lower end of the femur (upper leg bone) and the one atop the tibia (lower leg bone) begin to appear just prior to birth. Most long bones develop two secondary centers in addition to the primary centers of ossification. A few long bones develop a secondary center at one end only, and typical wrist and ankle bones ossify entirely from their primary centers. By adulthood, all of the primary and secondary centers have fused to yield the average adult human complement of 206 elements, the bones of the adult human skeleton. These bones are listed in Chapter 6, Figure 6.2.

4.8 Bone Repair

Bones occasionally break, or **fracture**, when subjected to abnormal stresses or when bone is weakened pathologically. The process of repair begins as soon as the fracture occurs. Blood vessels in the haversian canals, the periosteum, and the marrow are usually ruptured by a fracture. Blood flows into the fracture zone and normally forms a **hematoma** (bloody mass) that coagulates as the blood vessels are sealed off. The periosteum is usually torn at the fracture site and pulled away from ends of the broken bones. This stimulates the osteogenic layer of the periosteum to begin forming a **callus**, fracture repair tissue that forms a sort of natural splint. The callus first consists of fibrous connective tissue that bridges the broken bone surfaces, tying them together. Within two days the osteoblasts respond, and the callus is subsequently mineralized to form woven bone, the **primary bony callus.** The primary bony callus takes about six weeks to develop. Later, this woven bone callus is converted to lamellar bone. If orientation of the broken bone ends is close to the original, and if subsequent movement at the fracture site is limited (especially by immobilizing the bone), the callus may become so remodeled that evidence of fracture is eventually present only in radiographs. Further remodeling may completely eliminate any evidence of the fracture. Chapter 17 illustrates some effects of fracture in bone.

Chapter 5

Postmortem Skeletal Modification

Bones change as the individual grows. This process, **ontogeny**, continues until late in adulthood in some regions such as the pubic symphysis (see Chapter 19). Because bone is living tissue, it can respond to physical stimuli at any time during an individual's life. Individual variation in any human skeletal element, therefore, can be the result of the bone responding to genetic control, to environmental factors, or to both. The morphological changes discussed in Chapter 17 are **antemortem** effects. They include changes brought about by pathology. After death, however, further morphological changes can occur in bone, brought about by biological, chemical, and physical agencies operating on it. **Postmortem modification** alters both the condition of the individual bones and the completeness of the skeleton as a whole.

The study of the processes that operate between the time of death of the organism and the time of study by the osteologist is called **taphonomy**. Taphonomy, from the Greek words for "burial" and "laws," is a word coined in the 1940s by the Russian paleontologist Efremov. Taphonomy is usually described as a subdiscipline of paleontology, but its methods and data are often applied in archeological contexts. Human skeletal remains are recovered from a variety of contexts. These include geological deposits, such as cave floors, alluvial bodies, lacustrine deposits, peat bogs, and volcanic ash. Archeological contexts include house floors, wells, battlefields, megalithic structures, plague pits, cemeteries, funeral urns, refuse pits, and even hearths. Given this variety of contexts, postmortem modification of human skeletal remains can take many forms.

Taphonomy merits the attention of the human osteologist because hominid skeletal remains often bear the traces of past processes and activities useful in archeological interpretation. Bones have the potential to exhibit taphonomic modification in forensic, archeological, and paleontological contexts. Human osteologists are often called on to determine whether the distinctive patterns of damage or element representation in a skeletal assemblage or individual may have resulted from human behavior. An understanding of the many processes that alter bones and bone frequencies provides the basis for such interpretations. It is essential that these processes and their effects be understood in order to avoid the mistaken attribution of postmortem modification to antemortem pathological processes (see Chapter 17). In addition to modifying the bones themselves, postmortem processes can dramatically alter the composition of skeletal populations. Several pitfalls of demographic reconstruction involve the differential destruction of skeletal remains due to postmortem processes.

The forensic osteologist working in a crime scene context acts as a member of an investigative team searching for all available clues. However, some physical anthropologists working in archeological or paleontological contexts have focused exclusively on the retrieval of bones and thereby have missed important contextual clues about past behavior. This exclusive focus on the retrieval of bony specimens has the potential to sacrifice much critical information about the past. Archeologists often study burials to understand past cultural activities, particularly mortuary practices. Duday (1978; Duday and Masset, 1987) has consistently called attention to the need for communication between archeologist and osteologist during every phase of the recovery of skeletal remains. Nawrocki (1995) even suggests that this specialized, gap-bridging field of study should be called human taphonomy. It is important to remember that bodies are usually buried, not just skeletons. The disposition of the skeleton therefore provides critical information on how the body was buried. The cultural and taphonomic circumstances surrounding death and the primary burial of the individual influence the skeleton recovered by the archeologist. By using all available clues exposed during excavation, the cultural arrangement of the cadaver and the infilling of the burial space may be inferred.

It is most convenient to divide taphonomic agents into two major classes—biological and physical—and to consider human-induced modifications separately. It should be realized, however, that biological agents act through both physical and chemical pathways to alter bones. This chapter describes and illustrates the effects of the most commonly encountered postmortem alterations of human skeletal remains. The student is referred to Lyman's 1994 volume *Vertebrate Taphonomy* as an excellent extension of much of the subject matter of this chapter, from an archeological perspective. Haglund and Sorg's (1997) excellent edited volume *Forensic Taphonomy* is another valuable resource, as is Section III (Interpretation of Trauma and Taphonomy) of Steadman (2003).

5.1 Bone Fracture

In osteological analysis, it is critical to identify deviations of bones from the normal condition and to distinguish between deviations caused by pathological agents and those brought about by taphonomic agents. Assessing bone fracture in an archeological context is an example of the difficulties of such work. Fracture of a radius, for example, can occur a year before death, an hour before death, immediately after death, or during excavation. The causes of such fracture vary. Antemortem fracture can occur as the individual falls from a tree. Postmortem fracture can be caused by the corpse being forced into a small burial crypt or by a hyena scavenging the body. Impatient archeologists also have been known to fracture bones through carelessness. Signs of bony healing around the fracture could identify the fracture as antemortem. Without this healing, however, the osteologist may be forced to identify the fracture as **perimortem** (around the time of death), implying that it is not possible to ascertain whether the fracture occurred just before, during, or after death. Ubelaker (1992b) notes the significance of fracture of the hyoid in a forensic context. Death by strangulation some-

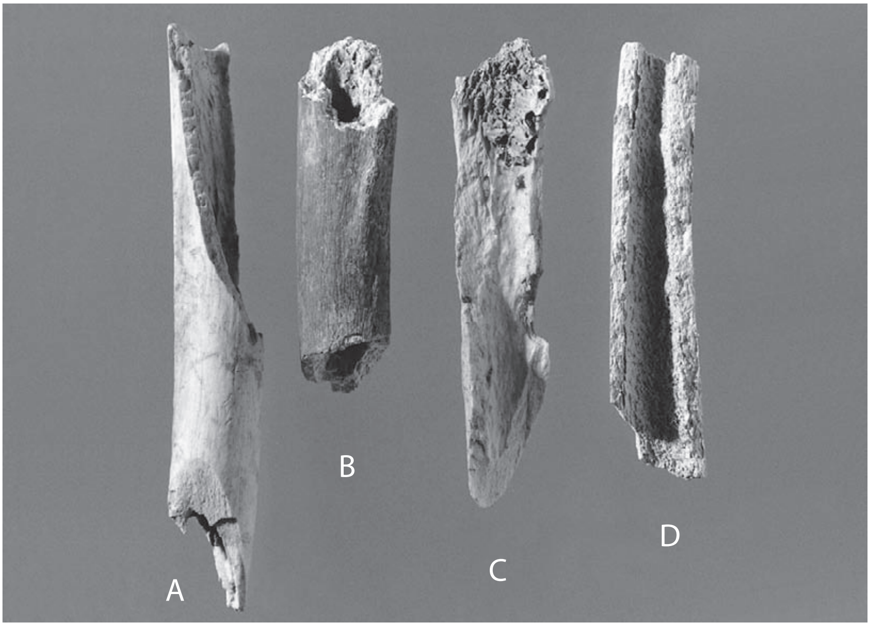


Figure 5.1 Recent (or modern, B and D) and ancient (A and C) fractures of human femoral shafts. Specimens A and C are from an archeological context in which the bone was fragmented when fresh, whereas specimens B and D were fractured during retrieval of the elements from the ground. Note the conchoidal impact scar on the internal surface of specimen C. One-half natural size.

times involves hyoid fracture. However, dissection during autopsy can also fracture the hyoid. Incomplete ankylosis of the horns to the body of the hyoid is sometimes mistaken for fracture. The hyoid can be fractured prior to death and not show significant remodeling at the time of death. The osteologist's most important contribution to a forensic investigation may be to bring all these possibilities to the attention of the investigative team.

The rate at which a bone loses its organic component and becomes "dry" as opposed to "green" or "fresh" varies widely, depending on the environment of deposition. Mineralization or "fossilization" of the bone also depends more on context than on elapsed time. Despite the variations in rate of change, it is often possible to distinguish between ancient (perimortem) fracture of bones that still retained much organic component when broken, and recent fractures of dry bones that occurred during excavation and transport. Discrimination is often facilitated by reference to the surface color and edge characteristics of the broken surfaces (Figure 5.1). Ancient longitudinal or spiral fractures of the shaft are usually straight, with sharp, linear edges. Because the fracture surface had already formed at the time of burial, this surface is usually the same color as the rest of the bone surface. However, dry or fossilized bones that have been recently broken usually have rougher, more jagged fractures, and the fracture surface is usually a different color (lighter in most unfossilized bone) than the adjacent unbroken surfaces.

As described in Chapters 7–16, individual bones perform different mechanical and physiological functions. These functions are reflected in the wide variation in size, shape, density, and internal structure of the bones. These characteristics, in turn, affect the potential for postmortem fracture of each element and even parts of elements. For example, human femoral shafts from archeological collections are far more likely to escape the ravages of biological and physical destruction than the smaller, more fragile sternum. Element representation in excavated skeletal assemblages can therefore be altered significantly from that predicted by element ratios in the intact skeleton. The absence of hand phalanges in an excavated cemetery assemblage usually does not mean that bodies were buried without fingers. Instead, such absence more often indicates that years of postburial rodent tunneling through the site displaced these small elements or that recovery techniques were not adequate. Attribution of the disproportion to some ritual activity involving removal of the fingers would be unwarranted in such a case.

The appreciation that patterns of element disproportions in the archeological record are not all attributable to human intervention has caused archeologists to look closely at natural bone modification in the modern world. These **actualistic** studies have shown repeatedly that the structure of the bones themselves is often a major determinant of patterning in the archeological record. For example, the edge of the tibial plateau is often eroded simply because of its prominence and thin cortex, whereas the shaft of this element is rarely damaged.

5.2 Bone Modification by Physical Agents

5.2.1 Chemistry

Postmortem changes in bone range from minor alterations of bone proteins to complete structural and chemical breakdown. As outlined in Chapter 4, the major constituents of bone are protein (mostly collagen) and minerals. The relationship between these constituents involves complex structural features and chemical bonds whose nature is not fully understood (Von Endt and Ortner, 1984). When the organism dies, the once-dynamic bone tissue begins to disintegrate. Soil acidity (pH) and permeability, moisture, temperature, and microorganisms can all dramatically affect the rate of skeletal deterioration. Depositional environments include conditions such as the dry Egyptian or Peruvian deserts and the cold, dry arctic—environments that preserve even soft tissues. Other depositional conditions ensure destruction of even the teeth. Differences in soil conditions, even within a single burial, can result in differential destruction. In general, better bone preservation is present in well-drained areas with low water tables, in soils with a neutral or slightly alkaline pH, and in temperate areas (Henderson, 1987). These generalizations are often violated, however, because preservation is so dependent on unique combinations of these variables in local depositional settings. The color and degree of fossilization are also controlled by the environment of deposition. Under the right conditions, a bone can become completely fossilized in a few thousand years.

When unfossilized bone is exposed to the elements, particularly rain and sun, its surface deteriorates at the same time that its organic content is lost. Weathering bones first display a network of fine, usually parallel surface cracks. These cracks progressive-

Figure 5.2 Burning and weathering of bone. The shaft fragments and phalanx on the right show characteristic cracking, degreasing, and exfoliation associated with weathering. These human bones lay exposed on an unprotected surface in Colorado for about 15 years. The femoral shaft fragment and phalanx in the middle show bone deterioration, discoloration, and exfoliation indicative of damage by burning. Note that the contact between damaged and undamaged surfaces is abrupt. Soft tissue protects the deeper bones, whereas subcutaneous bones or bone portions is more susceptible to such damage when fleshed bones are burned, so the pattern of damage provides clues to the amount of soft tissue on the body when burning occurs. The limb-bone shaft splinter and phalanx on the left are unaltered. Bar: 1 cm.

ly deepen and widen as the bone surface begins to deteriorate (Figure 5.2). The rate of weathering depends on temperature and humidity, but archeologists have attempted to use bone weathering to estimate how much time some bone assemblages took to accumulate on former land surfaces, and forensic osteologists use similar observations. Lyman and Fox (1997) discuss the pros and cons of weathering data in both realms.

5.2.2 Rock, Earth, and Ice

Bones on the surface of caves can be broken and scratched by rockfall. Buried bones can be fractured by earth movement. In colder climates, the freeze-thaw cycle can result in damage to bones. The postmortem alteration caused by these nonhuman physical agencies may include striations and polishing that might be attributed to human intervention. However, in such circumstances the depositional context and configuration of damage can provide important clues for the accurate interpretation of the bone modifications.

5.2.3 Abrasion

Particles of grit suspended in aerial or aqueous environments can abrade bones, reducing surface relief. Such sandblasting effects are commonly observed in bones exposed on the surface in desert conditions or transported in a river. Many fossil assemblages are recovered from fluviatile environments and their elements often show abrasion damage.

5.2.4 Fire

It is possible for bones to become charred by naturally occurring fires, but the effects are usually not as severe as damage caused by mortuary (cremation) or dietary (roasting) practices (Figures 5.2 and 5.3). For many archeologists and osteologists, an introduction to cremated human bone is the first encounter with burned bones. This is unfortunate because the objective of cremation as a mortuary practice is the destruction of the body. Cremated bones are typically heated to very high temperatures and characteristic color changes and cracking accompanies the loss of the organic portion of the bone tissue. It is necessary to recognize, however, that bone subjected to lower temperatures for shorter periods of time is not so conspicuously altered. In fact, burning of bone tissue may so closely mimic normal bone-weathering processes that microscopic or chemical analysis is necessary to distinguish the two (Taylor *et al.*, 1995). Burning (charring) of bone tissue is also sometimes confused with staining (particularly manganese staining) of bones in some depositional contexts (Shahack-Gross *et al.*, 1997). When analyzing evidence for the burning of human bones, the osteologist should always be attentive to the depth and character of the soft tissue that covered the particular osteological element at death. The molar enamel, for example, is exfoliated less frequently than incisor enamel because when the head is exposed to fire the incisors are very exposed to high temperature, whereas molars are more protected because of coverage by more soft tissue.

Figure 5.3 Burned human bone. Burning here has resulted in splitting, cracking, and discoloration of the specimens, exfoliation of the cranial vault bone (*upper right corner*), and destruction of the subcutaneous surface of the tibial shaft fragment (*bottom*). One-half natural size.

5.3 Bone Modification by Nonhuman Biological Agents

5.3.1 Nonhuman Animal

Carnivores such as hyenas, wolves, dogs, leopards, and even crocodiles and insects can have a dramatic impact on bones and bone assemblages. These animals, particularly the canids and hyenids, are agents of bone destruction because they break bones between their teeth in an effort to retrieve the fat and marrow within. The soft, trabecular portions of bones are favored by these animals, and even a small hyena is fully capable of splintering the shaft of an adult human femur. Carnivore damage to bones is recognized by the signature of the teeth—pitting, scoring, and puncturing of the bone surface (Figure 5.4). Haglund *et al.* (1988) provide a brief account of forensic cases in which human skeletal remains were ravaged by carnivores, whereas Haglund (1997) reviews canid data. Haglund (1992) contrasts rodent and carnivore damage.

Figure 5.4 Carnivore-gnawing marks on prehistoric human skeletal elements. The femur (*top left*) shows destruction of the spongy bone of the greater trochanter and associated broad horizontal grooves made by carnivore teeth just below the trochanter position. The humerus (*top right*) shows similar destruction of trabecular bone along with small punctures left by gnawing on the articular surface of the head. The os coxae (*bottom*) shows destruction of the iliac crest and adjacent perforations caused by gnawing. California. Natural size.

Although rodents are generally smaller than carnivores, their gnawing can be just as destructive. Rodents ranging in size from mice to large porcupines chew on bones. Like carnivores, large rodents can move bones around on the landscape, often carrying them over large distances to their dens, where they accumulate and modify them by chewing. The chisel edge of the rodent incisor is used to shave away the surface bone, producing a distinctive, fan-shaped pattern of regular, shallow, parallel or subparallel, flat-bottomed grooves that are usually concentrated on the projecting surfaces of bones. These traces can be patterned and regular, but they should not be confused with modifications to bone made by humans (Figure 5.5).

In addition to displaying traces of chewing by mammals, bones can be scarred by the action of mammalian feet. Trampling by ungulates and polishing by constant passage of carnivores in a lair may scratch and polish bone surfaces. The superficial striations that result from trampling might be mistaken for cut marks until it is appreciated that these marks, unlike cut marks, are usually randomly oriented and concentrated in fields of parallel striae across the most prominent parts of the bone.

5.3.2 Plant

Plants send their roots into the ground in search of water and nutrients. These roots secrete acids that can be very effective at etching the surfaces of buried bones. The initial pattern of root damage is usually a reticulate network of shallow grooves that should not be mistaken for the work of prehistoric engravers (Figure 5.6). This root-etched network can become so dense that the entire outer surface of a bone is etched away. Individual root-mark grooves are often whiter in color than the surrounding bone because of decalcification brought about by the acid.

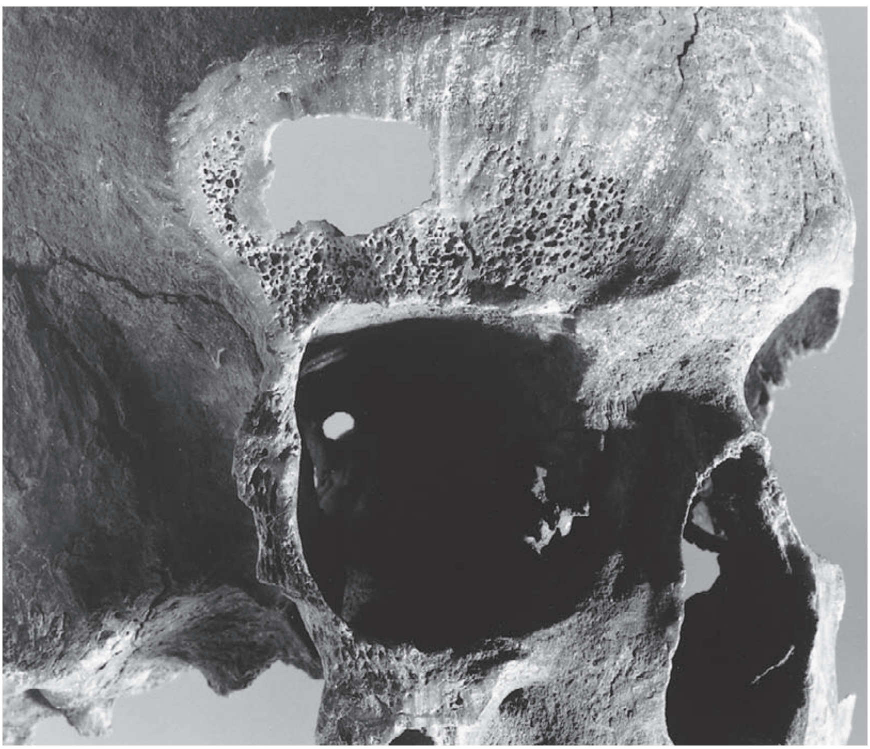
5.4 Bone Modification by Humans

Distinguishing human from nonhuman agents in the modification of skeletal remains continues to preoccupy anthropologists studying human origins in Africa, the peopling of the New World, and many other problems of prehistory. As noted previously, many actualistic studies have been conducted with the goal of discovering diagnostic attributes of human bone modification in archeological contexts. Most of these studies focus on nonhuman skeletal remains and are referred to as **zooarcheology**. Their results also apply in cases where human remains are the objects of human modification.

Human mortuary practices may have profound effects on the disposition of a skeleton. For example, the forcing of the corpse into a small space can cause strange anatomical juxtapositions and even fractures. In secondary burials, there are often traces of human activity left on the bones; defleshing can leave cut marks and scraping marks on the bones, and cremation usually causes charring (resulting in white, gray, black, and blue hues) and transverse cracking of the bones. Fortunately for the osteologist, aboriginal cremation may be inefficient, leaving identifiable fragments available for recovery and analysis.

Cannibalism in an archeological context is a topic of considerable anthropological interest. Humans can fracture long-bone shafts with hammerstones and pulverize

Figure 5.5 Highly patterned rodent gnawing marks on human skeletal elements. The tibia (*left*), from prehistoric California, shows gnawing by a very small rodent. The cranium (*below*), from a prehistoric African site, shows heavy gnawing, with broader gouges left by the incisors of an African porcupine. Natural size.



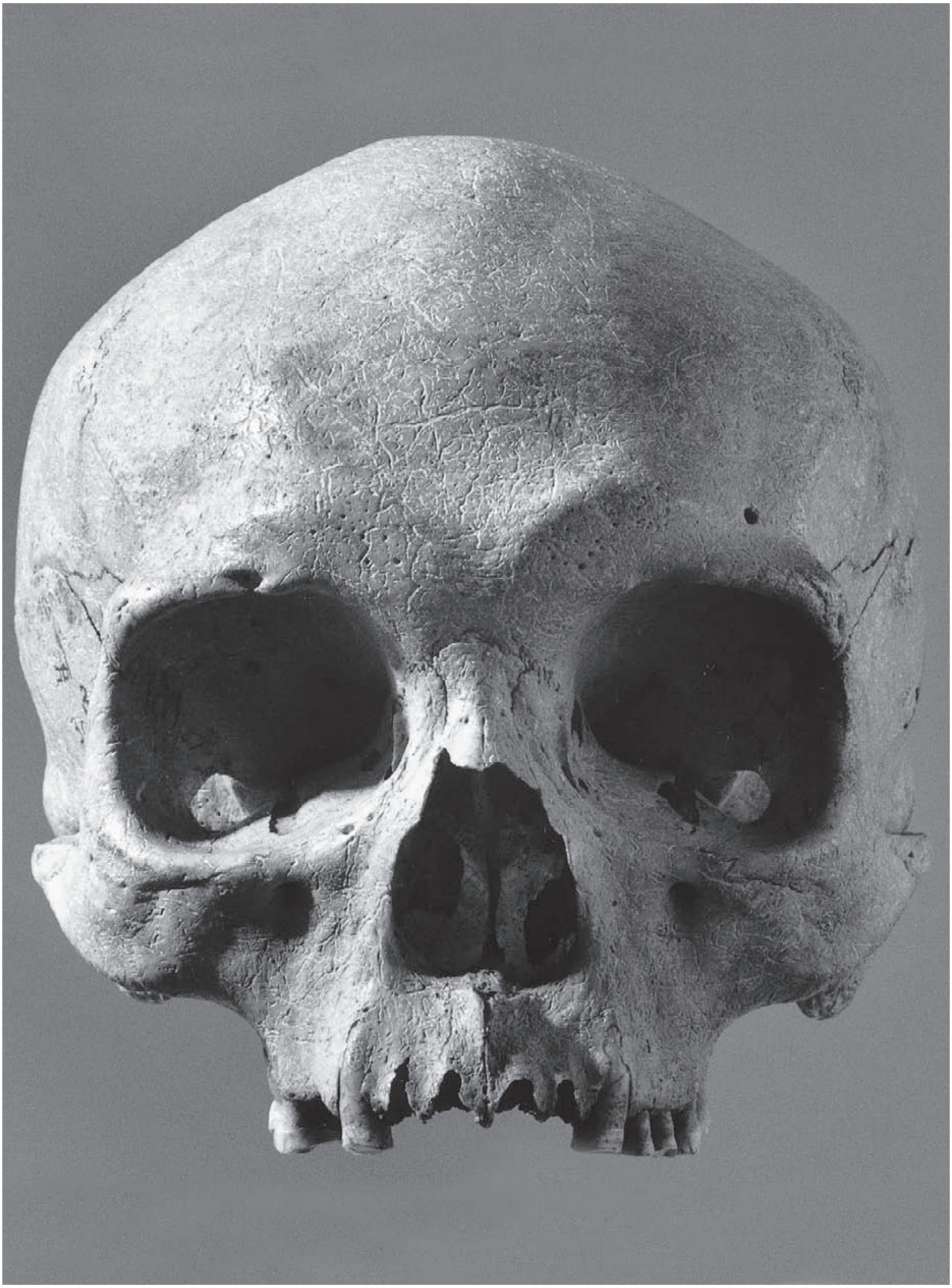


Figure 5.6 Root marking on a human cranium from a prehistoric California site. Such delicate, intricate etching of grooves should not be mistaken for cultural activities. Natural size.

long-bone ends to extract nutritious fat. Percussion pits and anvil scars are usually seen under these conditions (White, 1992). Cut marks made by stone or metal tools may also appear on skeletal remains in a cannibalized assemblage. Burning of the bone associated with roasting is often concentrated on the subcutaneous surfaces of bones such as the cranium, mandible, and tibia. Study of the patterns of bone destruction through bone assemblage composition and the actual physical traces left on individual bones often makes it possible to distinguish between human and nonhuman damage to bones.

As noted in Chapter 2, improper excavation, transport, and cleaning of bones in the field or laboratory can result in damage to skeletal remains. This "preparation," or cleaning, damage is usually easily discernible from perimortem damage on the basis of its distribution and surface characteristics. Many of the world's most famous hominid fossils have been damaged in this manner. Metal instruments, including dental picks, electric drills, and even wire brushes, can all leave traces on osteological specimens, but this damage should never be mistaken as evidence for prehistoric human behavior. The osteologist should take precautions to avoid inflicting such damage on skeletal remains. These excavation- and preparation-related defects are often easily diagnosed based on their color. Ancient surficial defects in a bone usually accumulate soil, matrix, stains, or other residues that darken them relative to the adjacent bone. Recently made defects are usually lighter in color and free of staining and microscopic and macroscopic foreign debris.

Discrimination between taphonomic agents or "actors" that anciently caused surface modifications to bones is often thought to be a more difficult task. For example, some have advocated the use of scanning electron microscopy to choose between diagnoses of carnivore chewing marks or humanly induced cut marks. Blind tests in a study by Blumenschine *et al.* (1996) demonstrated excellent inter-analyst agreement and accuracy in identifying cut marks, percussion marks, and carnivore tooth marks was excellent, approaching 100% for experts. Major human-made modifications to bone surfaces are outlined in the following sections and are illustrated and discussed fully in White (1992).

5.4.1 Cut marks, Chop marks, and Scrape marks

When the sharp, often irregular edge of a stone tool contacts the surface of a bone during defleshing or disarticulation activities, a **cut mark** (Figure 5.7) is formed. These marks are usually much narrower, finer, and more V-shaped than carnivore tooth marks. Unlike the single rough furrow of a carnivore mark or the flat-bottomed trough of a rodent incisor mark, cut marks usually display striae within the mark and often show "shoulder marks" or "barbs" where different parts of the tool edge contact the bone and thereby cut their own parallel or subparallel marks. Cut marks are usually the result of slicing activities in which the blade of the tool is used perpendicular to the grain of the tissue being sliced. **Chop marks** (Figure 5.8) are similar to cut marks, but result from forceful and abrupt contact between tool edge and bone rather than from slicing activities. Chop marks are less frequent in archeological bone assemblages modified by stone tools with fragile edges and are more frequent in forensic cases where metal implements allow the chopping of tissues. **Scrape marks**, made when the edge of the tool is scraped

Figure 5.7 Cut marks made by stone tools on two femoral shaft fragments and a clavicle. Cut marks are usually patterned with respect to the soft tissue that was being cut from the body—here, defleshing cut marks to remove leg musculature, and marks made in the process of decapitation. Bar: 1 cm. From White (1992).

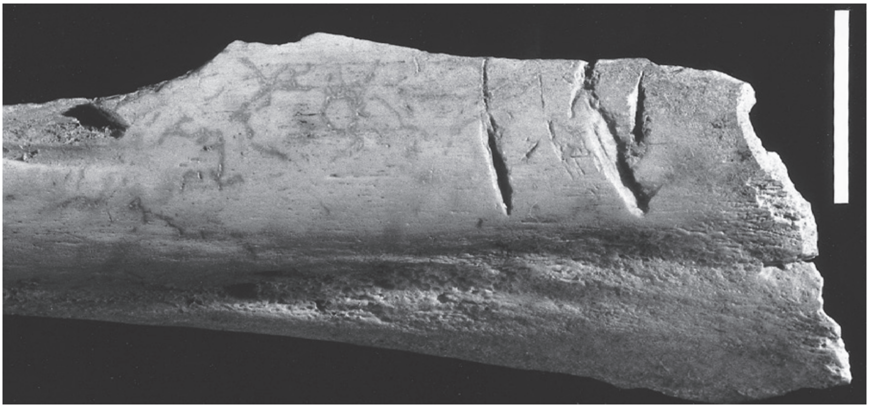


Figure 5.8 Chop marks made by stone tools on the posterior surface of a proximal tibial fragment. Bar: 1 cm. From White (1992).

across the surface of the bone, also show lower frequencies in archeological assemblages for the same reason. These are usually shallower than either cut marks or chop marks, but they cover wider areas with many parallel or subparallel striations.

5.4.2 Percussion Marks

Cut marks and chop marks are frequently encountered in both forensic and archeological contexts. In the forensic context, such marks can indicate antemortem trauma or postmortem attempts to disarticulate body segments. Once disarticulated and (less frequently) defleshed, the elements of the skeleton can be reduced further by direct percussion with a heavy object. This is rarely seen in forensic contexts, but it is virtually universal in zooarcheological contexts. Fat is highly prized by many people, and bones contain fatty marrow in both their medullary cavities and their trabecular regions. To obtain fat from the first location, the shafts are cracked and pulled apart. Fat in the spongy bone can be extracted by eating the crushed trabecular portions or by boiling them to render the fat in cooking vessels. All of these cultural activities have the potential to leave traces on the bones.

When fracture of the bone is effected with a stone hammerstone, irregular, roughened **percussion pits** (Figure 5.9) that correspond to the tip of the percussor may be left on the bone (particularly if all soft tissue has been removed). If this activity is undertaken on an anvil or if the percussor moves slightly as it impacts the bone, **percussion** (or **anvil**) **striae** (Figure 5.10) may result. This activity often produces **inner conchoidal scars** (Figure 5.11) on the medullary cavity surface of the bone shaft and **adhering flakes** on the shaft wall. When the target marrow is in the trabecular portions of the bone, the percussion to this area sometimes creates crushing (Figure 5.12), and when fresh bone fragments are pulled apart forcefully, the result is sometimes peeling, particularly on immature bones and ribs (Figure 5.13). When the fragmented bones are boiled in ceramic vessels in an attempt to render grease, some of the shaft fragments may acquire a peculiar form of abrasion on their tips called **pot polish** (White, 1992).

5.4.3 Projectiles

The previous examples of bone modification have been selected from archeological contexts, but because fresh bone interacts with foreign objects in the same way, the behavioral deductions based on such modifications also largely apply in the modern forensic realm. In this realm, matching bone modifications found on victims of knives and other tools to the tools themselves is sometimes possible and important. High-speed projectiles such as arrows have been modifying human skeletal remains for thousands of years (Figure 5.14). In the modern forensic context, projectiles are most often metal, in the form of bullets of various caliber, or shrapnel (Figure 5.15). The analysis of entry versus exit damage to osteological remains is often critical in forensic investigations. In addition to this bone modification evidence, the radiographic discovery of foreign metal or other objects in skeletal remains often constitutes an additional critical dimension of forensic analysis.

Figure 5.9 Percussion pits made by stone hammerstones. Bar: 1 cm. From White (1992).

Figure 5.10 Percussion pits associated with percussion striae on long bone shaft fragments. The co-occurrence of hammerstone and anvil striae with these pits is good evidence of human involvement in the processing of these bones. Bar: 1 cm. From White (1992).

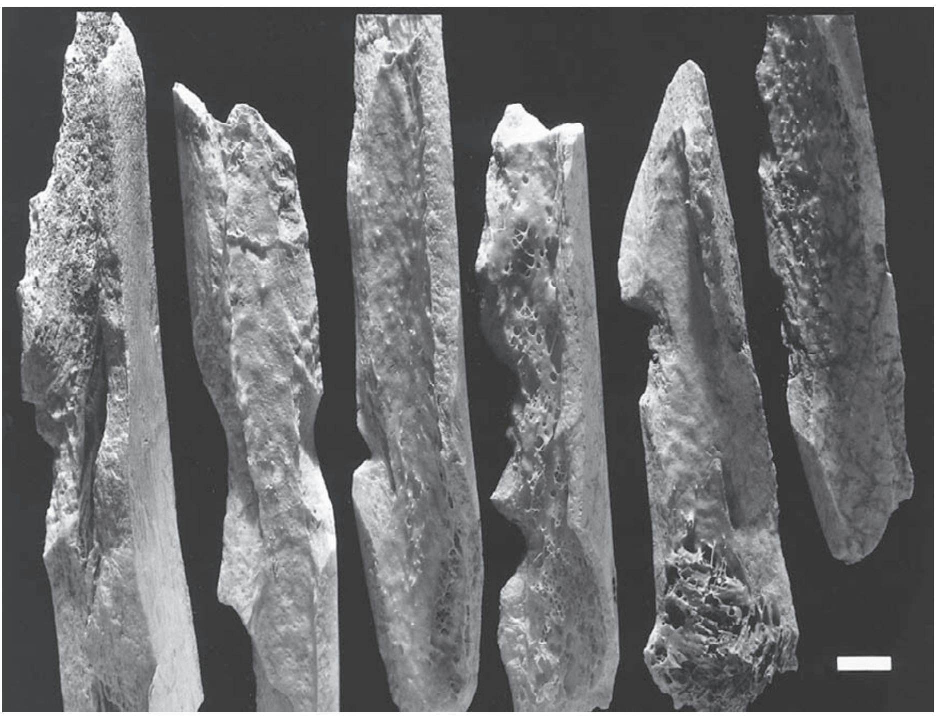


Figure 5.11 Inner conchoidal scars formed when these femoral specimens were fractured for their marrow. Bar: 1 cm. From White (1992).

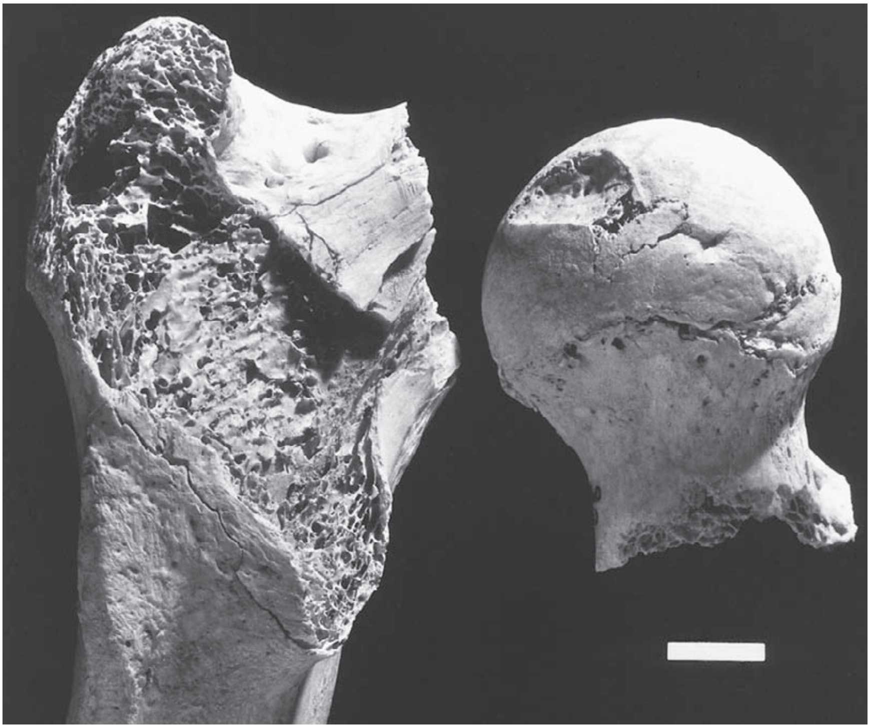


Figure 5.12 When spongy bone is crushed by force, cortex on the adjacent areas is pushed into the crushed area, as in these femoral specimens. Note also the disarticulation cut marks on the femoral neck. Bar: 1 cm. From White (1992).

Figure 5.13 Peeling on a juvenile's proximal ulna (*top*) and an adult's rib (*bottom*). Bar: 1 cm. From White (1992).

Figure 5.14 Projectile point embedded in the ventral surface of a human sternum. No bony reaction is seen, indicating that the event was perimortem, cause of death unknown. Prehistoric California.

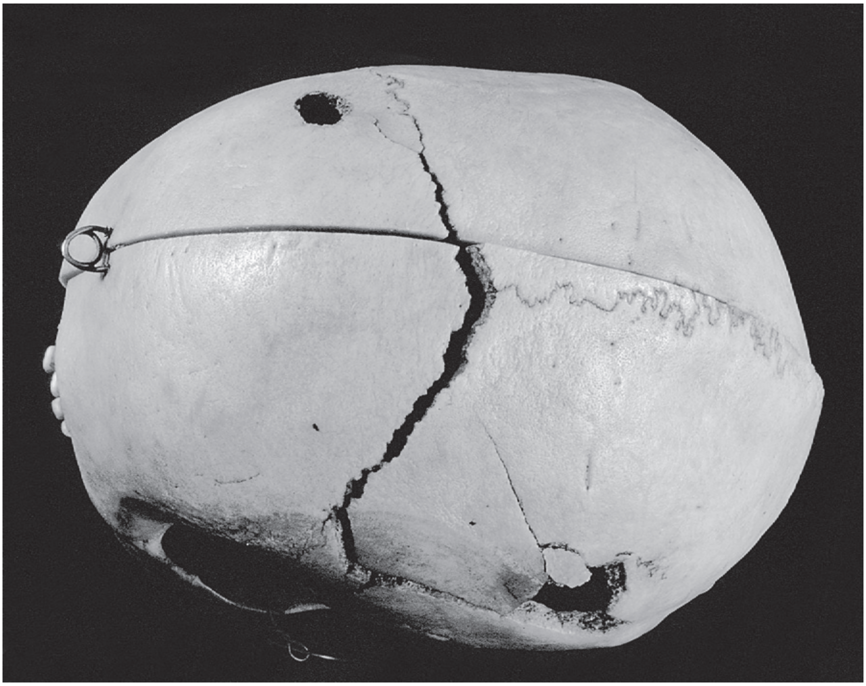


Figure 5.15 Bullet entry and exit wound, modern human homicide victim. Cause of death known from autopsy records. Modern Cleveland.

Chapter 6

Anatomical Terminology

Human anatomists and anthropologists throughout the world use a specific vocabulary to describe the human body. Anatomical nomenclature is both concise and precise, allowing unambiguous communication among all researchers who study skeletal material. Indeed, it is virtually impossible to follow even basic descriptions or interpretations in paleontology, physical anthropology, medicine, human anatomy, and a variety of allied disciplines without a command of the basic, general anatomical terms introduced in this chapter. Here we define the essential planes of reference, directional terms, body motions, and bony formations necessary for the detailed study of human osteology. Anatomical nomenclature has evolved from a classical foundation, and many of the names used to describe bones and their parts are derived from Latin and Greek terms. A working knowledge of these roots and prefixes may facilitate learning the names of bones and their parts.

Anatomical terminology for hominids refers to the body in what is called **standard anatomical position** (Figures 6.1–6.2). Standard anatomical position is that of a human standing, looking forward, feet together and pointing forward, with none of the long bones crossed from the viewer's perspective. To prevent the crossing of bones, the palms of the hands must face forward, with the thumbs pointing away from the body. The terms **left** and **right** refer to the sides of the subject being observed, not to the observer's own right or left sides. **Cranial** skeletal anatomy refers to the skull; the remainder of the skeleton is called **postcranial** anatomy. The **axial skeleton** refers to the bones of the trunk, including the vertebrae, sacrum, ribs, and sternum. The **appendicular skeleton** refers to the bones of the limbs, including the shoulder and pelvic girdles.

6.1 Planes of Reference

Three basic reference planes are used in human osteology. The **sagittal** (**midsagittal**, **median**, or **midline**) plane divides the body into symmetrical right and left halves. Any planar slice through the body that parallels the sagittal plane is called a **parasagittal section**. A **coronal** (**frontal**) plane divides the body into anterior and posterior halves and is placed at right angles to the sagittal plane. A **transverse** (**horizontal**) plane slices through the body at any height but always passes perpendicular to the sagittal and frontal planes.

6.2 Directional Terms

In osteology it is useful to refer to directions of motion or the relative locations of various skeletal parts. All of the directional terms used here refer to the human body in standard anatomical position, but it is important to note that most of these terms are applicable to all mammals. A few terms may occasionally cause confusion when hominid (the zoological family of primates to which humans and their immediate ancestors and near-relatives belong) and nonhominid bones are being compared because humans are **orthograde** (trunk upright) bipeds and most other mammals are **pronograde** (trunk horizontal) quadrupeds.

6.2.1 General

a. **Superior**: toward the head end of the hominid body. The *superior* boundary of the human parietal bone is the sagittal suture. **Cephalic** and **cranial** are synonymous terms that may be used homologously for bipeds and quadrupeds.
b. **Inferior**: opposite of superior; for hominids, body parts away from the head. The *inferior* surface of the calcaneus, or heel bone, is the part of the bone that rests nearest to, or lies in contact with, the ground. **Caudal**, toward the tail, is often used in the description of quadrupedal anatomy.
c. **Anterior**: toward the front of the hominid body. The breastbone, or sternum, is located *anterior* to the backbone, or vertebral column. **Ventral**, toward the belly, may be used homologously for bipeds and quadrupeds.
d. **Posterior**: opposite of anterior; for hominids, toward the back of the individual. The occipital bone is on the *posterior* and inferior end of the skull. **Dorsal** is often used for homologous parts of the quadruped anatomy.
e. **Medial**: toward the midline. The left side of the tongue is *medial* to the left half of the mandible.
f. **Lateral**: opposite of medial; away from the midline. The thumb occupies a *lateral* position relative to the little finger in standard anatomical position.
g. **Proximal**: nearest the axial skeleton, usually used for limb bones. The *proximal* end of the upper arm bone, the humerus, is the end toward the shoulder.
h. **Distal**: opposite of proximal; farthest from the axial skeleton. The *distal* end of the terminal foot phalanx fits into the front end of a shoe.
i. **External**: outer. The cranial vault is an *external* covering of the brain.
j. **Internal**: opposite of external; inside. The *internal* surface of the parietal is marked by a set of grooves made by blood vessels that lie external to the brain.
k. **Endocranial**: inner surface of the cranial vault. The brain fills the *endocranial* cavity.
l. **Ectocranial**: outer surface of the cranial vault. The temporal line is on the *ectocranial* surface of the parietal.
m. **Superficial**: close to the surface. The ribs are *superficial* to the heart.
n. **Deep**: opposite of superficial; far from the surface. The dentine core of a tooth is *deep* to the enamel.
o. **Subcutaneous**: just below the skin. The anteromedial surface of the tibia is *subcutaneous.*

6.2.2 Teeth

a. **Mesial**: toward the midline point of the dental arch where the central incisors contact each other. The anterior portion of molar and premolar crowns and the medial parts of canines and incisors are called the *mesial* parts of these teeth. The *mesial* surface of the canine touches the incisor next to it, and the *mesial* surface of the first molar touches the premolar next to it.
b. **Distal**: opposite of mesial. The *distal* half of a premolar is the posterior half of the tooth.
c. **Lingual**: toward the tongue. The *lingual* surfaces of tooth crowns are usually hidden from view when a person smiles.
d. **Labial**: opposite of lingual; toward the lips; usually reserved for incisors and canines. The *labial* surfaces of incisors are observed when a person smiles.
e. **Buccal**: opposite of lingual; toward the cheeks; usually reserved for premolars and molars. A wad of chewing tobacco is often wedged between the cheek and the *buccal* surfaces of the molars of American baseball players.
f. **Interproximal**: in contact with adjacent teeth in the same jaw. Dental floss often gets stuck in *interproximal* areas.
g. **Occlusal**: facing the opposing dental arch, usually the chewing surface of each tooth. Caries ("cavities") are often found on the irregular *occlusal* surfaces of the molar teeth.
h. **Incisal**: the biting, or occlusal, edge of the incisors. The *incisal* edges of the central incisors are used to bite into an apple.
i. **Mesiodistal**: axis running from mesial to distal. The *mesiodistal* dimension of a molar may be reduced by interproximal wear.
j. **Buccolingual** and **labiolingual**: axis running from labial or buccal to lingual. The incisors of Neanderthals often have large *labiolingual* dimensions.

6.2.3 Hands and Feet

a. **Palmar**: palm side of the hand. The *palmar* surface of the digits bears fingerprints.
b. **Plantar**: sole of the foot. The *plantar* surface of the foot contacts the ground during normal walking.
c. **Dorsal**: top of the foot or the back of the hand. The *dorsal* surfaces of hands and feet often bear hair, whereas the palmar and plantar surfaces do not.

6.3 Motions of the Body

Movement of the body is accomplished by muscles acting directly or via tendons on bones. The less mobile attachment point that anchors a muscle is called the origin of the muscle, and the insertion is the site of muscle attachment with relatively more movement than the origin.

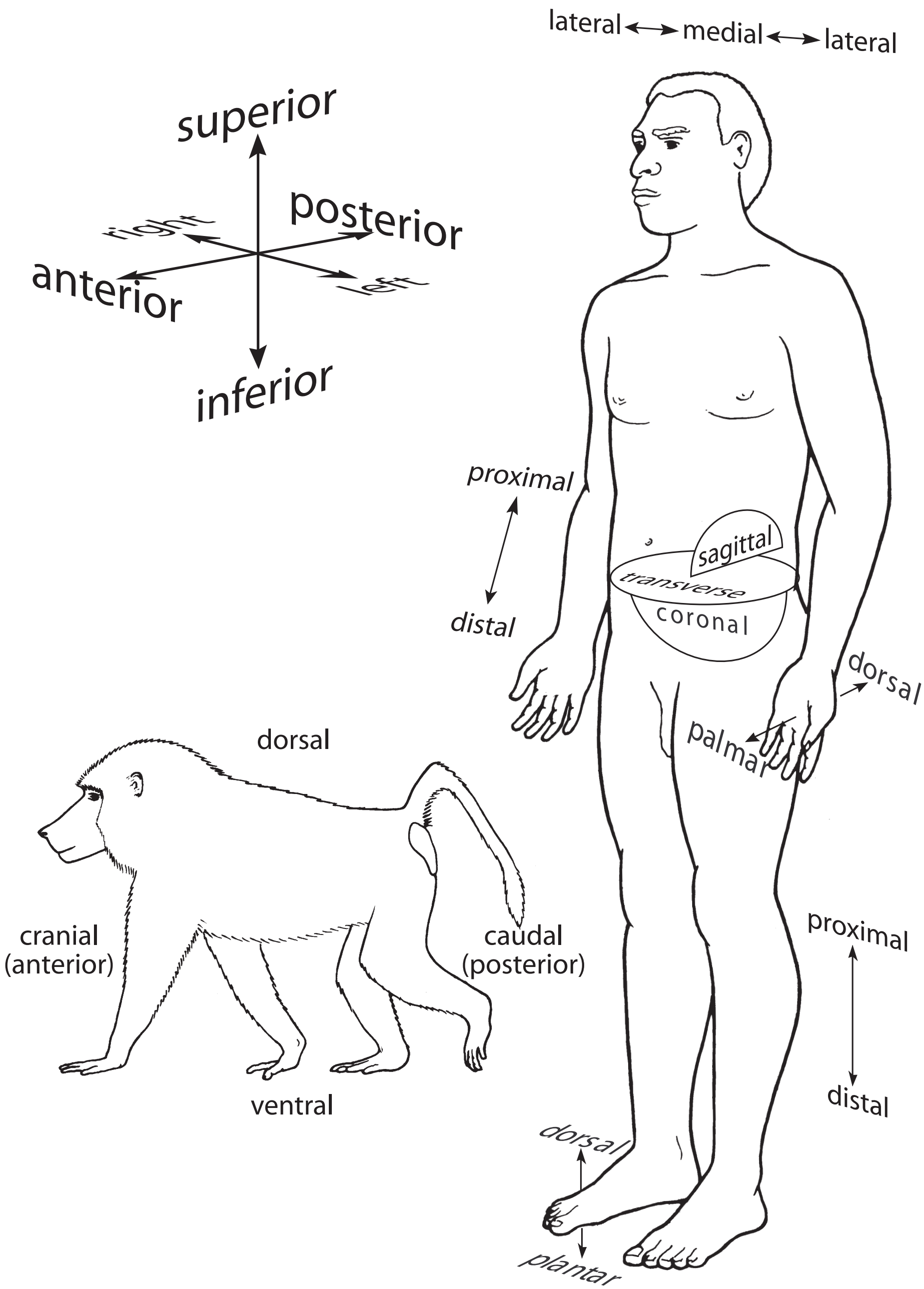
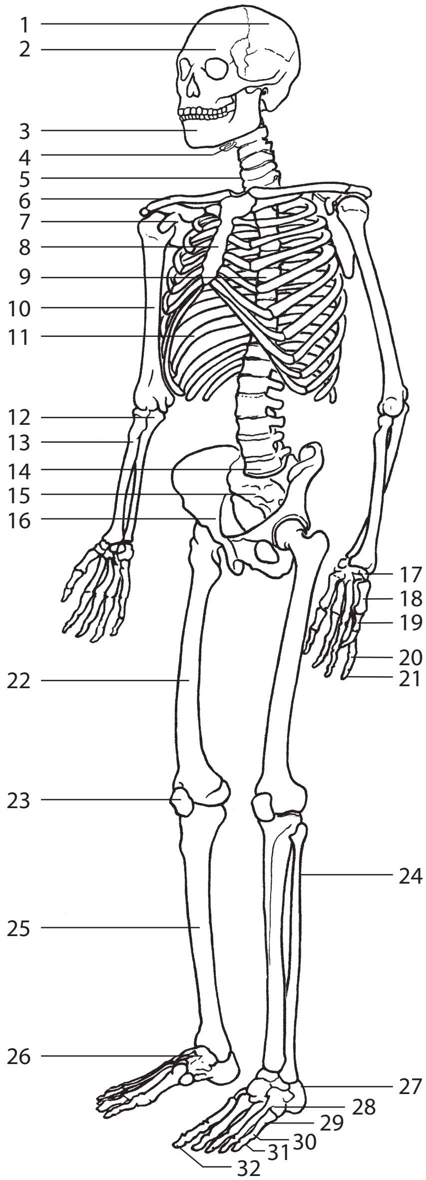


Figure 6.1 Directional terms and planes for a human and a quadrupedal mammal. Knowledge of the directional terms and planes of reference is necessary for any work in human anatomy. In human osteology, these terms are essential for the study and comparison of skeletal elements.



1. Paired cranial elements (22)
2. Single cranial elements (5)
3. Mandible (1)
4. Hyoid (1)
5. Cervical vertebrae (7)
6. Clavicle (2)
7. Scapula (2)
8. Sternum (1)
9. Thoracic vertebrae (12; var*)
10. Humerus (2)
11. Ribs (24; var*)
12. Ulna (2)
13. Radius (2)
14. Lumbar vertebrae (5; var*)
15. Sacrum (1)
16. Os coxae (2)
17. Carpals (16)
18. Metacarpals (10)
19. Proximal hand phalanges (10)
20. Intermediate hand phalanges (8)
21. Distal hand phalanges (10)
22. Femur (2)
23. Patella (2)
24. Fibula (2)
25. Tibia (2)
26. Talus (2)
27. Calcaneus (2)
28. Other tarsals (10)
29. Metatarsals (10)
30. Proximal foot phalanges (10)
31. Intermediate foot phalanges (8)
32. Distal foot phalanges (10)

    Coccyx (1; not visible)

TOTAL: 206 Adult

* Commonly variable elements indicated by (var*)

Figure 6.2 Skeletal elements.

6.3.1 General

a. **Flexion**: generally, a bending movement that decreases the angle between body parts. When a hand is clenched into a fist there is strong *flexion* of the phalanges on the metacarpal heads. By convention, flexion at the shoulder or hip joint refers to a ventral (forward) movement of the limb.

b. **Extension**: opposite of flexion; a straightening movement that increases the angle between body parts. The classic karate chop is made by a rigid hand in which the fingers are extended. By convention, *extension* at the shoulder or hip joint is a dorsal (backward) swing of the limb.
c. **Abduction**: movement of a body part, usually a limb, away from the sagittal plane. When the arm is raised to the side from standard anatomical position, *abduction* of the arm occurs. For the special case of fingers and toes, *abduction* is movement of the digit away from the midline of the hand or foot (spreading the digits).
d. **Adduction**: opposite of abduction; movement of a body part, usually a limb, toward the sagittal plane. Bringing the arm down to slap the side of the thigh is *adduction*. For the special case of fingers and toes, *adduction* is movement of the digit toward the midline of the hand or foot (closing the digits).
e. **Circumduction**: a combination of abduction and adduction, as well as flexion and extension, that results in an appendage being moved in a cone-shaped path. When the driver of a slow vehicle signals someone behind him to pass, this "waving on" is often done by *circumducting* the arm.
f. **Rotation**: motion that occurs as one body part turns on an axis. The head of the radius *rotates* on the distal humerus.
g. **Opposition**: motion in which body parts are brought together. *Opposition* of the thumb and finger tips allows us to grasp small objects.

6.3.2 Hands and Feet

a. **Pronation**: rotary motion of the forearm that turns the palm from anteriorly facing (thumb lateral) to posteriorly facing (thumb medial). Typewriters are used with the hand in *pronation*.
b. **Supination**: opposite of pronation; rotary motion of the forearm that returns the palm to a position in which the thumb is lateral. When chimpanzees beg for food the hand is often held in *supination*.
c. **Dorsiflexion**: flexion of the entire foot away from the ground. When a mime walks on her heels, her feet are *dorsiflexed*.
d. **Plantarflexion** (**volarflexion**): opposite of dorsiflexion; flexing of the entire foot inferiorly, toward the ground at the ankle. Action in both dorsiflexion and plantar flexion occurs at the ankle. When a ballerina walks on her toes, her feet are strongly *plantarflexed*.
e. **Eversion**: turning the sole of the foot outward so that it faces away from the midline of the body. Also known as **pronation** of the foot.
f. **Inversion**: turning the sole of the foot inward so that it faces toward the midline of the body. Also known as **supination** of the foot.

6.4 General Bone Features

Whereas the directions and motions described in Sections 6.2 and 6.3 have very precise meanings, the series of general terms applied to bony features is more ambiguous and cross-cutting. For example: the question—when is a tubercle big enough to be called a tuberosity (or a trochanter)—is rarely faced by the osteologist. This is because the conventional labels for various bones and bone parts are always adopted to ensure stability of nomenclature and effectiveness of communication. Specific terms for nearly all bones and their parts are already established, and have been for a long time. The "greater trochanter" of a femur, for example, identifies a particular, unique structure for all human osteologists. Recognize that the following terms are often vague by themselves, but are unambiguous when coupled with element-specific names introduced in Chapters 7–16.

6.4.1 Projections and Parts

a. **Process**: a bony prominence. The mastoid *process* forms the prominence behind the ear.
b. **Eminence**: a bony projection; usually not as prominent as a process. The articular *eminence* of the temporal bone is the rounded area with which the mandibular condyle articulates during chewing.
c. **Spine**: generally a longer, thinner, sharper process than an eminence. Vertebral *spines* are used in the identification of various vertebrae.
d. **Tuberosity**: a large, usually rugose (roughened) eminence of variable shape; often a site of tendon or ligament attachment. The deltoid *tuberosity* marks the shaft of the humerus.
e. **Tubercle**: a small, usually rugose eminence; often a site of tendon or ligament attachment. The conoid *tubercle* is found along the inferior edge of the clavicle.
f. **Trochanters**: two large, prominent, blunt, rugose processes found on the femur. The larger of these is called the greater *trochanter,* the smaller is the lesser *trochanter*.
g. **Malleolus**: a rounded protuberance adjacent to the ankle joint. It is easy to palpate (examine by touch) both lateral and medial *malleoli*.
h. **Boss**: a smooth, round, broad eminence. Female skulls tend to show more *bossing* of the frontal bone than those of males.
i. **Articulation**: an area where adjacent bones are in contact (via cartilage or fibrous tissue) at a joint. The most proximal surface of the tibia is said to *articulate* with the distal end of the femur.
j. **Condyle**: a rounded articular process. The occipital *condyles* lie on the base of the cranium and articulate with the uppermost vertebra, the atlas.
k. **Epicondyle**: a nonarticular projection adjacent to a condyle. The lateral *epicondyle* of the humerus is located just proximal to the elbow, adjacent to the lateral condylar surface.
l. **Head**: a large, rounded, usually articular end of a bone. The *head* of the humerus is the superior (proximal) end of the bone.
m. **Shaft**, or **diaphysis**: the long, straight section between the ends of a long bone. The femoral *shaft* is roughly circular in cross section.
n. **Epiphysis**: in general usage, usually the end portion or extremity of a long bone that is expanded for articulation. The proximal *epiphysis* of the tibia is the expanded end of the bone that articulates with the femur. See Chapter 4 for more

precise definitions of the diaphysis, epiphysis, and metaphysis.

o. **Neck**: the section of a bone between the head and the shaft. The *neck* of the femur is long relative to the size of the femoral head in some early hominids.
p. **Torus**: a bony thickening. The supraorbital *torus* on some *Homo erectus* frontal bones is very thick.
q. **Ridge**: a linear bony elevation, often roughened. The lateral supracondylar *ridge* of the humerus borders the bone above the lateral epicondyle.
r. **Crest**: a prominent, usually sharp and thin ridge of bone; often formed between adjacent muscle masses. The sagittal *crest* is a structure that forms during the development of large temporalis muscles in the gorilla.
s. **Line**: a raised linear surface, not as thick as a torus or as sharp as a crest. The inferior temporal *lines* mark the superior extent of the temporalis muscles.
t. **Hamulus**: a hook-shaped projection. The hamulus of the wrist's hamate bone gives the bone its name.
u. **Facet**: a small articular surface, or a tooth contact. Bodies of the thoracic vertebrae have *facets* for articulation with the heads of ribs. Occlusal *facets* form on the chewing surfaces of the teeth shortly after crown eruption.

6.4.2 Depressions

a. **Fossa**: a depressed area; usually broad and shallow. The olecranon *fossa* is located on the posterior surface of the distal humerus, where it receives the proximal ulna during full extension of the arm.
b. **Fovea**: a pit-like, depressed area; usually smaller than a fossa. The anterior *fovea* of an unworn molar is seen in occlusal view.
c. **Groove**: a long pit or furrow. The intertubercular *groove* passes between two tubercles on the humerus.
d. **Sulcus**: a long, wide groove. A strong supratoral *sulcus* is present on African ape crania but is weak or absent on *Australopithecus* crania.
e. **Fontanelle**: a space between cranial bones of an infant. The soft spot atop a baby's head indicates the presence of a *fontanelle*.
f. **Suture**: where adjacent bones of the skull meet (articulate). The lambdoidal *suture* is between occipital and parietal bones.
g. **Foramen**: an opening through a bone, usually a passage for blood vessels and nerves. The mental *foramen* is an opening on the lateral surface of the mandible.
h. **Canal**: a tunnel-like, extended foramen. The carotid *canal* is found at the base of the skull.
i. **Meatus**: a short canal. The external auditory *meatus* is the canal that connects the middle and outer ear.
j. **Sinus**: a cavity within a cranial bone. The frontal *sinus* is well developed in some early hominid crania.
k. **Alveolus**: a tooth socket. The canine *alveolus* in the mandible is deeper than the incisor alveolus.

Chapter 7

Skull

The skull is the most complex portion of the skeleton and is of major importance for human osteology. It is one of the keys to aging, sexing, and understanding the evolutionary history of hominids. The complexity of the human skull can best be understood by recognizing the widely differing functions it performs. It forms the bony foundation for the senses of sight, smell, taste, and hearing. It houses and protects the brain. In addition, the skull forms the framework of the chewing apparatus. Given these varied functions, it is no wonder that the skull is a complex structure.

Before moving to a detailed consideration of the individual bones of the skull, it is useful to consider this part of the anatomy as a unit (Figures 7.1–7.6b). A few convenient landmarks are useful in this analysis. The eye sockets are the **orbits**. The hole between and below the orbits, the nose hole, is the **anterior nasal aperture**, or **piriform aperture**. The ear holes are **external auditory meati** (the singular is **meatus**), and the large oval hole in the base of the skull is the **foramen magnum**. The thin bony bridges at the sides of the skull are the **zygomatic arches**. The teeth are part of the skull, but because of their importance and peculiar anatomy an entire chapter is devoted to them (see Chapter 8).

7.1 Handling the Skull

In addition to being one of the most complex parts of the skeleton, some of the elements of the skull are also the most delicate. During study, the skull should be handled above a padded surface and stabilized against rolling on the surface by means of sandbags or cloth rings designed for this purpose. It is rarely necessary to store or manipulate the lower jaw in its natural anatomical position relative to the upper jaw. When this position is called for, however, note that the colliding upper and lower teeth are fragile and susceptible to chipping. Care should be exercised when occluding the upper and lower jaws in this fashion, and padding should always be placed between the teeth if the skull is stored in this position.

In handling the skull, always use common sense and both hands. A finger or thumb placed in and behind the foramen magnum will not damage the bone, but other openings, such as the orbits or zygomatic arches, are more fragile and should never be used as gripping surfaces. In addition to the thin bones within the orbits, those delicate parts that are susceptible to damage during cranial manipulation include the edges and insides of the nasal aperture and the thin, projecting pterygoid plates and

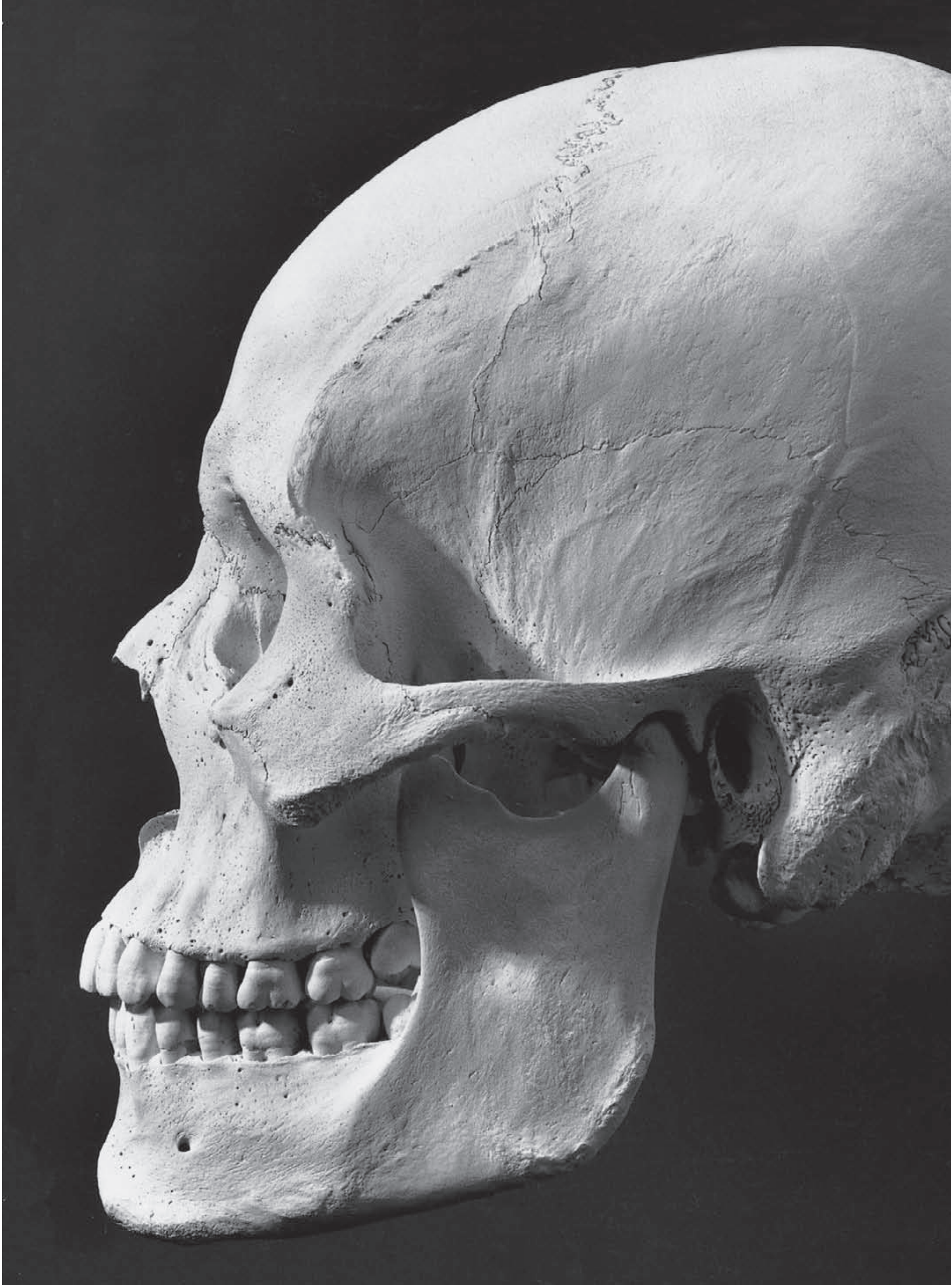
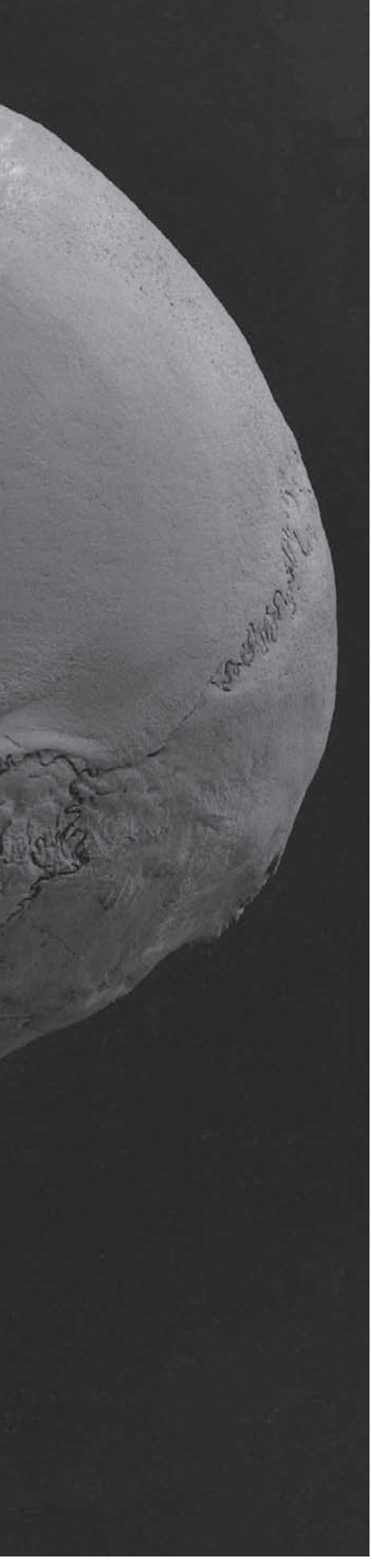


Figure 7.1 **Adult male skull, lateral.** Natural size.



styloid processes at the base of the skull. If teeth become dislodged during study, replace them immediately in the correct sockets.

The temptation to test the mechanical properties of dry bone by probing, twisting, poking, stabbing, and scraping should always be resisted. However, in the course of handling osteological material, breakage does occur. Fortunately, it is normally a simple matter to glue the bone back together. This should be done promptly by the laboratory supervisor so that the broken pieces are not lost permanently (see Chapter 18).

7.2 Elements of the Skull

The term "skull" suffers from common misuse. It is worthwhile to review the proper use of cranial terminology.

- The **skull** is the entire bony framework of the head, including the lower jaw.
- The **mandible** is the lower jaw.
- The **cranium** is the skull without the mandible.
- The **calvaria** is the cranium without the face.
- The **calotte** is the calvaria without the base.
- The **splanchnocranium** is the facial skeleton.
- The **neurocranium** is the braincase.

The three basic divisions of the endocranial surface at the base of the neurocranium correspond to the topography of the base of the brain. These anterior, middle, and posterior cranial fossae are respectively occupied by the frontal lobes, temporal lobes, and cerebellum of the brain.

When the ear ossicles (three pairs of tiny bones associated with hearing) are included and the hyoid excluded, there are usually twenty-eight bones in the adult human skull. Distinguishing these bones is occasionally made difficult because some of them fuse together during adult life. For this reason, it is advisable to begin study with young adult specimens, in which the bones are most readily recognizable. Bones of the skull are listed in Figure 7.8 according to whether they are single (unpaired) or paired in the adult skull. In addition to the bones listed in Figure 7.8, there are often sutural bones (also called **Wormian bones**, or **extrasutural bones**), irregular ossicles occurring along sutures. A large, triangular **inca bone** is occasionally found at the rear of human crania.

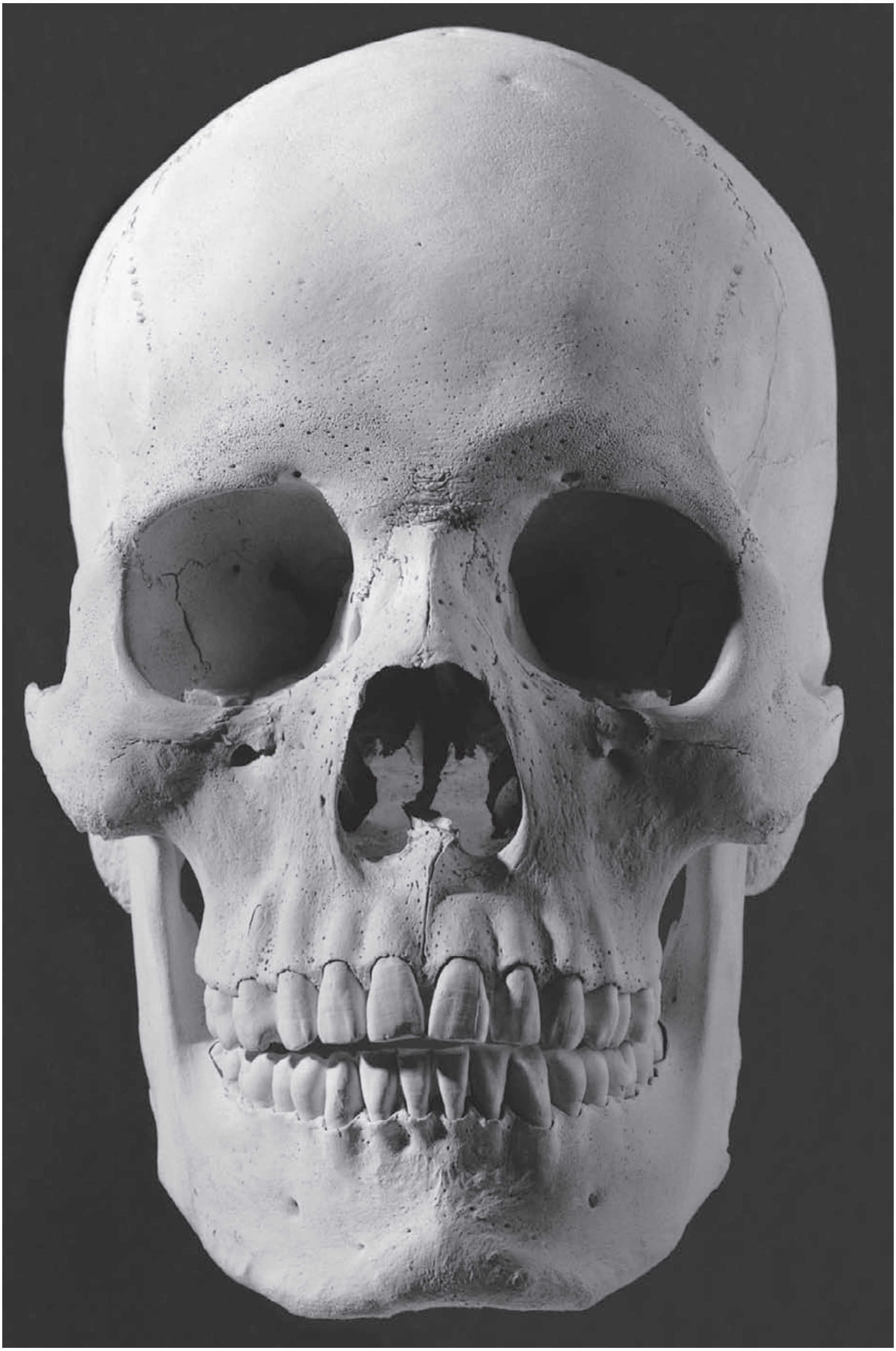


Figure 7.2 **Adult male skull, anterior.** Natural size.

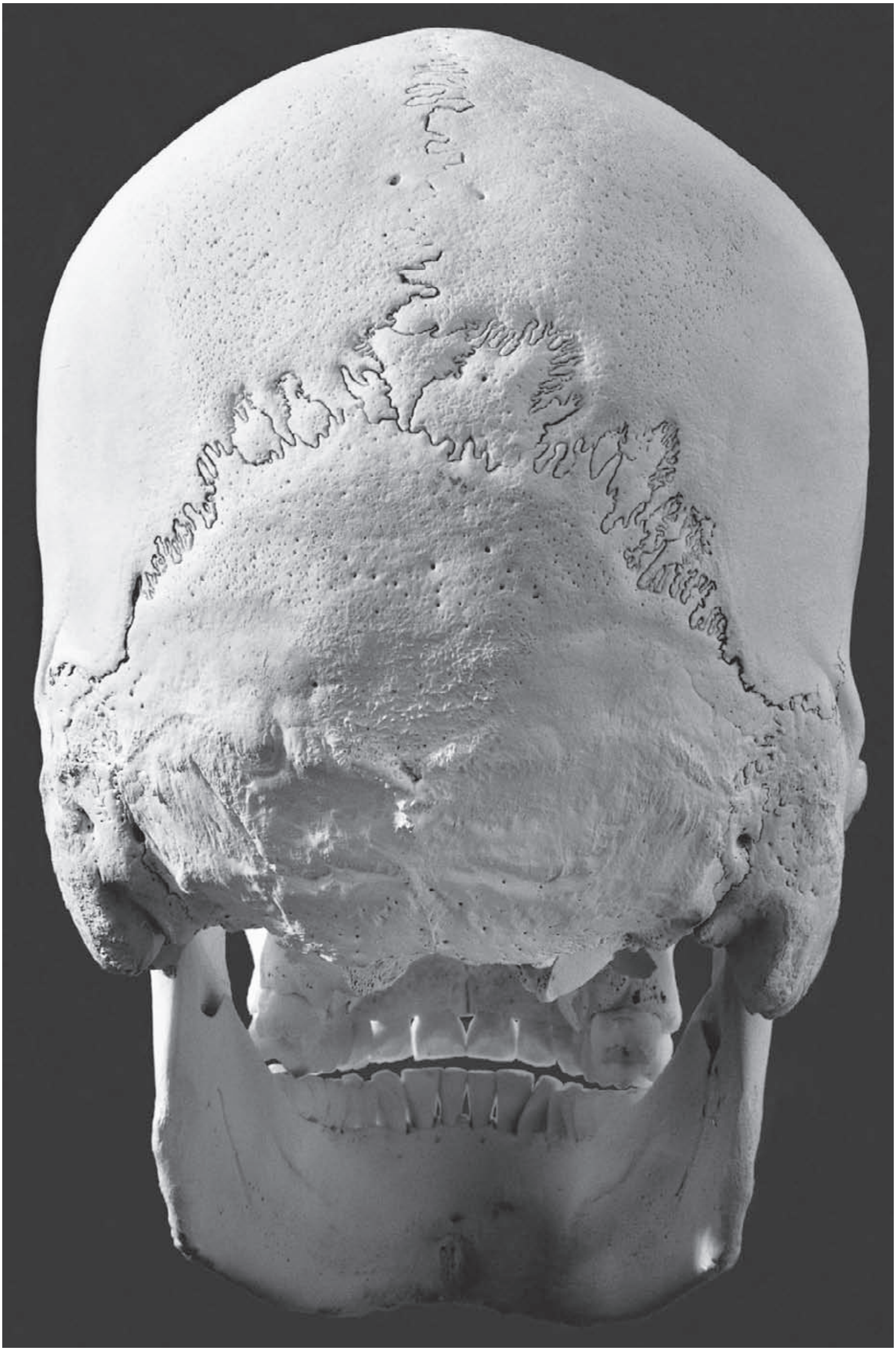


Figure 7.3 **Adult male skull, posterior.** Natural size.

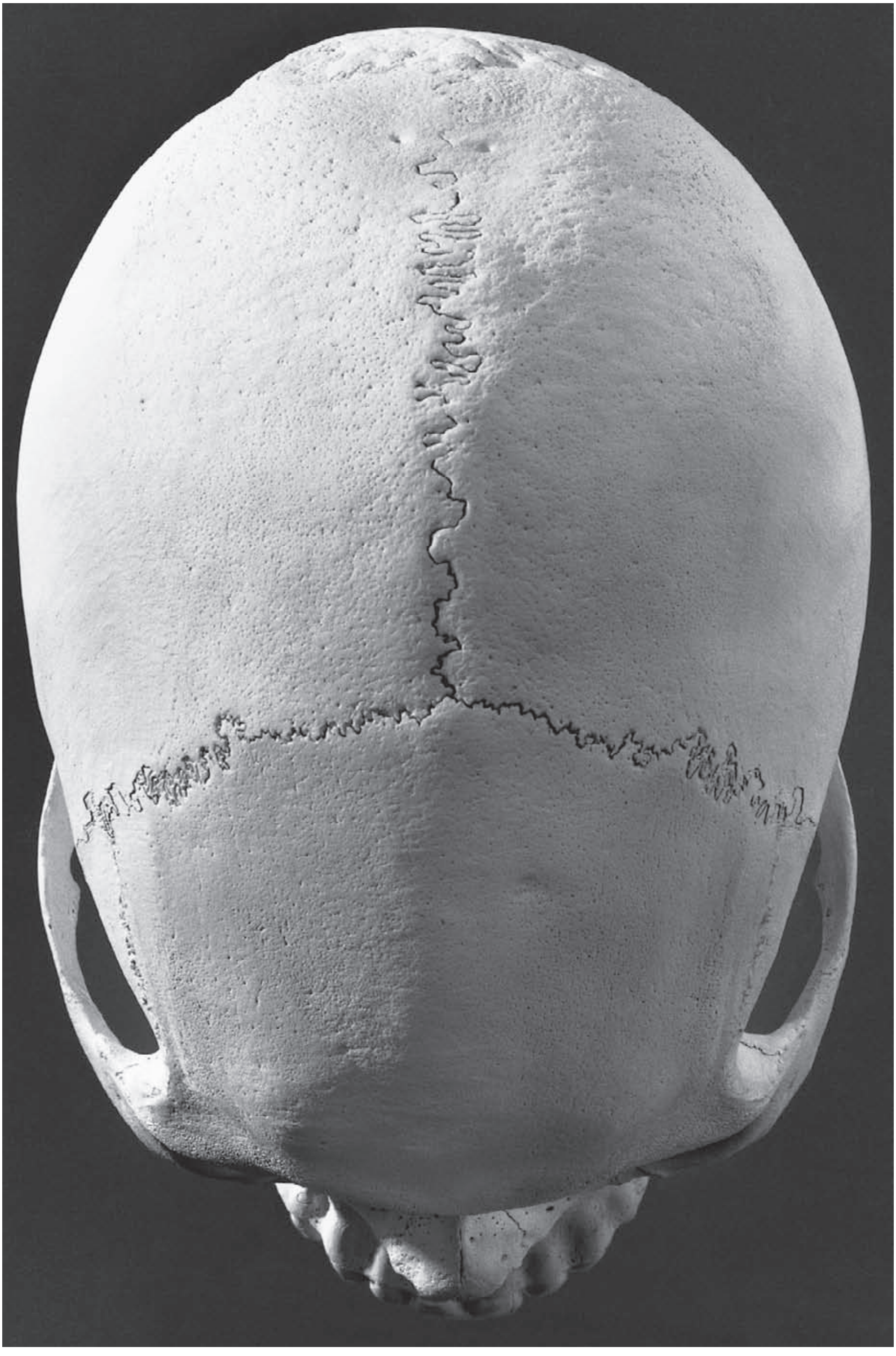


Figure 7.4 **Adult male cranium, superior.** Natural size.

Figure 7.5 **Adult male cranium, inferior.** Natural size.

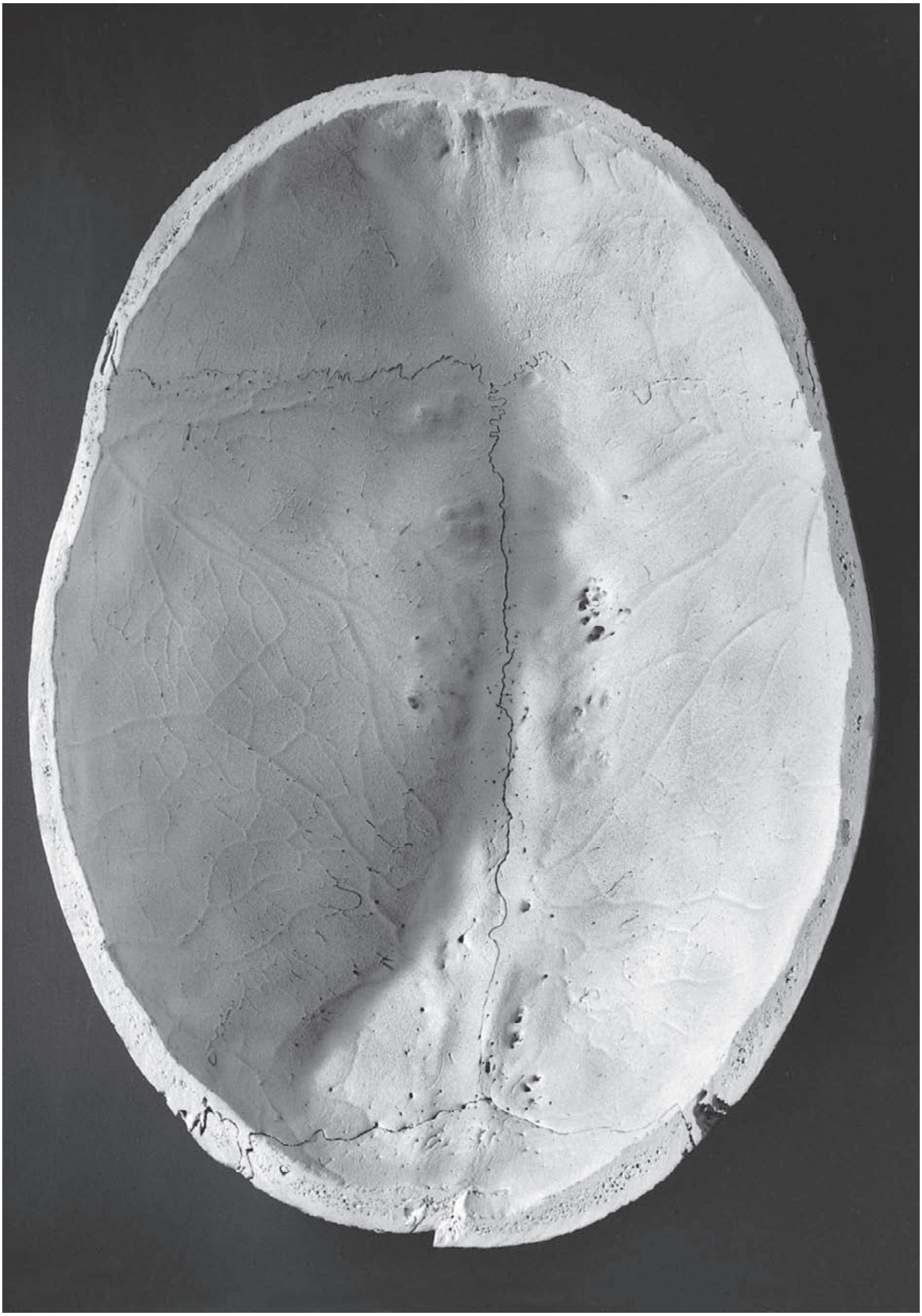


Figure 7.6a **Adult male cranium, endocranial,** superior part. Natural size.

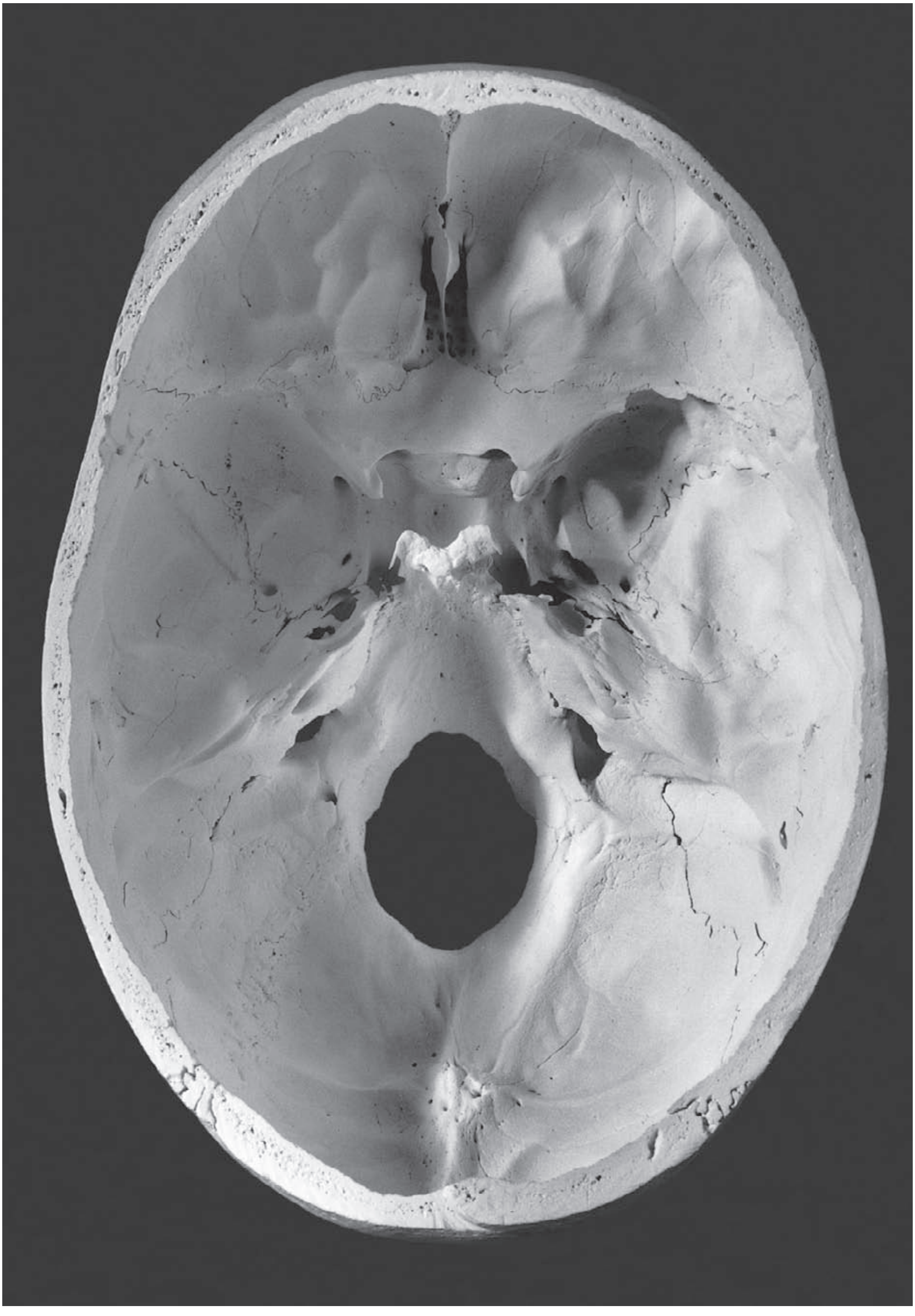


Figure 7.6b **Adult male cranium, endocranial,** inferior part. Natural size.

7.3 Growth and Architecture, Sutures and Sinuses

At birth the skull is made up of forty-five separate elements and is large relative to other parts of the body. The facial part of the newborn skull, however, is relatively small, reflecting the dominance of brain development at this stage of maturation. The face "catches up" to the neurocranium as development, particularly in the mandible and maxilla, proceeds. Important stages in the development of the skull include emergence of the first set of teeth (between the ages of 6 and 24 months), the emergence of

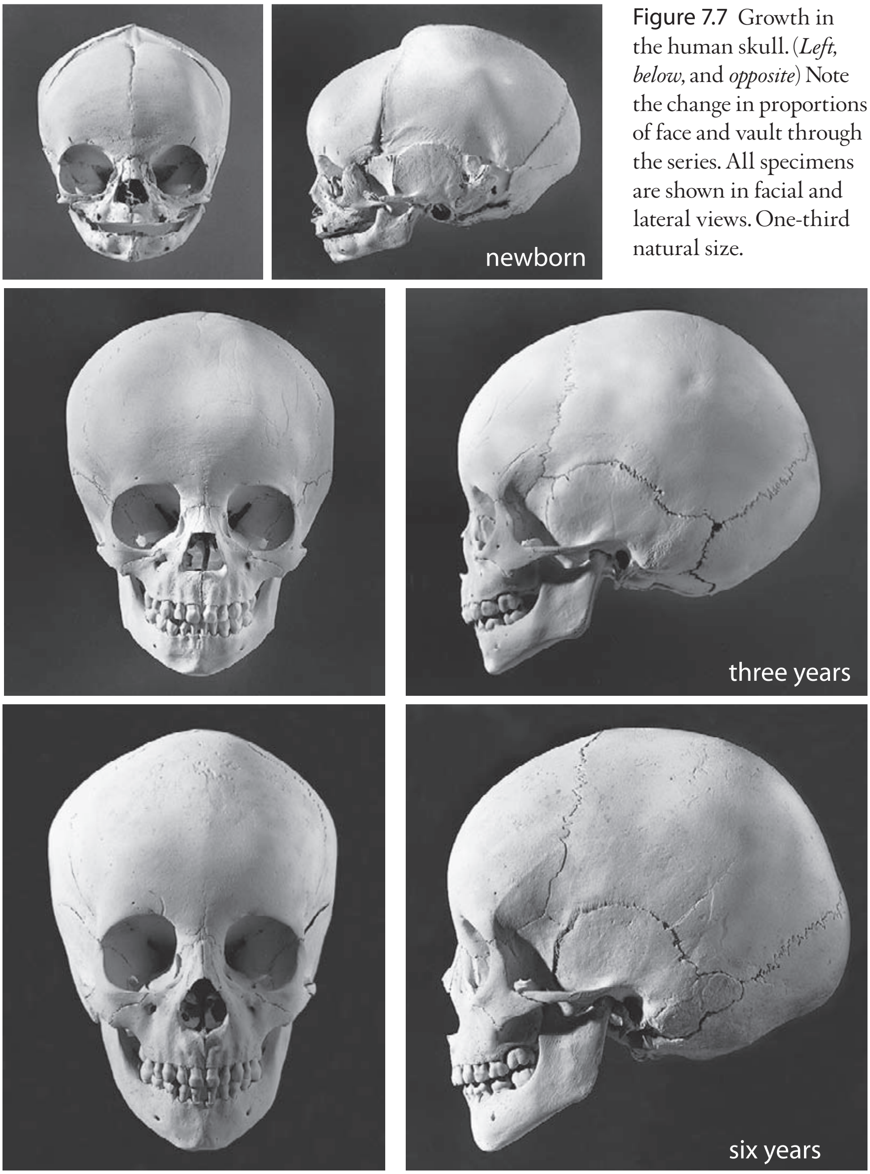
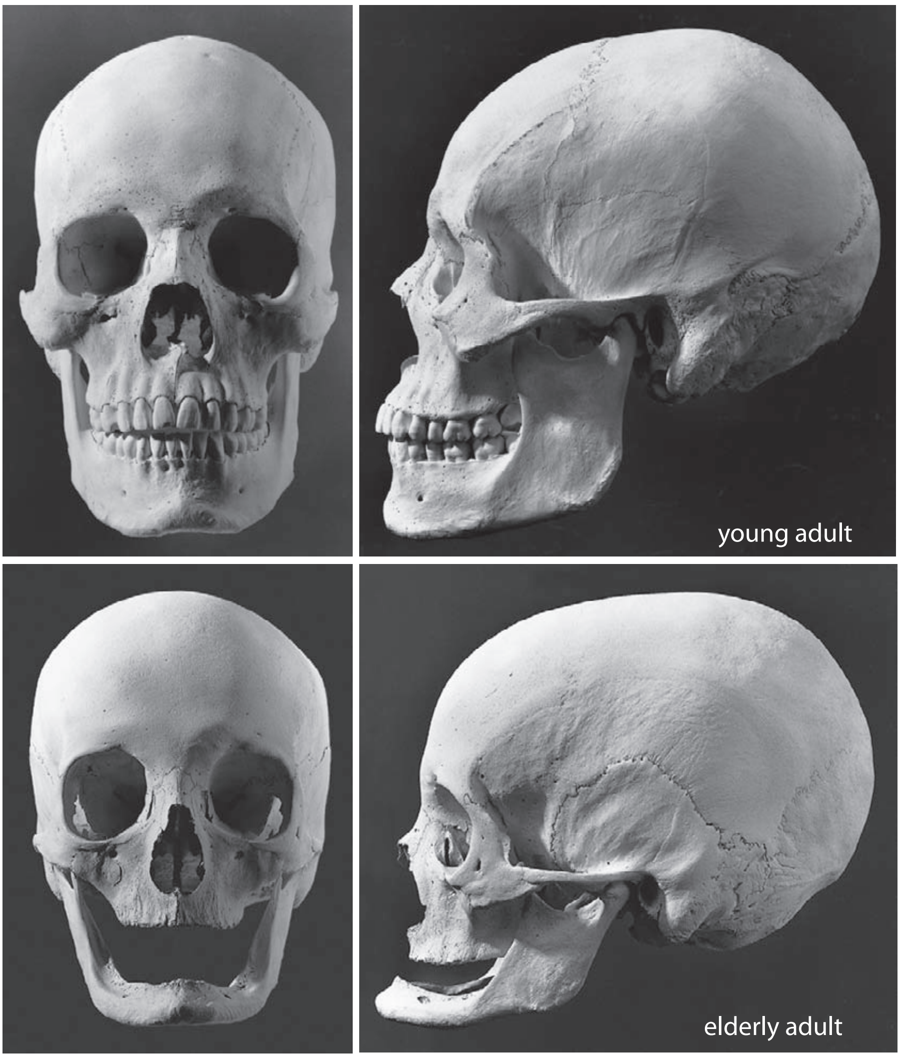


Figure 7.7 Growth in the human skull. (*Left, below,* and *opposite*) Note the change in proportions of face and vault through the series. All specimens are shown in facial and lateral views. One-third natural size.

the permanent teeth (beginning at about 6 years), and puberty. Figure 7.7 illustrates growth of the skull.

At birth the skull contains intervals of dense connective tissue between plates of bone. These "soft spots," or **fontanelles**, are cartilaginous membranes that eventually harden and turn to bone. In the adult the skull bones contact along joints with interlocking, sawtooth, or zipper-like articulations called **sutures**. Cranial articulations in the adult human skull are summarized in Figure 7.8. Many of these sutures derive their name directly from the two bones that contact across them. For example, **zygomaticomaxillary sutures** are sutures between the zygomatics and maxillae, and **frontonasal sutures** are short sutures between the frontal and nasals. Some sutures have special names. The **sagittal suture** passes down the midline between the parietal bones. The **metopic suture** passes between unfused frontal halves and only rarely persists into



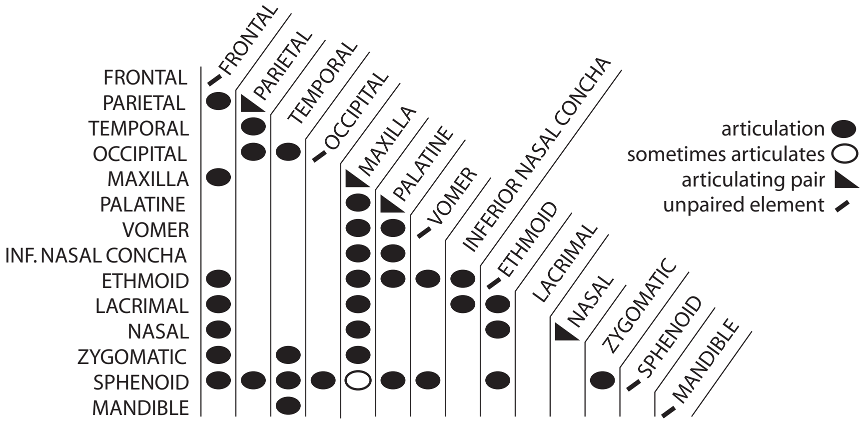


Figure 7.8 Articulation of bones in the human skull.

adulthood. The **coronal suture** lies between the frontal and parietals. The **lambdoidal suture** passes between the two parietals and the occipital. **Squamosal sutures** are unusual, scale-like, beveled sutures between temporal and parietal bones. The **spheno-occipital**, or **basilar suture** (actually a synchondrosis) lies between the sphenoid and the occipital. **Parietomastoid sutures** pass between the parietals and the temporals, constituting posterior extensions of the squamosal suture. **Occipitomastoid sutures** pass between the occipital and temporals on either side of the vault.

Sinuses are void chambers in the cranial bones that enlarge with the growth of the face. There are four basic sets of sinuses, one each in the maxillae, frontal, ethmoid, and sphenoid. These sinuses are linked to the nasal cavity and, in life, irritation of their mucous membranes may cause swelling, draining, and headache-related discomfort.

7.4 Skull Orientation

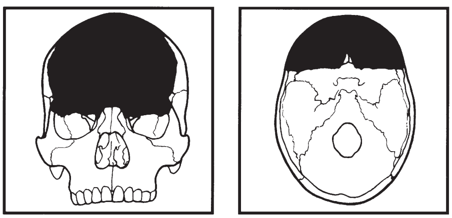
The most useful and informative comparisons between skulls of different individuals are usually comparisons made when both skulls are in the same orientation. The convention used in orienting the skull is the **Frankfurt Horizontal** (**FH**), named for the city in which the convention was established in 1884. The Frankfurt Horizontal is a plane defined by three points: the right and left **porion** points and the left **orbitale**. These osteometric points are at the top of each external auditory meatus and the bottom of the left orbit.

Skulls are normally viewed from six standard perspectives, all in Frankfurt Horizontal (as illustrated in Figures 7.1–7.5). Viewed from above, the skull is seen in **norma verticalis**. When viewed from either side, the skull is seen in **norma lateralis**. **Norma occipitalis** is the posterior view of the skull. Viewed from the front the skull is seen in **norma frontalis**; viewed from the base it is seen in **norma basilaris**. All of these views are perpendicular or parallel to the Frankfurt Horizontal. A constellation of **osteometric points** is used to report and compare skull shapes and sizes. See Martin and Saller (1957) and White and Folkens (2000) for their definitions.

7.5 Learning Cranial Skeletal Anatomy

To learn cranial skeletal anatomy, approach the skull systematically. First, study the skull of a young adult, observing all sutures between the bones. Then, study a growth series, noting how each bone and suture changes during ontogeny. Finally, use the descriptions in Sections 7.6–7.20 to learn the features of each bone of the skull. These features are the keys to diagnosing various bones of the skull by element and side. Intact cranial bones have rather unique morphologies. You will rarely have difficulty identifying them.

Because the various bones of the skull are often found in a disarticulated or fragmentary state, each bone or pair of bones must be given individual consideration. To identify and side fragments of the cranium, follow these steps: Determine whether the piece is cranial vault or face. Note any blood vessel impressions, sutures, foramina, surface textures, bone thickness changes, muscle attachments, sinus walls, or tooth roots or sockets. Note the thickness of the piece and its cross-sectional anatomy at the break, including sinus development. Carefully note the morphology of any visible sutures.



7.6 Frontal (Figures 7.9 – 7.12)

7.6.1 Anatomy

The frontal is located at the front of the neurocranium. It articulates with the parietals, nasals, maxillae, sphenoid, ethmoid, lacrimals, and zygomatics. The frontal is one of the largest and most robust cranial bones. It consists of two general parts, one vertical and one horizontal.

a. The vertical **frontal squama** forms the forehead.
b. The **horizontal portion** acts to roof the orbits and to floor the frontal lobes of the brain.
c. **Frontal eminences** (**frontal tubers**, or **bosses**) dominate the ectocranial surface. These paired frontal bosses mark the location of the original centers of ossification of this bone.
d. **Temporal lines** on the lateral ectocranial surface mark the attachment of the *temporalis muscle*, a major elevator of the mandible, and its covering, the *temporal fascia*, a fascial sheet that covers the temporalis. The temporal line defines the superior edge of the temporal surface (and fossa). This line becomes a crest in its

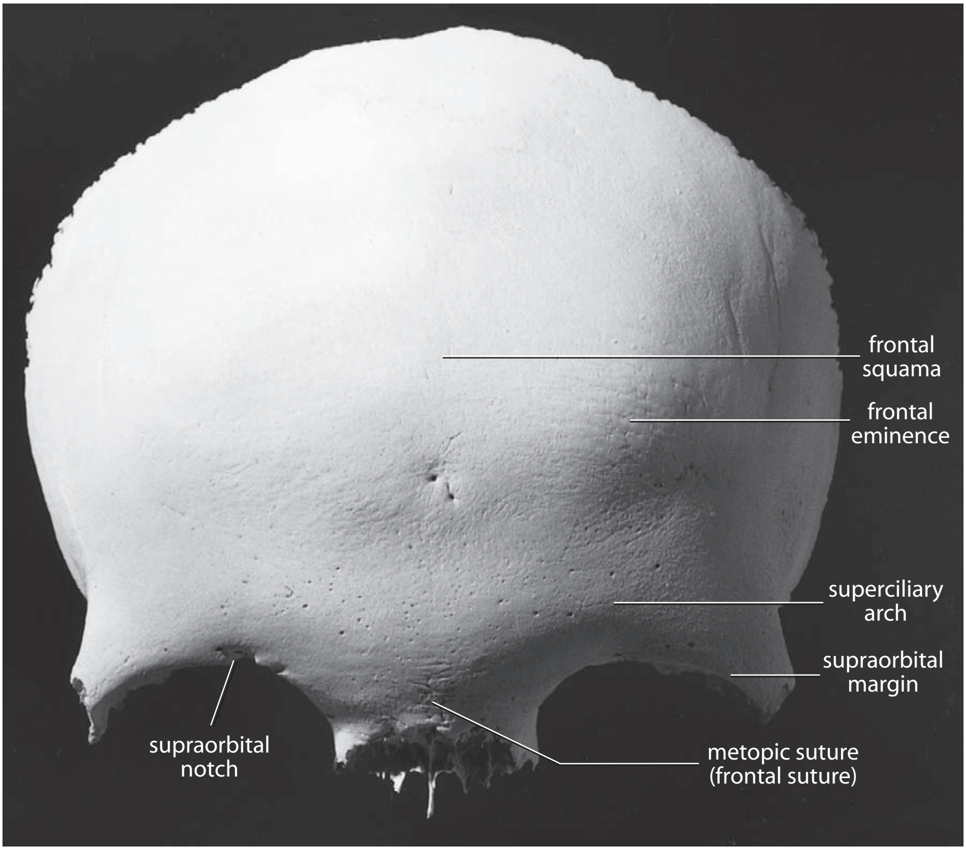


Figure 7.9 **Frontal, anterior** (ectocranial). Natural size.

anterior, lateral extent (on the zygomatic process of the frontal). It often divides into superior and inferior lines as it sweeps posteriorly.

e. **Zygomatic processes** form the most lateral and anterior corners of the frontal.
f. **Superciliary arches** (brow ridges) are the bony tori over the orbits. They are most prominent in males and are sometimes joined by a prominent glabellar region.
g. **Supraorbital margins** are the upper orbital edges. These are notched or pierced by the supraorbital notch or foramen.
h. **Supraorbital notches** (or **foramina**, if the notches are bridged) are set along the medial half of the superior orbital rim. They transmit the *supraorbital vessels* and *supraorbital nerve* as they pass superiorly to the forehead region.
i. The **metopic suture** (**frontal suture**) is a vertical suture between right and left frontal halves. Its persistence is variable, but only occasionally does it last into adulthood. Traces of it are observed most often in the glabellar region in adults.
j. **Meningeal grooves** for the *middle meningeal arteries* are present on both sides of the concave endocranial surface of the frontal squama. The *brain* is covered with

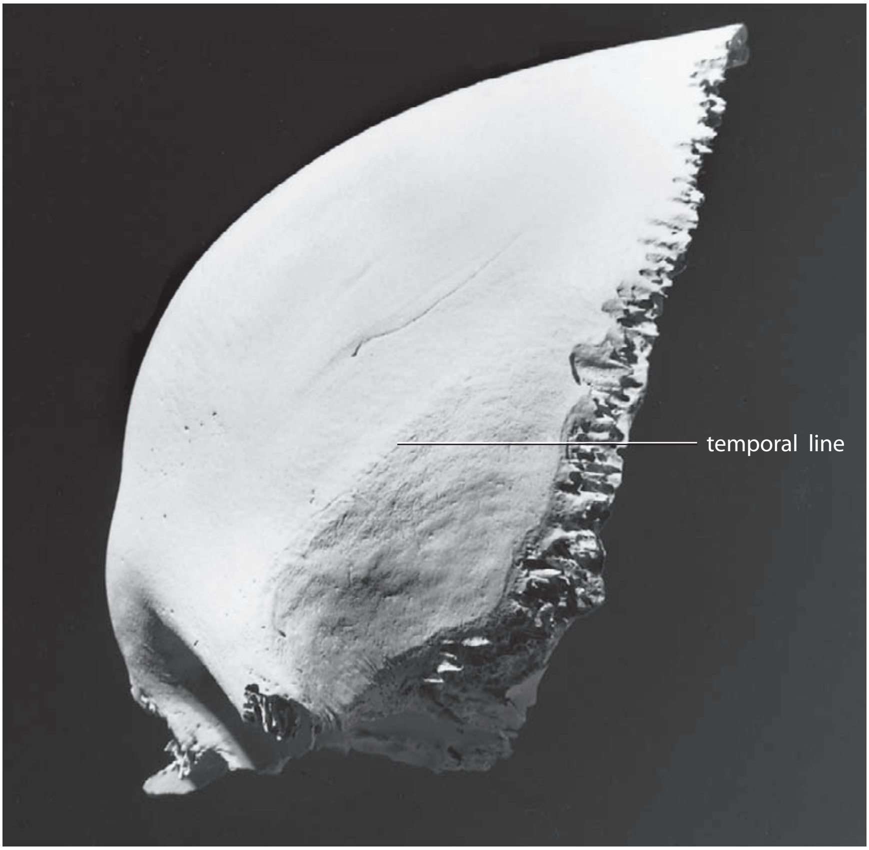


Figure 7.10 **Frontal, left lateral** (ectocranial). Natural size.

a tough outer protective membrane, the *dura mater*, whose blood supply comes from the *meningeal arteries*.

k. The **sagittal sulcus** is a vertical groove that runs down the midline of the endocranial surface. It lodges the *superior sagittal sinus*, a large vessel that drains blood from the brain.
l. The **frontal crest** is a midline crest confluent with the anterior end of the sagittal sulcus. This crest gives attachment to the *falx cerebri*, a strong membrane between the two cerebral hemispheres of the brain.
m. The **foramen cecum**, a foramen of varying size, is found at the root, or base, of the frontal crest and transmits a small vein from the frontal sinus to the superior sagittal sinus.
n. **Arachnoid foveae** (**granular foveae**) are especially apparent near the coronal suture along the endocranial midline. They are features associated with another covering layer of the brain, the *arachnoid*, which is a delicate, avascular membrane lying beneath the *dura mater*. Tufts of arachnoid, the *arachnoid granulations*, push outward against the dura, causing resorption of the bone and the formation of

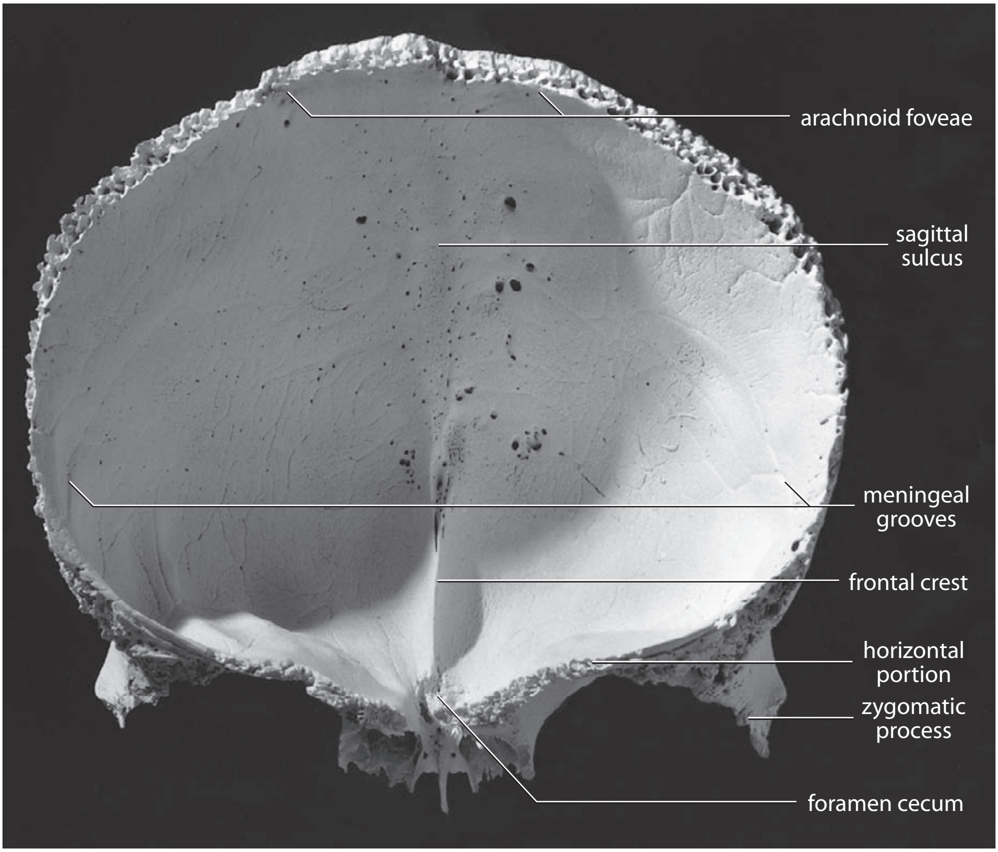


Figure 7.11 **Frontal, posterior** (endocranial). Natural size.

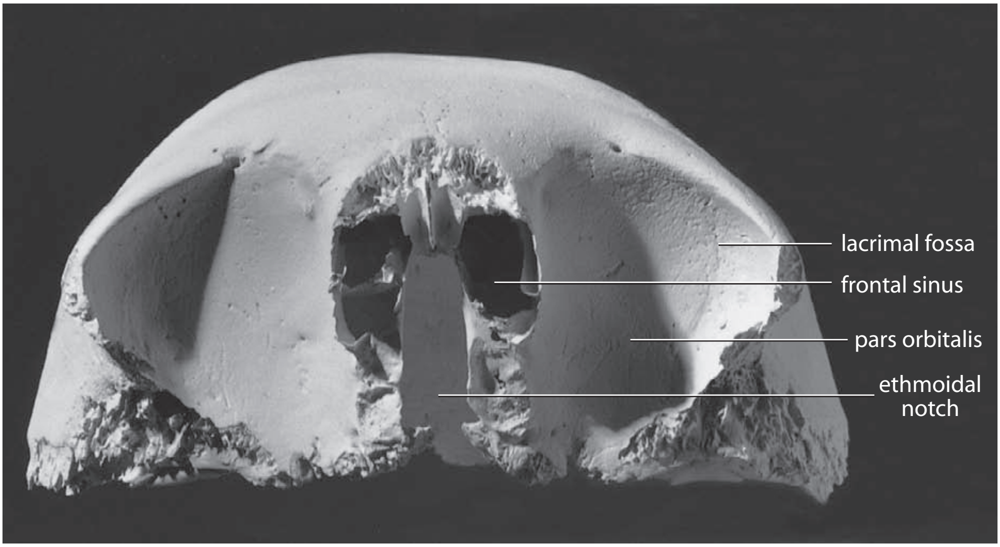


Figure 7.12 **Frontal, inferior** (ectocranial). Natural size.

foveae on the endocranial surface. On both sides of the midline the endocranial surface of the frontal bears depressions for convolutions of the frontal lobes of the brain.

o. The **pars orbitalis**, or **orbital plate**, is the horizontal portions of the frontal. Its endocranial surfaces is undulating (bumpy), conforming to the inferior surface of the frontal lobe. Its inferior surface (orbital surface) is smoother and concave.
p. **Lacrimal fossae**, for the *lacrimal glands*, are found at the lateral, inferior parts of the orbital (inferior) surfaces of the frontal.
q. The **ethmoidal notch** is the gap separating the two orbital plates of the frontal. The ethmoid bone fills this notch in the articulated cranium.
r. **Frontal sinuses**, generally anterior to the ethmoid notch, extend for a variable distance between outer and inner bone tables of the frontal and sometimes penetrate the orbital plates. Personal identification in forensic cases has been accomplished by employing radiographs of this region. Distinctive patterns of frontal sinuses can then be used for individuation.

7.6.2 Growth

The frontal ossifies in membrane from two primary centers. At birth these centers are separate. They fuse along the metopic suture (midline), usually during a child's second year.

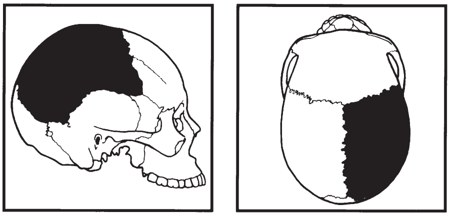
7.6.3 Possible Confusion

- When fragmentary, the frontal is confused most often with the parietals. The meningeal impressions are larger and more dense on the parietals, and the endocranial surfaces of the parietals are less undulating than those of the frontal.
- The frontal is the only major vault bone with a substantial sinus and adjacent orbital rims.

7.6.4 Siding

Isolated fragments of frontal squama may be difficult to side. Siding the frontal or any other bone or tooth, whether fragmentary or intact, is often simplified by holding the element in its correct orientation adjacent to that region of your own skull. In other words, attempt to imagine the fragment fitting into your own anatomy. The coronal suture is posterior and courses anterolaterally, toward the face, from bregma (intersection of coronal and sagittal sutures). This means that the sagittal and coronal sutures do not meet at right angles. This fact can be very useful in siding fragments of frontal squama.

- The anteromedially placed frontal sinus is often exposed in broken pieces.
- The ectocranially placed temporal lines swing medially and weaken posteriorly.



7.7 Parietals (Figures 7.13–7.14)

7.7.1 Anatomy

The parietals form the sides and roof of the cranial vault. Each parietal articulates with the opposite parietal and with the frontal, temporal, occipital, and sphenoid. Parietals are basically square and are the largest bones of the vault, with a fairly uniform thickness.

a. The **frontal angle** is located at bregma.
b. The **sphenoidal angle** is located at pterion (where the sphenoid, parietal, temporal, and frontal bones converge).

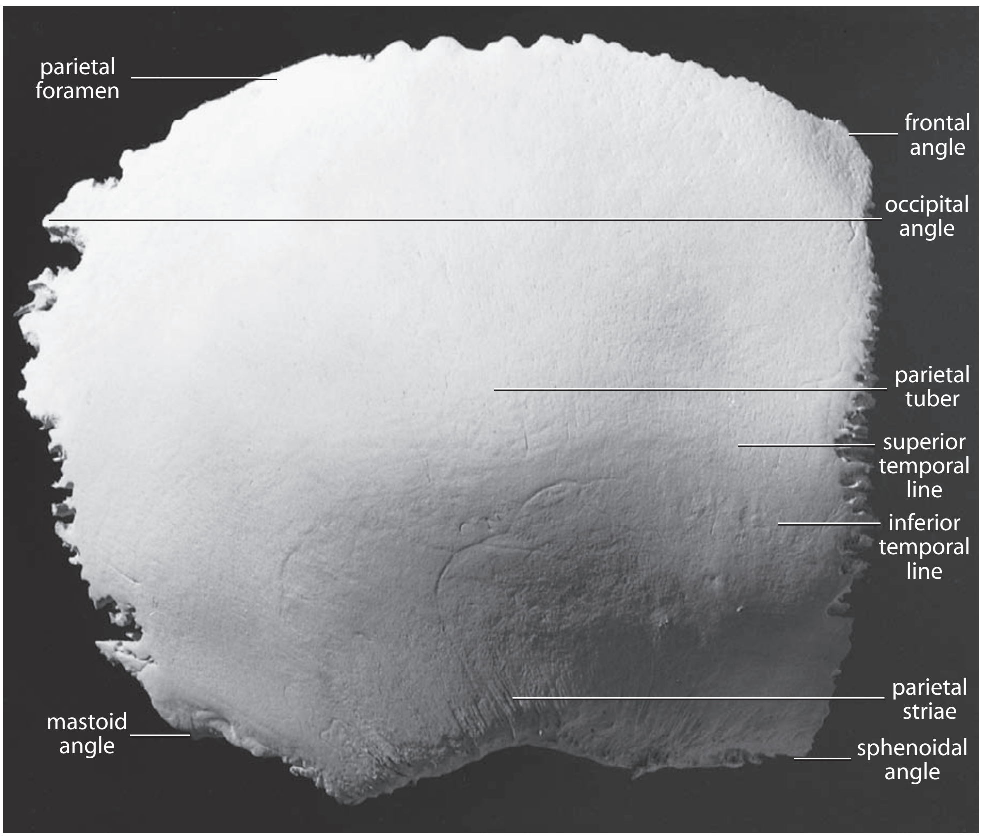


Figure 7.13 **Right parietal, lateral** (ectocranial). Anterior is toward the right, superior is up. Natural size.

c. The **occipital angle** is located at lambda (intersection of sagittal and lambdoidal sutures).
d. The **mastoid angle** is located at asterion (where the lambdoidal suture contacts the temporal).
e. The **parietal tuber** (**boss, eminence**) is the large, rounded eminence centered on the ectocranial surface of the parietal. It marks the center of ossification of the bone.
f. **Temporal lines** dominate the ectocranial surface, arching anteroposteriorly.
g. The **superior temporal line** anchors the *temporal fascia*.
h. The **inferior temporal line** indicates the most superior extent of the *temporalis muscle*.
i. When present, the **parietal foramen** is located close to the sagittal suture near lambda. It transmits a small vein through the parietal to the superior sagittal sinus.
j. The **parietal striae** are striations, or "rays," that pass posterosuperiorly for some distance on the ectocranial surface of the parietal from their origin on its beveled squamosal edge.
k. **Meningeal grooves** for *middle meningeal arteries* dominate the endocranial surface of the parietal. These arteries supply the *dura mater*. The most anterior branch parallels the coronal edge of the parietal, and most of the branches tra-

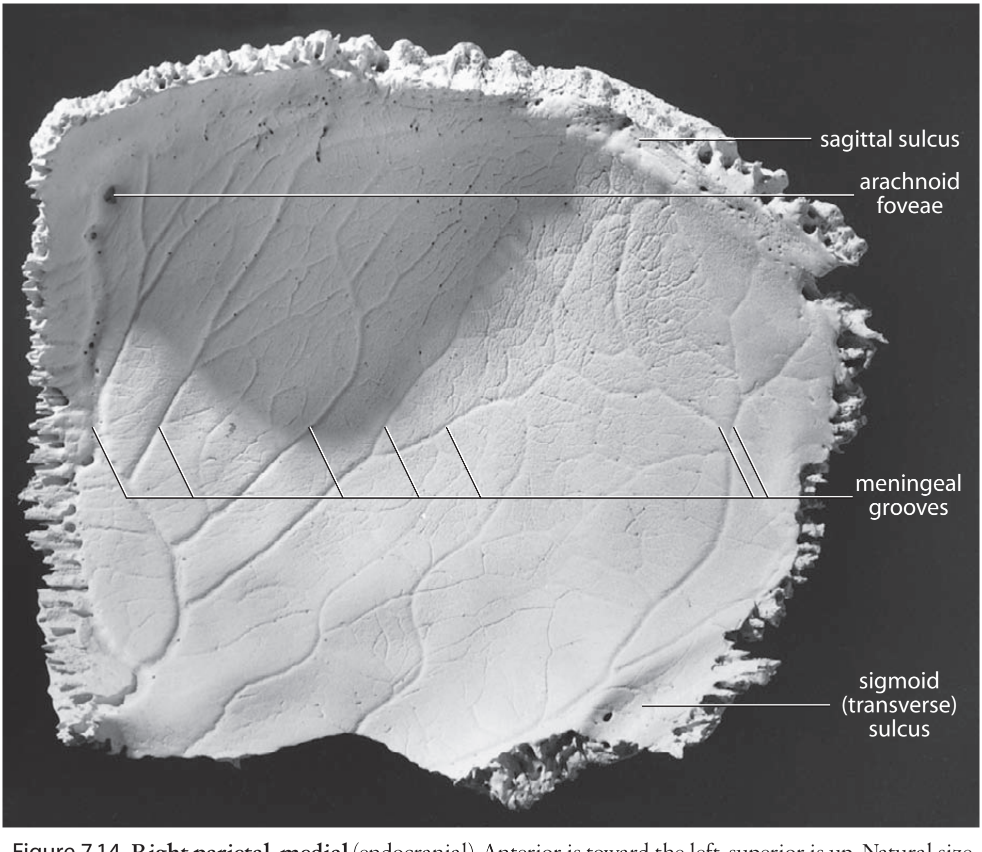


Figure 7.14 **Right parietal, medial** (endocranial). Anterior is toward the left, superior is up. Natural size.

verse the bone toward its occipital angle.

l. The **sagittal sulcus** is made when the parietals are articulated and the shallow grooves along the sagittal edge of each parietal combine along the endocranial midline. This sulcus is a posterior continuation of the same feature on the frontal.

m. **Arachnoid foveae** (**granular foveae**) are concentrated endocranially along the anterior extent of the sagittal edge of each parietal. They are functionally equivalent to structures of the same name described for the frontal.

n. The **sigmoid sulcus** (**the sulcus for the sigmoid and/or transverse sinus**) crosses the mastoid angle of the parietal, cutting a groove on the endocranial surface. It marks the course of the *transverse* (or *sigmoid*) *sinus*, a vessel that drains blood from the brain.

7.7.2 Growth

The parietal bone ossifies in membrane, with ossification extending radially from a combined center near the parietal boss. The four corners of the bone are not ossified at birth, and the remaining spaces are the fontanelles.

7.7.3 Possible Confusion

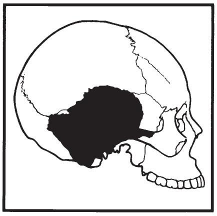
When fragmentary, the parietal is confused most often with the frontal, occipital, or temporal. The frontal, occipital, and temporal do not have parietal foramina, as many meningeal grooves, or ectocranial striae associated with an externally facing beveled suture (the squamosal).

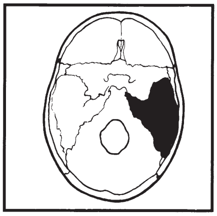
- The cross section of a parietal is more regular (thickness does not vary as much) than those of the other vault bones.
- The temporal line is a constant feature across the length of the parietal.
- The endocranial surface of this bone is not as undulating and irregular as that of the frontal or the occipital.

7.7.4 Siding

Siding is difficult only when the parietal bone is very fragmentary. The meningeal grooves are oriented vertically along the coronal suture and more horizontally near the squamosal suture.

- The coronal suture, unlike the sagittal suture, is an interfingering rather than an interlocking, zipper-like, or jigsaw-like articulation. The large *anterior middle meningeal vessel* makes an impression along this suture endocranially.
- The thickest corners are the occipital and mastoid angles.
- The mastoid angle bears a sulcus endocranially.
- The squamosal suture is lateral and inferior, and the parietal striae angle posterosuperiorly.





7.8 Temporals (Figures 7.15–7.18)

7.8.1 Anatomy

Temporals form the transition between cranial wall and base, house the delicate organs of hearing, and form the upper surface of the jaw joints. The highly irregular shape of the temporal is related to the varying functions of the bone. The temporal articulates with the parietal, occipital, sphenoid, zygomatic, and mandible. The jaw joint, or temporomandibular joint, is often abbreviated TMJ. Parts of the temporal bone are very robust and, for this reason, are often more resistant to destruction than other parts of the cranial vault.

a. The thin, plate-like **squama** rises almost vertically to form the cranial walls and articulate with the parietals along the squamosal suture.
b. The **petrous pyramid** is the massive, dense bony part that dominates the endocranial aspect of the temporal. The sharp superior edge of the endocranial petrous surface angles anteromedially, separating the *temporal* and *occipital lobes* of the brain and housing the internal ear. The petrous is wedged between the occipital and the sphenoid. The end-on view (view from anteromedial) is into the carotid canal. This petrous part of the bone houses the delicate organs of hearing and equilibrium, including the tiny movable malleus, incus, and stapes bones.
c. The **external acoustic** (**auditory**) **meatus** (**EAM**) is the external opening of the ear canal, which passes anteromedially for about 2 cm. The inner end of the canal is closed by the *tympanic membrane* (eardrum) in the living individual.
d. The **zygomatic process** of the temporal is a thin projection of bone that forms the posterior half of the zygomatic arch. Its anterior edge is the serrated zygomaticotemporal suture, its superior edge is an attachment for the *temporal fascia*, and its inferior edge anchors fibers of the *masseter muscle*.
e. The **suprameatal crest** is the superior root of the zygomatic process. It runs horizontally above the EAM where the osteometric point auricular is located.
f. The **supramastoid crest** is the posterior extension of the suprameatal crest. The continuous raised edge of these crests marks the limit of the *temporalis muscle* and *temporal fascia* attachment.
g. The **parietal notch** is formed by the posterosuperior border of the temporal where the squamosal and parietomastoid sutures meet.
h. The **mastoid process** bears an external surface that is roughened for the attachment of several muscles including the following: *sternocleidomastoideus, splenius capitis,* and *longissimus capitis*. These muscles function in extension, flexion, and rotation of the head. The *temporalis muscle* may also attach in this region when the supramastoid crest is present on the mastoid area, as in some humans and

many fossil hominids. Internally, the thin-walled mastoid process is occupied by a number of variably developed voids known as **mastoid cells**.

i. The **mastoid foramen** (occasionally multiple) is located near the posterior edge of the mastoid process along the occipitomastoid suture. It transmits a small branch of the *occipital artery*, which supplies the dura mater, the diploë (spongy bone sandwiched between inner and outer bone tables of cranial vault bones), and the mastoid air cells.

j. The **mastoid notch** (**digastric groove**) for attachment of the *digastric muscle* is the vertically oriented furrow medial to the mastoid process.

k. The **occipital groove** (**sulcus**) lies just medial to the mastoid notch. It is a shallow furrow that lodges the *occipital artery*.

l. The **temporomandibular articular surface** is the smooth, articular surface inferior to the root of the zygomatic process. There is considerable topographic relief to this inferiorly facing surface.

m. The **articular eminence** forms the anterior portion of the temporomandibular articular surface.

n. The **mandibular fossa** (**glenoid fossa**) lies posterosuperior to the articular eminence. The eminence and the fossa itself are bounded medially by the sphenosquamosal suture. In chewing, the condyle of the mandible moves anteriorly onto the eminence and posteriorly into the fossa as well as from side to side in actions at the TMJ. In life there is a fibrocartilaginous *articular disk* interposed between the mandibular condyle and the fossa.

o. The **postglenoid process** is a projection that lies just anterosuperior to the EAM, interposed between the **tympanic part** of the bone (which forms most of the rim

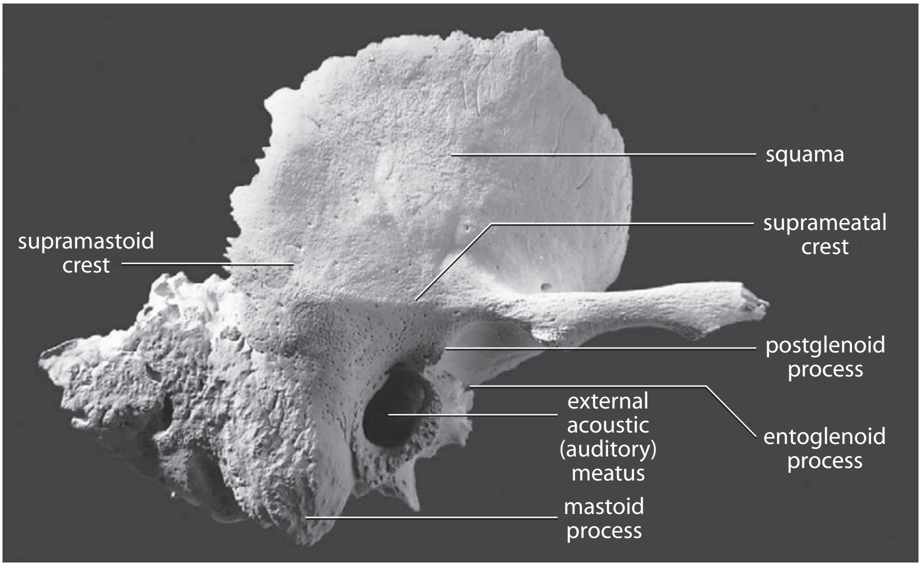


Figure 7.15 **Right temporal, lateral** (ectocranial). Anterior is toward the right, superior is up. Natural size.

of the EAM) and the mandibular fossa. This rim is roughened for the attachment of the cartilaginous part of the EAM.

p. The **entoglenoid process** is the inferior projection of the articular surface at the medial edge of the articular eminence.
q. The **tympanic** part of the temporal lies posterior to the TMJ. Its anterior surface, forming the rear wall of the mandibular fossa, is nonarticular.
r. The **styloid process** is a thin, pointed bony rod that points anteroinferiorly from the base of the temporal bone. It is a slender projection of variable length and is fragile and often broken or missing (as on the illustrated specimen, where its distal end has snapped off). It anchors the *stylohyoid* (sometimes partly ossified) *ligament* and several small muscles.
s. The **stylomastoid foramen**, located immediately posterior to the base of the styloid process, is for the exit of the *facial nerve* (cranial nerve 7) and the entrance of the *stylomastoid artery*.
t. The **vaginal process** ensheaths the base of the styloid process.
u. The **jugular fossa** is located just medial to the base of the styloid process. This deep fossa houses the *bulb of the internal jugular vein*, a vessel that drains blood from the head and neck.
v. The **carotid canal** is a large circular canal that transmits the *internal carotid artery*, a major source of blood for the head, and the *carotid plexus* of nerves. It is situated medial to the styloid process at the level of the sphenosquamosal suture, just anterior to the jugular fossa.
w. **Middle meningeal grooves** are narrow, well-defined channels which mark the endocranial surface of the temporal. The larger, more diffuse undulations on this

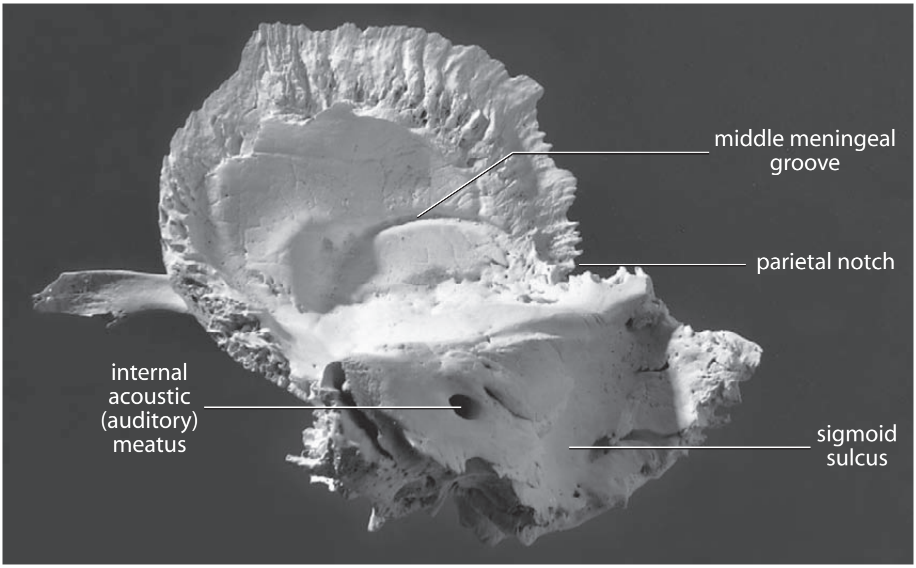


Figure 7.16 **Right temporal, medial** (endocranial). Anterior is toward the left, superior is up. Natural size.

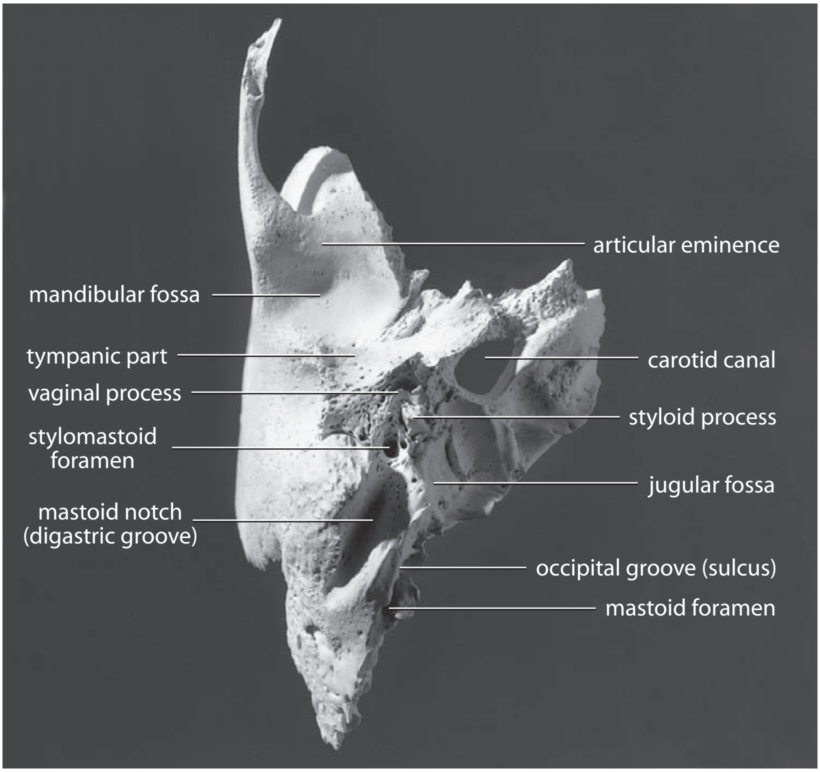


Figure 7.17 **Right temporal, inferior.** Anterior is up, medial is toward the right. Natural size.

surface are related to convolutions of the *temporal lobe* of the brain.

x. The **internal acoustic (auditory) meatus** is located about midway along the posterior surface of the petrous pyramid and transmits the *facial* and *acoustic nerves* (cranial nerves 7 and 8, respectively) as well as the *internal auditory artery*.

y. The **sigmoid sulcus** is the large, curving groove set at the posterior base of the petrous pyramid on the endocranial surface of the mastoid part of the temporal bone. This sulcus houses the *sigmoid sinus*, an anteroinferior extension of the *transverse sinus*, which is a major vessel draining blood from the brain into the *internal jugular vein*. Note that this sulcus is a continuation of the sulcus on the posteroinferior corner of the parietal.

7.8.2 Growth

Growth of the temporal is complex, with both membranous and endochondral ossification. It ossifies from eight centers during fetal development, not counting those of the middle ear or tympanic ring. As birth approaches, only three main centers remain: the squama, the petrous part, and the tympanic ring.

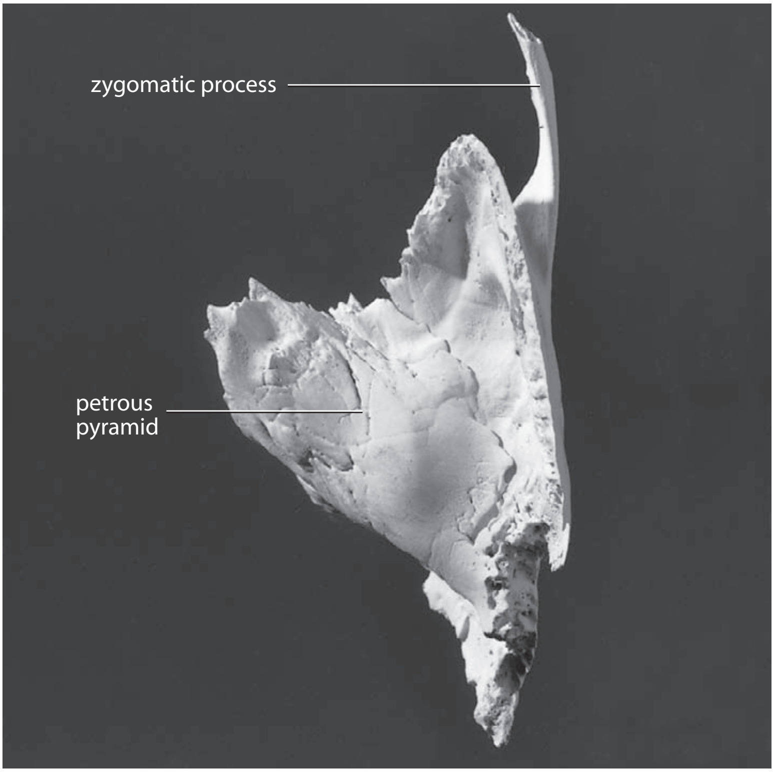


Figure 7.18 **Right temporal, superior.** Anterior is up, medial is toward the left. Natural size.

7.8.3 Possible Confusion

Even when fragmentary, it is difficult to confuse the temporal with other bones because of its unique morphology. The broken elements that may present some trouble are the squama and zygomatic process.

- The temporal squama overlaps the parietal. It is thinner than the parietal or frontal.
- Fragmentary temporal processes of the zygomatic bone are not as thin and long as the zygomatic process of the temporal.

7.8.4 Siding

- For isolated mastoid sections, the mastoid tip points inferiorly and the entire mastoid angles anteriorly.
- The digastric groove is posterior and medial.
- For isolated petrous pyramids, the internal acoustic foramen is posterior and the pyramid tapers anteromedially.

- For isolated fragments of squama, the squamosal suture surface overlaps the ectocranial surface of the parietal. Grooves for the middle meningeals branch posteriorly and slightly superiorly.
- For broken zygomatic processes, the articular eminence is posterior, the superior edge of the arch is thinnest, and the zygomaticotemporal suture runs from posteroinferior to anterosuperior.

7.9 Auditory Ossicles (Figure 7.19)

The tiny ear ossicles [**malleus** (hammer), **incus** (anvil), and **stapes** (stirrup)] are housed in the tympanic cavity of the temporal. The first is connected to the *tympanic membrane*, or *eardrum*, and the others are located more medially. These bones are so small that they are best observed under magnification. They are often lost during skeletal recovery and are seldom studied.

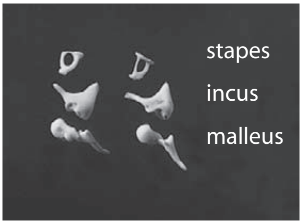
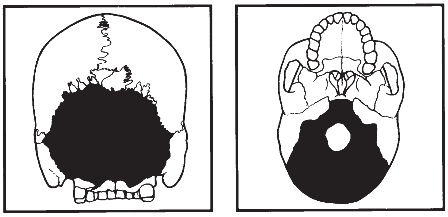


Figure 7.19 **Auditory ossicles** viewed from both sides. Natural size.



7.10 Occipital (Figures 7.20–7.21)

7.10.1 Anatomy

The occipital bone is set at the rear of the cranium and articulates with the temporals, sphenoid, parietals, and the uppermost vertebra, the atlas.

a. The **foramen magnum** is the large hole in the occipital through which the *brainstem* passes inferiorly into the vertebral canal.
b. The **squamous** portion of the occipital bone is by far the largest, constituting the large plate of bone posterior and superior to the foramen magnum.
c. The **occipital planum** is that part of the occipital squama that lies above the superior nuchal lines. The section of squama inferior to the lines is the **nuchal planum**.
d. The **external occipital protuberance** lies on the ectocranial midline where the occipital and nuchal planes meet. It is highly variable in appearance and heavier and more prominent in male individuals.
e. **Superior nuchal lines** lie to either side of the midline on the ectocranial surface

of the squamous portion. The nuchal plane and occipital planes merge at these superiorly convex lines. Several *nuchal muscles* attach to and below these lines and function to extend and rotate the head.

f. **Inferior nuchal lines** parallel the superior lines but are located about midway on the ectocranial nuchal plane. Fascia separating nuchal muscles attach to the line, whereas additional nuchal muscles attach inferior to this line.

g. The **external occipital crest** (**median nuchal line**) is a highly variable median line or crest that passes between the right and the left *nuchal musculature*. It stretches from the external occipital protuberance to the rear of the foramen magnum, anchoring the *nuchal ligament*.

h. The **basilar part** is the thick, square projection anterior to the foramen magnum. This part articulates with the petrous portions of both temporals and with the sphenoid via the sphenooccipital suture.

i. The **lateral**, or **condylar**, **parts** of the occipital lie to either side of the foramen magnum, articulating with the temporals.

j. **Occipital condyles** are raised oval structures on either side of the foramen magnum. Their inferior surfaces are convex. The articular surfaces of these condyles fit into the concave facets of the atlas vertebra.

k. **Condylar fossae** are ectocranial depressions immediately posterior to the condyles. These fossae receive the posterior margin of the superior facet of the atlas vertebra when the head is extended backward.

l. **Condylar foramina** (**canals**) perforate the occipital at the depth of the condylar fossae, where each transmits an *emissary vein*.

m. **Hypoglossal canals** are tunnels through the anterior part of the base (therefore superior in placement) of each condyle. These canals give exit to *hypoglossal nerves* (cranial nerve 12) and entrance to arteries.

n. **Jugular processes** are laterally directed corners of the bone placed lateral to the condyles. The tips of these processes lie at the anteriormost point along the occipitomastoid suture.

o. The **jugular notch** is excavated into the anterior surface of the jugular process. This notch forms the posterior half of the jugular foramen in the articulated cranium, with the anterior half being contributed by the temporal bone.

p. The **cruciform eminence** divides the endocranial surface of the occipital squama into four fossae. It is so named because it is cross-shaped.

q. **Cerebral fossae** are triangular depressions below the lambdoidal suture on the endocranial surface of the occipital. They house the *occipital lobes* of the brain's *cerebrum*.

r. The **cerebellar fossae** occupy the inferior part of the endocranial surface of the occipital squama. Therein rest the *cerebellar lobes* of the brain.

s. The **internal occipital protuberance** lies at the center of the cruciform eminence.

t. The **occipital** (**sagittal**) **sulcus** passes superiorly from the internal occipital protuberance. It is a deep endocranial groove marking the posterior extension of the *sagittal sinus*, a major blood drainage pathway from the brain.

u. The **internal occipital crest** is the inferior arm of the cruciform eminence. Sometimes it bears a sulcus that continues on one or both sides of the foramen magnum. Such a sulcus, called an **occipitomarginal sulcus**, represents an alternative pathway for blood to drain from the brain.

Figure 7.20 **Occipital, posteroinferior** (ectocranial). Superior is up. Natural size.

v. **Transverse sulci** form the transverse arms of the cruciform eminence. They house the *transverse sinuses*. The one on the right is usually larger and communicates directly with the sagittal sulcus. However, variations in the soft tissue and bony manifestations of this cranial venous drainage system are common and sometimes pronounced. The transverse sulcus of the occipital connects with the sigmoid sulcus of the temporal and endocranial jugular process, often via the transverse (or sigmoid) sulcus on the mastoid corner of the parietal.

w. The **groove for the medulla oblongata** is the hollowing on the endocranial surface of the basilar part of the occipital, the clivus.

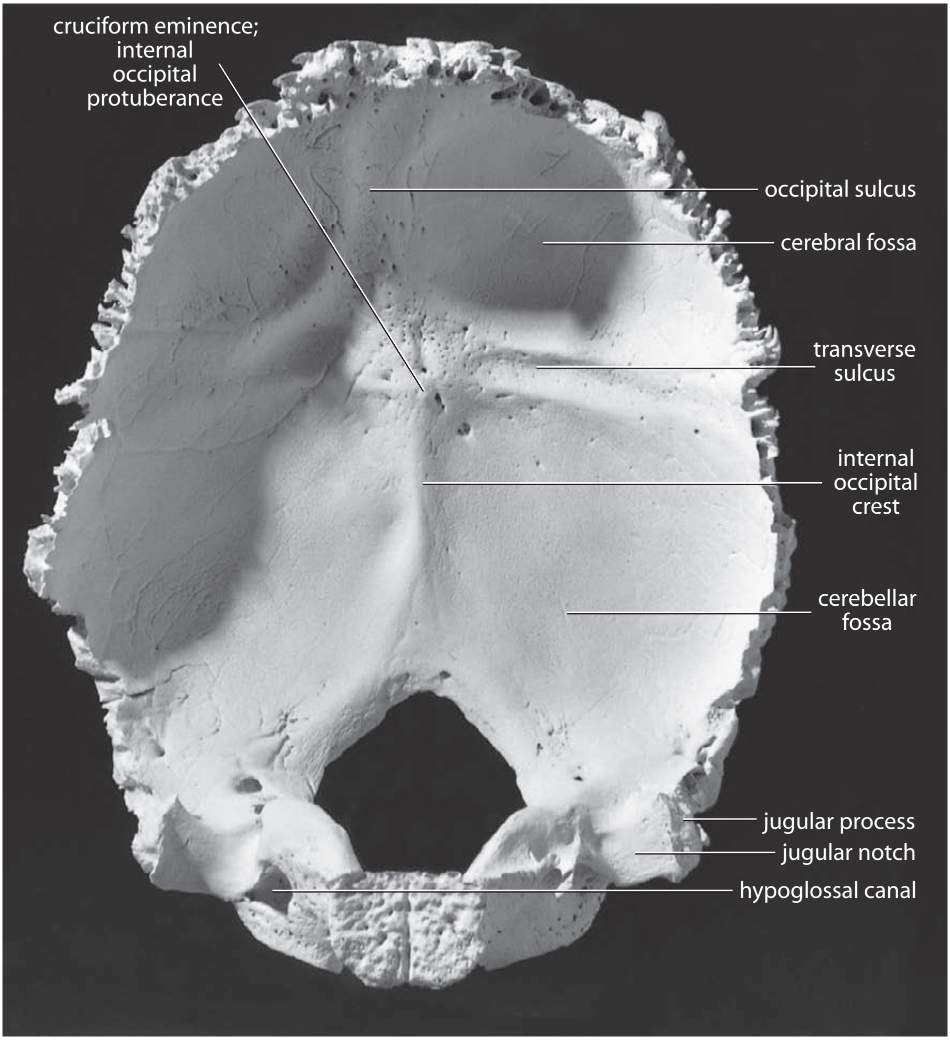


Figure 7.21 **Occipital, anterior** (endocranial). Superior is up. Natural size.

7.10.2 Growth

The occipital is another bone with both membranous and endochondral ossification. At birth the occipital consists of four parts: the squama, the lateral parts that bear the condyles, and the basilar part. The squama and lateral portions unite at about age 4, and by age 6 the basilar part attaches to these. The synostosis (fusion) between the occipital and the sphenoid (across the sphenooccipital synchondrosis) normally takes place between 18 and 25 years of age.

7.10.3 Possible Confusion

Even when fragmentary, the occipital is difficult to confuse with other bones of the vault.

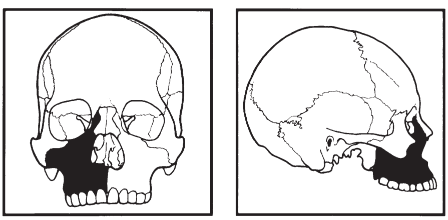
- There is wide variation in thickness across the occipital squama that is not found in the parietals or the frontal.
- The occipital lacks meningeal grooves endocranially and has much more ectocranial rugosity than seen on the parietal or frontal.

Other possible confusion may come when extrasutural bones are encountered. These bones are sometimes quite large, particularly along the lambdoidal suture. One even has a name, the **inca bone**. This is a large, triangular, symmetrical bone placed at the top of the occipital, just below lambda.

7.10.4 Siding

Isolated fragments of occipital are easily sided by locating the lambdoidal suture.

- For isolated condyles, the edge of the foramen magnum is medial and somewhat posterior to the condylar body centers.
- The condylar fossa is posterior, and the hypoglossal canals tunnel from anterolateral to posteromedial.



7.11 Maxillae (Figure 7.22)

7.11.1 Anatomy

Maxillae are a pair of bones that form the dominant portion of the face. Functionally, the maxillae hold the tooth roots and form most of the nasal aperture and floor, most of the hard palate, and the floors of the orbits. Most of the maxillary bone is light and fragile, the exception being the portion that holds the teeth. Maxillae comprise four basic processes and they articulate with each other and with the frontal, nasals, lacrimals, ethmoid, inferior nasal conchae, palatines, vomer, zygomatics, and sphenoid.

a. The **alveolar process** is the horizontal portion of the maxilla that holds the

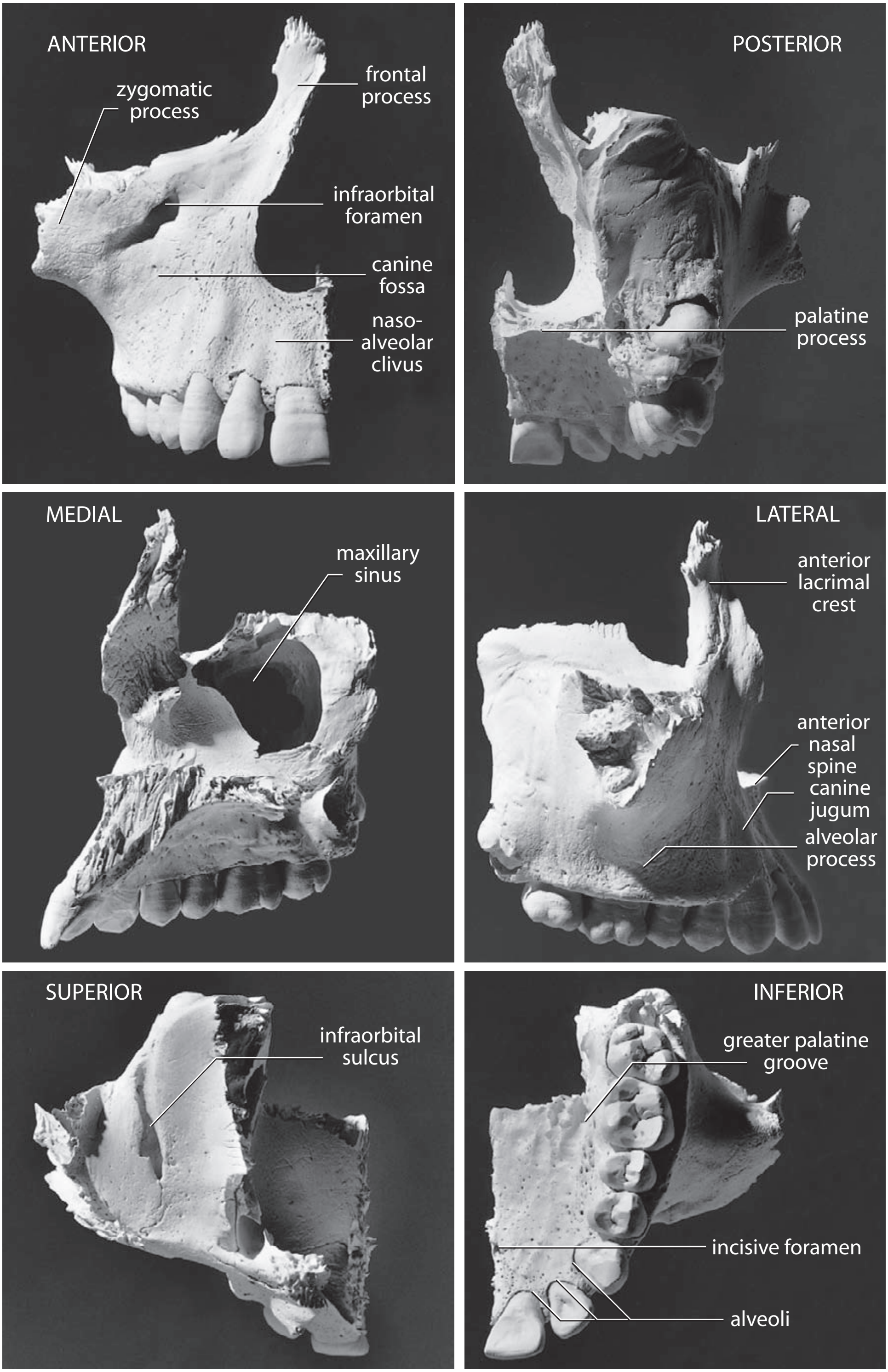


Figure 7.22 **Right maxilla.** Natural size.

tooth roots.

b. **Alveoli** for the tooth roots are present all along the alveolar process, except where these have been resorbed following the loss of teeth.
c. The **canine jugum** is a bony eminence over the maxillary canine root on the facial surface of the maxilla.
d. The **zygomatic process** forms much of the cheek.
e. The **infraorbital foramen** is located below the inferior orbital rim on the facial surface and transmits the *infraorbital nerve* (a division of cranial nerve 5) and *vessels* to the face.
f. The **canine fossa** is a hollow of variable extent located on the facial surface just below the infraorbital foramen, where the zygomatic, frontal, and alveolar processes of the maxilla come together.
g. The **anterior nasal spine** is the thin projection of bone on the midline at the inferior margin of the nasal aperture.
h. The **infraorbital sulcus** (**groove**) is centered on the posterior half of the orbital floor and opens posterosuperiorly. It connects anteroinferiorly with the infraorbital foramen via the **infraorbital canal**.
i. The **maxillary sinus** is the large void in the body of the maxilla superior to the alveolar process and inferior to the orbital floor.
j. The **frontal process** rises to articulate with the frontal, nasals, lacrimal, and ethmoid.
k. The **anterior lacrimal crest** is a vertical crest located on the lateral aspect of the frontal process of the maxilla. The maxilla combines with the lacrimal bone to form the **lacrimal groove** and **canal**. This canal houses the *nasolacrimal duct,* which drains tears inferiorly into the nasal cavity.
l. The **palatine process** forms the anterior two-thirds of the hard palate and floor of the nasal cavity.
m. The **incisive foramen** perforates the anterior hard palate at the midline.
n. The **incisive canal** is bilobate, opening via the incisive foramen, with each lobe enclosed by one of the maxillae. Each lobe of the canal transmits the *terminal branch of the greater palatine artery* and the *nasopalatine nerve*.
o. The **premaxillary suture** is sometimes seen in the wall of the incisive canal and on the adjacent palatal surface, particularly in young individuals.
p. The **greater palatine groove** at the rear of the hard palate marks the junction of the palatine and alveolar processes. This groove is for the *greater palatine vessels* and *nerve*.
q. The **maxillary tuber** is the rugose surface at the posterior end of the alveolar process. It is variable in expression, articulating with the pyramidal process of the palatine and sometimes with the lateral pterygoid plate of the sphenoid.
r. The **nasoalveolar clivus** is the surface between the canine jugae, the base of the piriform aperture, and the alveolar margin.

7.11.2 Growth

Each maxilla ossifies from two main combined centers, one for the maxilla proper and one for the premaxilla. These fuse early in human development, about the ninth week *in utero*, but the suture between them may persist into adulthood in the region adjacent to the incisive canal.

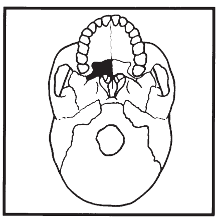
7.11.3 Possible Confusion

Small fragments of maxilla might be confused with other cranial bones. Because the bone is complex, it is helpful to note the diagnostic features useful in identifying it. These include the alveolar region, the sharp edges of the nasal aperture, the edge of the lacrimal canal, the large maxillary sinus, and the unique, serrated intermaxillary suture.

7.11.4 Siding

Fragments of maxilla may prove difficult to side, and the use of comparative specimens may prove necessary.

- For a broken frontal process, the thinner edge is anterior and medial, the medial surface is vascularized (perforated by blood vessels), and the anterior lacrimal crest is lateral.
- For any segment with alveolar bone preserved, tooth roots or sockets can be used as a guide to medial, lateral, anterior, and posterior.



7.12 Palatines (Figures 7.23–7.24)

7.12.1 Anatomy

The small, delicate, L-shaped palatine bones form the rear of the hard palate and part of the wall and floor of the nasal cavity. Individual palatine bones are almost never found in an isolated, intact state; they generally accompany the maxillae and sphenoid, to which they are tightly bound. In addition to these two, palatines articulate with the vomer, inferior nasal conchae, ethmoid, and with each other.

a. The **horizontal plate** of the palatine forms the posterior third of the hard palate.
b. The **greater palatine foramen** (**canal**) perforates the rear corner of the hard palate and is formed as the alveolar process of the maxilla meets the horizontal plate

of the palatine. This canal transmits the *greater palatine vessels* and *nerve*.

c. The two halves of the **pterygopalatine canal** become visible, sweeping postero-superiorly, when the maxilla and perpendicular plate of the palatine are disarticulated.

d. The **posterior nasal spine** is located on the superior surface of the horizontal plate. The superior, or nasal cavity, surface of the plate is smoother and more regular than the palatal surface.

e. **Lesser palatine foramina**, for the transmission of *lesser palatine nerves*, are located on the posterolateral corner of the hard palate posterior to the greater palatine foramina, near the junction of the perpendicular and horizontal plates.

f. The **perpendicular** (**vertical**) **plate** is appressed tightly to the posteromedial wall of the maxilla opposite the maxillary sinus, between the pterygoid plates of the sphenoid and the posterior margin

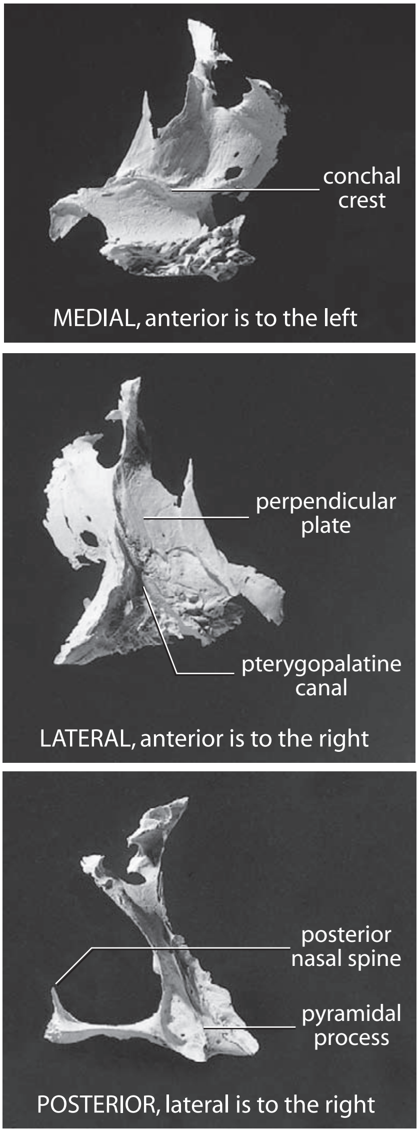


Figure 7.23 **Right palatine.** Superior is up. Natural size.

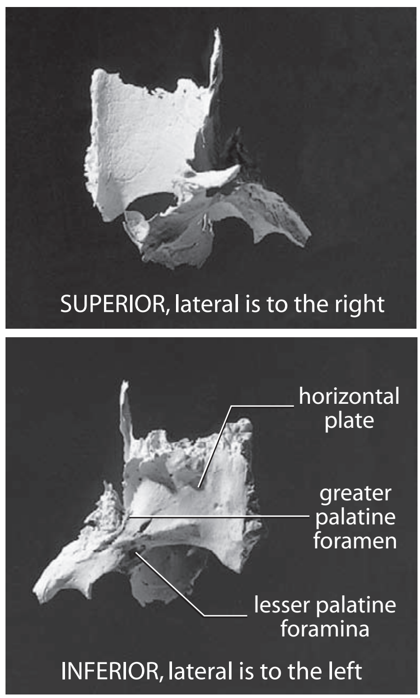


Figure 7.24 **Right palatine.** Anterior is up. Natural size.

of the alveolar process of the maxilla.

g. The posterior border of the perpendicular plate is the thickest border. It bears a serrated groove that articulates with the medial pterygoid plate of the sphenoid. This area of the bone is called the **pyramidal process**.
h. The **conchal crest** is a subhorizontally oriented crest placed not quite halfway up the perpendicular plate on the medial surface of the plate. This crest is for articulation with the inferior nasal concha.

7.12.2 Growth

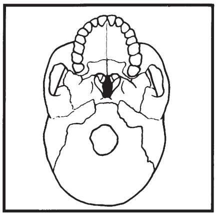
Palatine bones ossify in membrane from single centers.

7.12.3 Possible Confusion

Because the palatines are almost always attached to the maxillae and sphenoid, identification is not usually difficult. When small, isolated fragments of palatine are encountered, note the free posterior edge of the horizontal plate and the smooth, even concavity on the nasal surface of this plate.

7.12.4 Siding

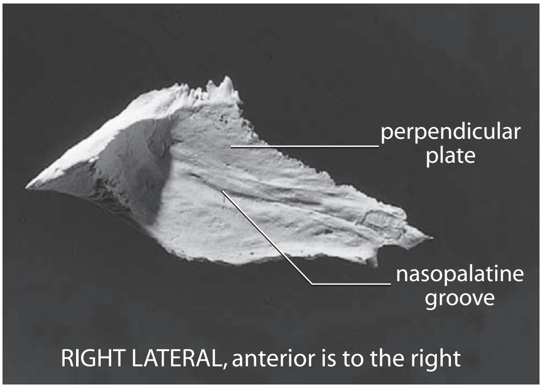
Because isolated fragments of palatine most often preserve the horizontal plate, note that the superior surface is smooth, that the inferior (palatal) surface is rough, that the posterior edge is nonarticular, and that greater and lesser palatine foramina are posterolateral.



7.13 Vomer (Figure 7.25)

7.13.1 Anatomy

The vomer is a small, thin, plow-shaped, midline bone that occupies and divides the nasal cavity. It articulates inferiorly on the midline with the maxillae and the palatines, superiorly with the sphenoid via its wings, and anterosuperiorly with the ethmoid. Thus, the bone forms the posteroinferior part of the nasal septum, which divides the nasal cavity.



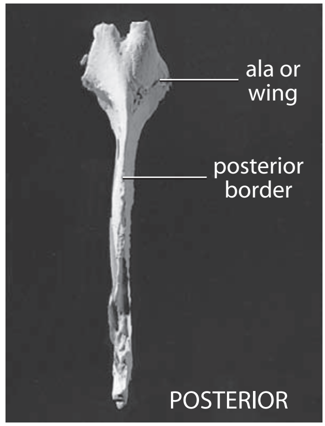


Figure 7.25 **Vomer.** Superior is up. Natural size.

a. **Alae**, or **wings**, of the vomer are located on either side of a deep midline furrow on the superior surface of the vomer. This part of the bone is the thickest and sturdiest and is tightly appressed to the sphenoid.
b. The **perpendicular plate** of the vomer is a thin vertical sheet of bone on the midline below the wings.
c. The nonarticular **posterior border** of the vomer divides the posterior nasal aperture into two halves.
d. **Nasopalatine grooves** lodge *nasopalatine nerves* and *vessels*, marking both sides of the perpendicular plate, where they run anteroinferiorly from the alae.

7.13.2 Growth

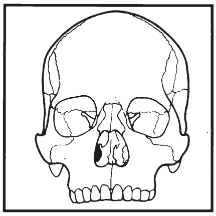
Another bone with both endochondral and membranous ossification, the vomer ossifies from two plates (laminae) on either side of a median plate of cartilage. By puberty, the lamellae are virtually united, but the bilaminar origin of the bone is discernible in the cleft between the alae.

7.13.3 Possible Confusion

Because of the midline placement of the vomer, symmetry is the best guide to identification. Isolated vomers are rarely found and almost never recovered intact. To avoid confusion with other thin bones, such as the sphenoid, note that the vomer has alae and that the perpendicular plate is symmetrical, with a free posterior edge.

7.13.4 Siding

The nonmidline portions of the vomer are so small that siding criteria are unnecessary for this bone.



7.14 Inferior Nasal Conchae (Figure 7.26)

7.14.1 Anatomy

Inferior nasal conchae extend horizontally along the lateral walls of the nasal cavity, articulating with the medial wall of the maxillae and with the palatines. They also articulate with the ethmoid and lacrimals superiorly. The bones are rarely found isolated because they are so fragile. Their shape is variable, with the anterior and posterior extremities tapered to a point, and the inferior surface free, thickened, and vascularized. Inferior nasal conchae function in olfaction and in moistening inhaled air.

7.14.2 Growth

The inferior nasal conchae ossify from single centers.

7.14.3 Possible Confusion

Because inferior nasal conchae are so fragile, they are virtually never found intact as isolated specimens. Small fragments might be mistaken for ethmoid, sphenoid, or lacrimal. Note, however, that the surface texture of the inferior nasal conchae is highly perforated by numerous tiny apertures, giving them a fragile and lightweight aspect.

7.14.4 Siding

There is little use for knowledge of siding inferior nasal conchae.

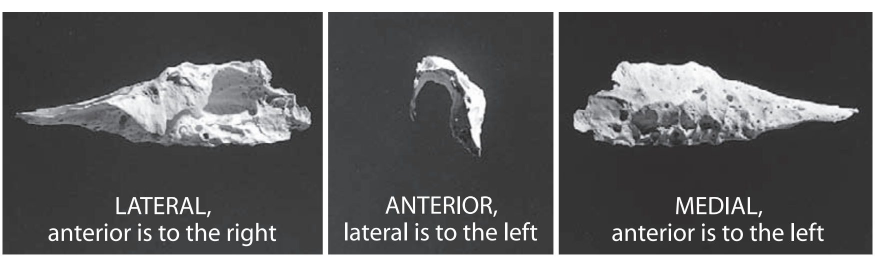
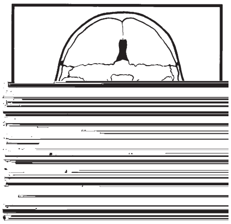


Figure 7.26 **Right inferior nasal concha.** Superior is up. Natural size.



7.15 Ethmoid (Figure 7.27)

7.15.1 Anatomy

The ethmoid bone is exceedingly light and spongy. It is roughly the size and shape of an ice cube, but is only a fraction as heavy. It is located between the orbits, centered on the midline. It articulates with thirteen bones: the frontal, sphenoid, nasals, maxillae, lacrimals, palatines, inferior nasal conchae, and vomer. The ethmoid is virtually never found as a unit because of its fragility. It is best viewed in a specially disarticulated skull, where its complexity can be appreciated.

a. The **cribriform plate** is best observed endocranially, where the ethmoid can be seen to fill the ethmoid notch of the frontal. The cribriform plate roofs the nasal cavities, and because it is perforated by many tiny foramina it looks like a sieve. *Olfactory nerves* (cranial nerve 1) perforate this plate as they pass up to the brain from the mucous lining of the nose.
b. The **crista galli** is a perpendicular projection of the cribriform plate of the ethmoid into the endocranial cavity. It is interposed between *olfactory bulbs*, and its posterior surface anchors the *falx cerebri*, a fold of the *dura mater* extending into the longitudinal fissure of the brain between the two *cerebral hemispheres*.
c. The **labyrinths**, or **lateral masses**, of the ethmoid lie to either side of the midline and consist of a series of thin-walled ethmoidal cells. The lateral

Figure 7.27 **Ethmoid.** Natural size.

d. The **subscapular fossa** is the shallow concavity that dominates the anterior (costal) surface of the scapula.
e. The **oblique ridges** that cross the subscapular fossa from superolateral to inferomedial are formed by *intramuscular tendons* of the *subscapularis muscle*, a major muscle that functions in medial rotation and adduction of the humerus and assists in other movements of the arm at the shoulder.
f. The **lateral** (**axillary**) **border** is the anteroposteriorly thickest border. It is usually slightly concave.
g. The **glenoid cavity** (**glenoid fossa**) is a shallow, vertically elongate concavity that receives the head of the humerus. The shallowness of this joint allows great mobility of the humerus (circumduction comes easily), but the shoulder joint is consequently more prone to dislocation than the hip joint.
h. The **supraglenoid tubercle** sits adjacent to the superior edge of the glenoid cavity, at the base of the coracoid. This anchors the *long head of the biceps brachii muscle*, a flexor of the arm and forearm.
i The **infraglenoid tubercle** sits just adjacent to the inferior edge of the glenoid cavity. It gives origin to the long head of the *triceps brachii muscle*, an extensor of the forearm and an extensor and adductor of the arm at the shoulder.
j. The **scapular neck** is the slightly constricted region just medial to the glenoid fossa.
k. The **medial** (**vertebral**) **border** is the straightest, longest, and thinnest border.
l. The **scapular spine** dominates the posterior surface of the scapula. It passes mediolaterally across this surface, merging medially with the vertebral border and projecting laterally as the acromion process.
m. The **acromion** (**acromion process**) is the lateral projection of the scapular spine. Its cranial surface is very rough, providing attachment for a portion of the *deltoideus muscle*, a major arm abductor whose origins continue along the inferior edge of the scapular spine. The upper fibers of the *trapezius muscle*, which act as scapular rotators, also insert here. The anteromedial corner of the acromion bears a small articular facet for the distal end of the clavicle.
n. The **supraspinous fossa** is the large, mediolaterally elongate hollowing superior to the base of the spine. It is the site of origin of the *supraspinatus muscle*, a major abductor of the arm.
o. The **infraspinous fossa** is the hollowing inferior to the scapular spine. This extensive, weakly concave area is the site of origin of the *infraspinatus muscle*, a lateral rotator of the arm. The intramuscular tendons of this muscle attach to the ridges on the surface of the fossa.
p. The **superior angle** of the scapula is where the superior and medial (vertebral) borders intersect. The *levator scapulae muscle* attaches to the dorsal surface of the scapula in this region.
q. The **inferior angle** of the scapula is where the vertebral (medial) and axillary (lateral) borders intersect. Rugosities on the costal and dorsal surfaces in this area mark the insertions of the *serratus anterior muscles* and origin of the *teres major muscle* from the medial and lateral borders, respectively.

11.2.2 Growth (Figure 11.8)

The scapula ossifies from seven or more centers. One of these is for the body, two each for the coracoid and acromion, and one each for the vertebral border and inferior angle. Ossification of the borders is variable, with elongated plates appearing and fusing during adolescence.

11.2.3 Possible Confusion

- When fragmentary, the scapula might be mistaken for the pelvis. In all of its flat parts, however, the scapula is thinner than the pelvis. Indeed, the scapular blade is mostly a single, thin layer of bone instead of spongy bone sandwiched between cortices as in the pelvis.

Figure 11.8 Clavicular and scapular growth.
(*Top*) Superior view of a one-year-old (*left*) and a six-year-old clavicle (*right*).
(*Bottom*) Dorsal view of a one-year-old (*left*) and a six-year-old (*right*) scapula. Natural size.

- A broken fragment of glenoid could be mistaken for the hip joint. The glenoid is much shallower and smaller than the acetabulum.
- The coracoid could be mistaken for the transverse process of a thoracic vertebra, but the coracoid is nonarticular.
- The lateral part of the acromion is sometimes mistaken for a fragment of lateral clavicle. However, because the acromion is continuous with the thin, plate-like spine, rather than a cylindrical shaft, this misattribution can be avoided. The inferior acromial surface is also smooth and concave; the distal clavicle is not.
- Tiny fragments of scapular blade or infant scapulas could be mistaken for wings of the sphenoid, but the thin bone of the scapula will be bounded by broken surfaces, whereas broken pieces of sphenoid pieces normally have free or sutural edges.

11.2.4 Siding

When intact, the glenoid is lateral and the spine is posterior. When fragmentary, use the following criteria:

- For an isolated glenoid, the fossa is teardrop-shaped, with its blunt end inferior. When looking directly into the correctly oriented glenoid fossa, note that the anterior edge of the fossa has a broad notch in it. The supraglenoid tubercle at the superior edge of the glenoid is displaced anteriorly. Posteriorly, the border of the glenoid is waisted, and the edge is raised and roughened. The anterior border is not as raised; it gently slopes into the rest of the scapula.
- For an isolated acromion, the inferior surface of the acromion is concave and is smoother than the superior. The clavicular facet is placed anteriormedially relative to the tip.
- For an isolated vertebral border, the anterior surface is concave and the posterior is convex. The oblique ridges run from superolateral to inferomedial (parallel to the scapular spine).
- For an isolated inferior angle, the anterior surface is concave, while the posterior is convex. The thickest border is lateral (axillary).
- For an isolated axillary border, the broad sulcus inferior to the glenoid parallels the border and is displaced anteriorly. The border itself thins inferiorly. The bony thickening is greatest (forming a "bar") on the anterior surface. Thickness of the cortex increases as the glenoid is approached along this border.
- For an isolated coracoid, the smooth surface is inferior, the rough superior. The anterior border is longer. The hollow on the inferior surface faces the glenoid area (posteroinferiorly).
- For an isolated spine, the spine thins medially (vertebrally) and thickens towards the acromion. The inferior border has a tubercle that points inferiorly. Adjacent to the spine, the infraspinous fossa is most deeply excavated medially. The supraspinous fossa is most deeply excavated laterally. A variably present foramen (or foramina) perforates the scapula at the superolateral base of the spine, at the depth of the supraspinous fossa.

Chapter 12

Arm: Humerus, Radius, & Ulna

The first vertebrates lacked jaws. These animals, similar to modern lampreys and hagfish, also lacked paired fins. Jaws and fins evolved 400 million years ago, allowing fish to locomote and feed more effectively. Jawed fish have paired fins set on flat plates of bone that are attached to the muscles of their body walls. These paired fins, flexible fans of small bones, are used primarily as aids in stabilizing and steering. The limbs of terrestrial animals evolved from this structural arrangement as fins were transformed into rod-bearing segments. Although the limbs of land vertebrates seem very different from fish fins, the two homologous structures are actually highly comparable.

Each vertebrate limb has a base and three segments. The bases (the limb girdles) are the old basal fin plates of fish, which evolved to take on the function of transferring the weight of the body to the limbs of the terrestrial tetrapod. The proximal vertebrate limb segments constitute the upper arm and thigh. The intermediate limb segments, the forearm and foreleg, each bear two bones in humans, the radius and ulna in the arm, and their serial homologs, the tibia and fibula, in the leg. This chapter considers the three bones of the two uppermost segments of the forelimb: the humerus, radius, and ulna.

12.1 Humerus (Figures 12.1–12.6)

12.1.1 Anatomy

The upper arm bone, or humerus, is the largest bone in the upper limb (arm). It comprises a proximal end with a round articular head, a shaft, and an irregular distal end. The humerus articulates proximally with the glenoid fossa of the scapula and distally with both the radius and the ulna.

a. The **head** is a hemisphere on the proximal end of the humerus that faces medially and articulates with the glenoid fossa of the scapula.
b. The **anatomical neck** is the groove that encircles the articular surface of the head for the attachment of the *joint capsule*.

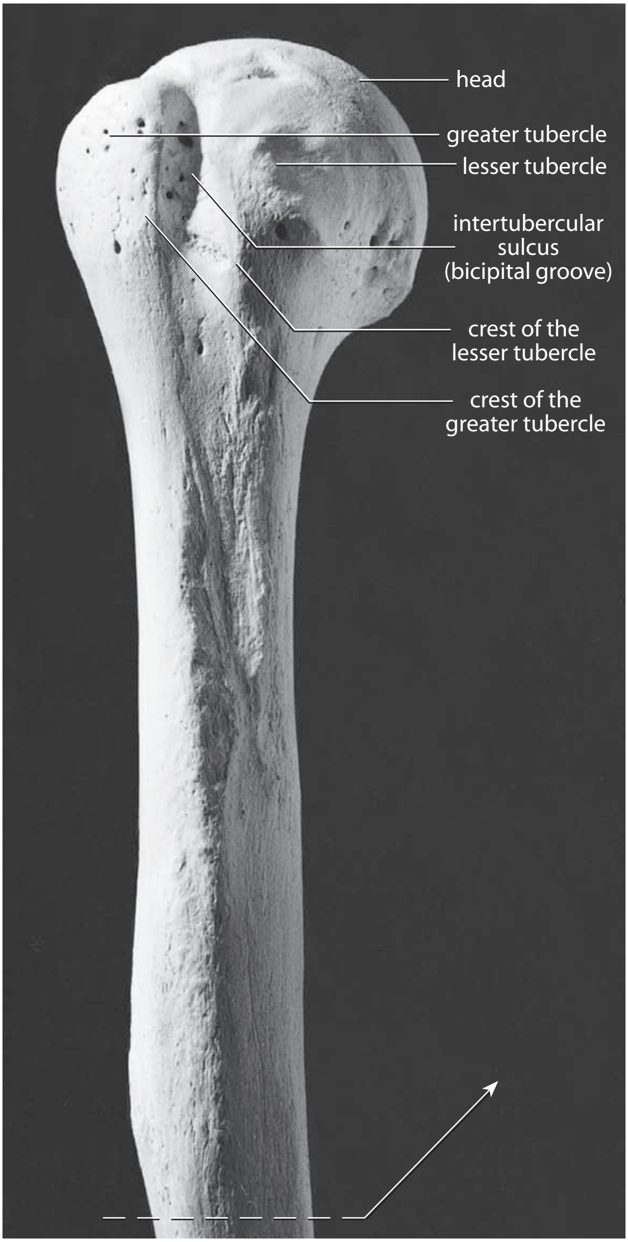


Figure 12.1a **Right humerus, anterior.** Proximal end. Natural size.

c. The **surgical neck** is the short segment inferior to the head. It links head and shaft.
d. The **lesser tubercle** is a small, blunt eminence anterolateral to the head on the proximal shaft. The lesser tubercle marks the insertion of the *subscapularis muscle*, which originates on the costal surface of the scapula and rotates the humerus medially.
e. The **greater tubercle** is larger, more posterior, and projects more laterally than the lesser tubercle. The greater tubercle bears rugosities for the insertion of the *su-*

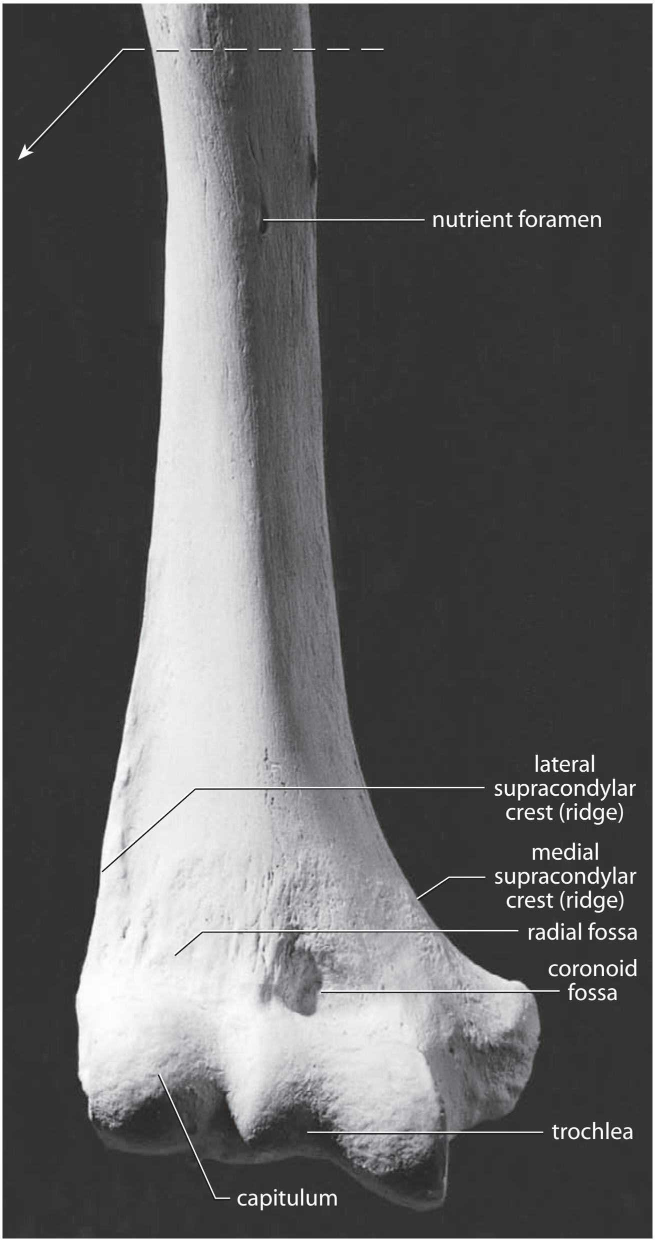


Figure 12.1b **Right humerus, anterior.** Distal end. Natural size.

ARM

praspinatus, *infraspinatus*, and *teres minor muscles*. These muscles, together with the *subscapularis muscle*, constitute the *rotator cuff muscles*. In addition to medial and lateral rotation, these muscles also aid in adduction and abduction of the arm.

f. The **intertubercular sulcus** (**bicipital groove**) extends longitudinally down the proximal shaft. It begins between the two tubercles and houses the *tendon of the long head of the biceps brachii muscle*. In life, the *transverse humeral ligament* connects the two tubercles to bridge the groove and form a canal.

Figure 12.2a **Right humerus, posterior.** Proximal end. Natural size.

g. The **crest of the greater tubercle** forms the lateral lip of the intertubercular groove. It is the insertion site for the *pectoralis major muscle*, a muscle that originates on the anteromedial clavicle, the sternum, and the cartilage of the true ribs. This muscle acts to flex, adduct, and medially rotate the arm.
h. The **crest of the lesser tubercle** forms the medial lip of the intertubercular groove. It is the insertion site for the *teres major* and *latissimus dorsi muscles*, medial rotators and abductors of the arm.

Figure 12.2b **Right humerus, posterior.** Distal end. Natural size.

ARM

i. The humeral **shaft** is variably triangular, ranging from more cylindrical in its proximal section to an anteroposteriorly compressed, rounded triangle distally.
j. The **deltoid tuberosity** is on the lateral surface of the shaft. It is the insertion site of the *deltoideus muscle*, a major abductor (among other functions) of the arm that originates from the anterior border and superior surface of the clavicle, the lateral margin and superior surface of the acromion, and the scapular spine. The deltoid tuberosity is recognized by its roughened surface. It tapers to a V-shape on the

Figure 12.3a **Right humerus, medial.** Proximal end. Natural size.

lateral humerus.

k. The **radial sulcus** (**spiral groove**) is found on the posterior surface of the shaft. It is a shallow, oblique groove for the *radial nerve* and deep vessels that pass parallel and immediately posteroinferior to the deltoid tuberosity. Its inferior boundary is continuous distally with the lateral border of the shaft.

l. The **nutrient foramen** is located anteromedially and exits the shaft from distal to proximal. A good way to remember the direction of entry of nutrient foramina

Figure 12.3b **Right humerus, medial.**
Distal end.
Natural size.

into all of the long bones is to imagine tightly flexing your own arms (at the elbows) and legs (at the knees) in front of you. In this position you can look into the bones via the foramina. In long bones, these foramina carry the *nutrient arteries*.

m. The **olecranon fossa** is the largest of three hollows on the distal humerus. It is posterior, accommodating the olecranon process of the ulna during forearm extension. The deepest area of this fossa may be perforated, forming a foramen, or **septal aperture**.

Figure 12.4a **Right humerus, lateral.** Proximal end. Natural size.

n. The **coronoid fossa** is the larger, medially placed hollow on the anterior surface of the distal humerus. It receives the coronoid process of the ulna during maximum flexion of the forearm.
o. The **radial fossa** is the smaller, laterally placed hollow on the anterior surface of the distal humerus. It receives the head of the radius during maximum flexion of the forearm.
p. The **capitulum** is the rounded eminence that forms the lateral portion of the

Figure 12.4b **Right humerus, lateral.** Distal end. Natural size.

distal humeral surface. It articulates with the head of the radius.

q. The **trochlea** is the notch- or spool-shaped medial portion of the distal humeral surface. It articulates with the ulna.
r. The **lateral epicondyle** is the small, nonarticular lateral bulge of bone superolateral to the capitulum. It serves as a site of attachment for the *radial collateral ligament* of the elbow and for the common tendon of origin of the *supinator* and the *extensor muscles* in the forearm.

Figure 12.5 **Right humerus, proximal.** Anterior is up, lateral is toward the right. Natural size.

Figure 12.6 **Right humerus, distal.** Anterior is up, lateral is toward the left. Natural size.

s. The **medial epicondyle** is the nonarticular, medial projection of bone superomedial to the trochlea. It is more prominent than the lateral epicondyle. It provides a site of attachment to the *ulnar collateral ligament*, to many of the *flexor muscles* in the forearm, and to the *pronator teres muscle*.
t. The **medial supracondylar crest** (**ridge**) is superior to the medial epicondyle and forms the sharp medial border of the distal humerus.
u. The **lateral supracondylar crest** (**ridge**) is superior to the lateral epicondyle and forms the sharp lateral border of the distal humerus.

12.1.2 Growth (Figure 12.7)

The humerus ossifies from eight centers: the shaft, the head, and both tubercles (a composite of several early centers including the head itself and each tubercle; a "conjoint"), the capitulum and trochlea (the capitulum fuses to the trochlea before either fuses to the shaft), and each epicondyle.

Figure 12.7 **Humeral, ulnar, and radial growth.** The pairs of immature humeri (*left*), radii (*center*), and ulnae (*right*), shown here in anterior view, are from a one-year-old and a six-year-old. Natural size.

ARM

12.1.3 Possible Confusion

The humeral head cannot be mistaken for a femoral head because the former is only half of a sphere, whereas the latter is substantially more than half.

- The femoral head has a distinct depression, or **fovea capitis**, which the humerus lacks.
- The humeral shaft is larger and more circular in section than the radial, ulnar, or fibular shafts.
- The humeral shaft is smaller and more irregular in section than the femoral shaft.
- The humeral shaft is smaller and less triangular than the tibial shaft.

12.1.4 Siding

- For an intact bone, the head faces medially, the capitulum is lateral, and the olecranon fossa is posterior.
- For an isolated proximal end, the head is medial, and the lesser tubercle and intertubercular groove are anterior.
- For an isolated distal end, the olecranon fossa is posterior, the medial epicondyle is larger, and the capitulum is lateral and oriented anteriorly. If the articular end is missing, the coronoid fossa is larger and more medial than the radial fossa.
- For an isolated shaft fragment, the deltoid tuberosity is lateral, with its posterior arm passing from posterosuperior to anteroinferior, and the nutrient foramen exits the bone toward its proximal end. A small, thin ridge runs along the entire medial edge of the shaft, and the nutrient foramen is found on this edge. The lateral lip of the intertubercular groove is stronger and longer.

12.2 **Radius** (Figures 12.8–12.12)

12.2.1 Anatomy

The radius is the shortest of the three arm bones. It is named for its action, a turning movement about the capitulum of the humerus, which allows the bone to rotate relative to the more fixed ulna. The radius articulates proximally with the humerus at the capitulum and medially with the ulna on both proximal and distal ends. Distally, the radius articulates with two carpal bones of the wrist.

a. The **head** is a round articular structure on the proximal end of the radius. It articulates, via its cupped proximal surface (articular fovea), with the humeral capitulum, whereas the edge of the radial head (circumferential articulation) articulates with the radial notch of the ulna.
b. The **neck** is the slender segment of the radius between the head and the radial tuberosity.
c. The **radial tuberosity** (**bicipital tuberosity**) is a blunt, rugose, variably shaped

structure on the anteromedial side of the proximal radius. It marks the insertion of the *biceps brachii muscle*, a flexor and weak medial rotator of the forearm, and a large *biceps bursa* that underlies this muscle.

d. The **shaft** of the radius is the long, thin section between the radial tuberosity and the expanded distal end.
e. The **nutrient foramen** exits the bone toward its distal end and is located on the anterior surface of the proximal half of the radius.
f. The **interosseous crest** is the sharp medial edge of the radial shaft. It serves as the attachment site for a fibrous membrane, the *interosseous membrane*, which divides the forearm into two compartments, anterior and posterior. These house the flexor and extensor groups of muscles that act across the wrist.
g. The **oblique line** is on the anterior surface of the shaft. It spirals inferolaterally from its origin at the base of the radial tuberosity. This line gives origin to extrinsic muscles of the hand.
h. The **pronator teres insertion** is a midshaft roughening on the lateral surface.
i. The **ulnar notch** is a concave articular hollow on the medial corner of the distal radius. It articulates with the distal end of the ulna.
j. The **distal radial articular surface** articulates with carpal bones — the lunate on the medial side, and the scaphoid on the lateral side.
k. The **styloid process** is a sharp projection on the lateral side of the distal radius.
l. The **dorsal tubercle** (**Lister's tubercle**) is a large tuberosity on the posterior surface of the distal radius. The grooves between this and other tuberosities on the dorsum of the distal radius house the *tendons of extrinsic extensor muscles* of the hand.

12.2.2 Growth (Figure 12.7)

The radius ossifies from three centers: the shaft, the head, and the distal end.

12.2.3 Possible Confusion

Radial shaft segments might be mistaken for the ulna or fibula, and distal ends might be mistaken for the clavicular notch of the manubrium, but the following features help identify fragments of the radius.

- The ulnar shaft tapers continuously (the circumference decreases) from proximal to distal, whereas the radius does not.
- The ulnar shaft has a sharp interosseous crest, but the two other corners are not as evenly rounded as they are in the radius, which has a teardrop shape in cross section and a smoother, more uniform crest.
- Most of the ulnar shaft is triangular. The ulnar shaft only becomes round in cross section at its distal end. In contrast, the radial shaft is circular proximally and is a rounded triangle at midshaft. It is a broad, anteroposteriorly compressed oval with cortex that thins at more distal cross sections.
- The fibula, also a long slender bone with crests, is much more irregular in cross

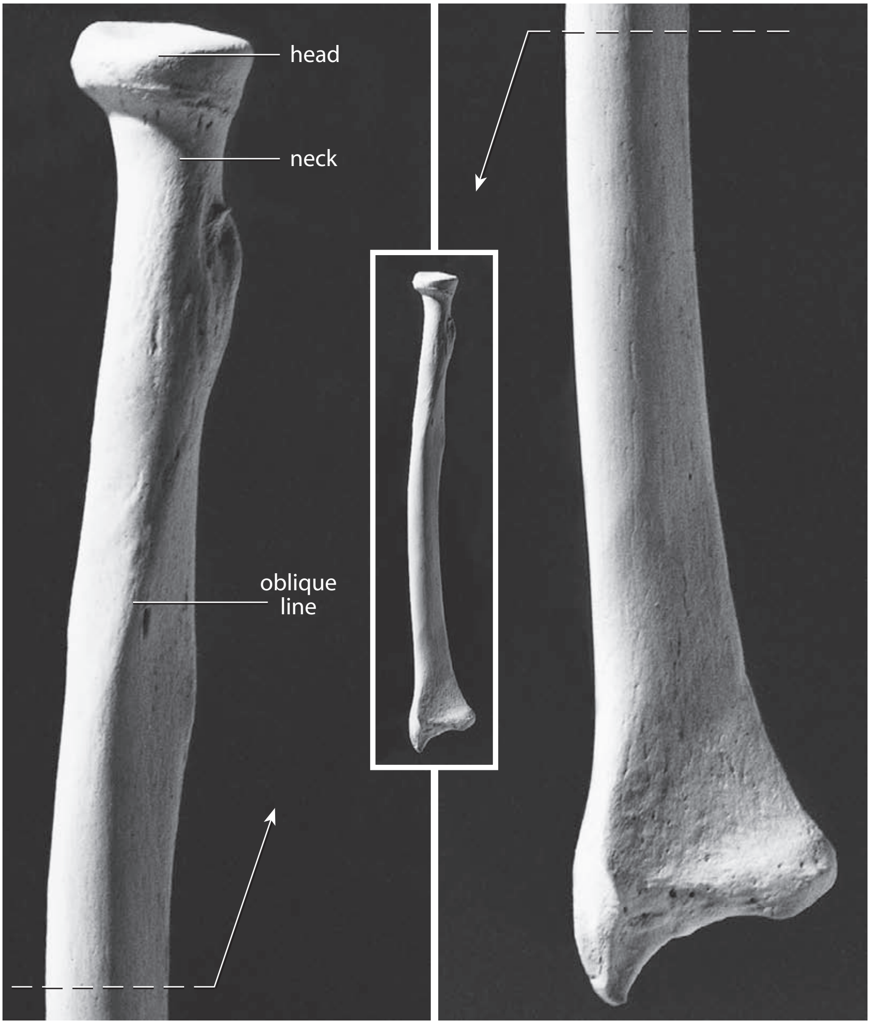


Figure 12.8 **Right radius, anterior.** *Left*, proximal end; *right*, distal end. Natural size.

section and much longer than the radius.

- The distal radial articulation has two discernable articular surfaces" (or "facets," see Figure 12.12), whereas the clavicular notch of the manubrium is singular.

12.2.4 Siding

- For an intact radius, the ulnar notch is medial, the radial tuberosity and interosseous crest are medial, the dorsal tubercles are posterior, and the styloid process is lateral.
- For an isolated proximal end, the tuberosity faces anteromedially. The medial

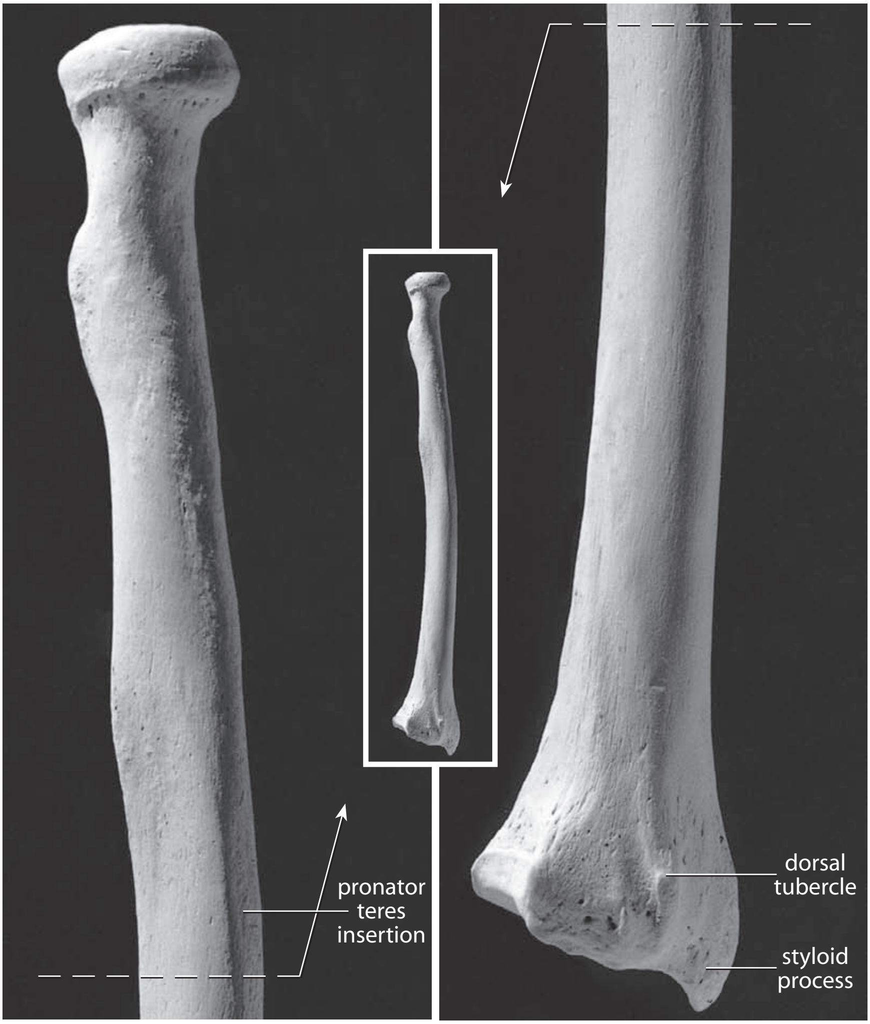


Figure 12.9 **Right radius, posterior.** *Left*, proximal end; *right*, distal end. Natural size.

portion of the proximal ulnar articular surface has the greatest proximodistal dimension.

- There is a small ridge on the posteromedial aspect of the neck, congruent with the superior aspect of the medial edge of the radial tuberosity.
- For an isolated segment of shaft, the interosseous crest is medial, and the oblique line is anterior. The nutrient foramen exits the bone distally and is situated anteriorly on the shaft. The posterolateral surface has the greatest rugosity at about midshaft.
- For an isolated distal end, the anterior surface is smooth and flat, the posterior surface has extensor grooves, the ulnar notch is medial, and the styloid process is lateral. The styloid process is smooth on its anterior surface.

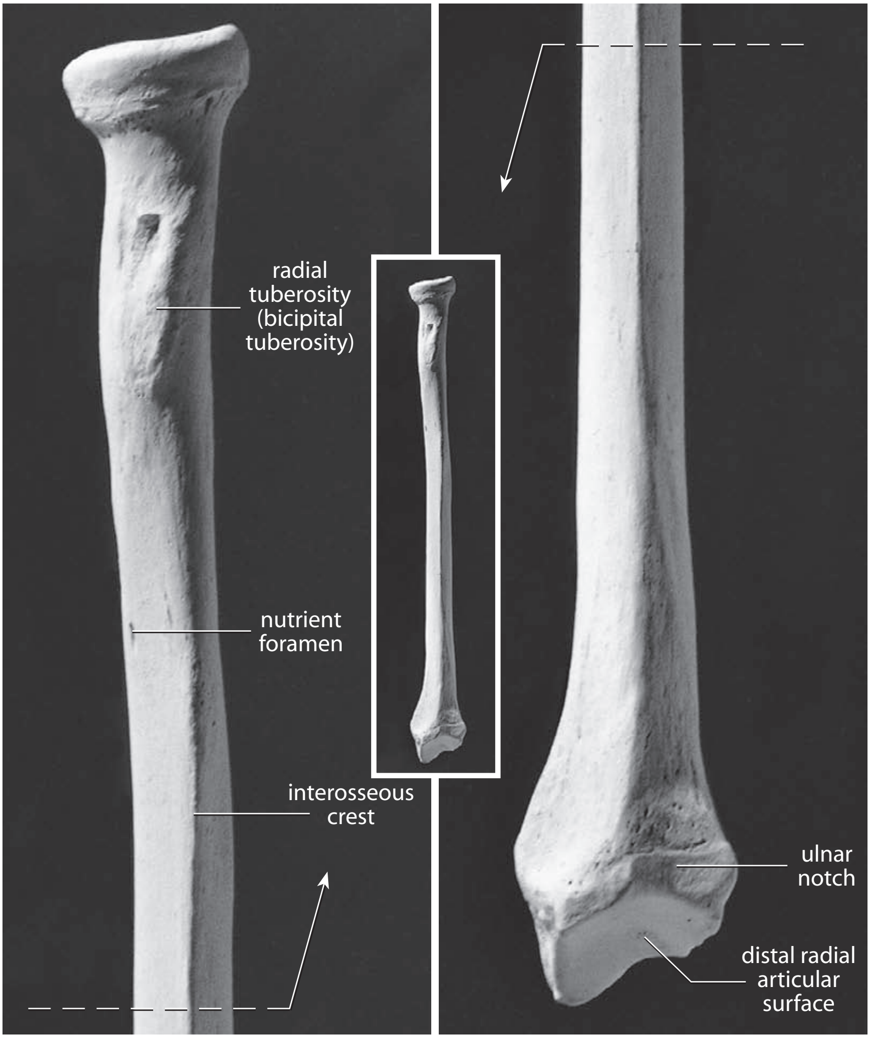


Figure 12.10 **Right radius, medial.** *Left*, proximal end; *right*, distal end. Natural size.

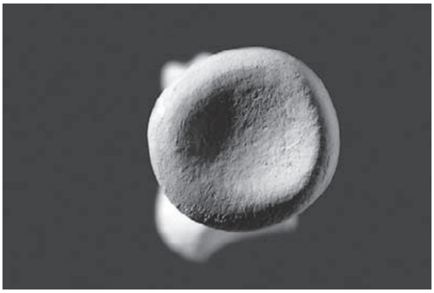


Figure 12.11 **Right radius, proximal.** Lateral is up, anterior is toward the left. Natural size.

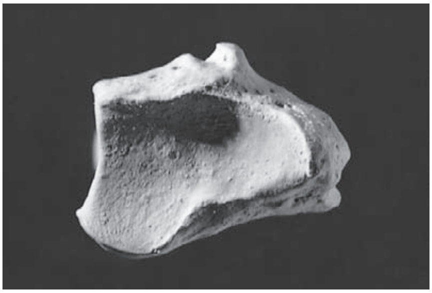


Figure 12.12 **Right radius, distal.** Dorsal is up, lateral is toward the right. Natural size.

12.3 Ulna (Figures 12.13–12.18)

12.3.1 Anatomy

The ulna is the longest, thinnest bone of the forearm. It articulates proximally with the trochlea of the humerus and head of the radius. Distally it articulates with the ulnar notch of the radius and with an articular disk that separates it from the carpal bones and provides freer rotation of the hand and radius around the ulna than is seen in many other mammals.

a. The **olecranon** (**olecranon process**) of the ulna is the most proximal part of the bone. It is a massive, blunt process. The *triceps brachii muscle*, the primary extensor of the forearm, inserts on the tuberosity of the process.
b. The **trochlear notch** (**semilunar notch**) of the ulna articulates with the trochlear articular surface of the distal humerus. In contrast to the more mobile radius, rotary motion is very restricted at the ulnar part of the elbow joint, sharply limiting the ulna in its ability to rotate around its long axis.
c. The vertical **guiding ridge** separates the trochlear notch into medial and lateral portions.
d. The **coronoid process** is the anterior, beak-shaped projection at the base of the semilunar notch.
e. Immediately inferior to the coronoid process is a roughened depression called the **ulnar** (**brachial**) **tuberosity** for the insertion of the *brachialis muscle*, a flexor of the elbow that originates from the anterior surface of the humerus.
f. The **radial notch** is the small articular surface for the radius. It is located along the lateral margin of the coronoid process.
g. The **shaft** is the long segment of bone between the brachial tuberosity and the inflated distal end of the ulna.
h. The **nutrient foramen** exits the bone in a distal direction and is found on the anteromedial ulnar shaft.
i. The **interosseous crest** lies opposite the radius, on the lateral surface of the ulnar shaft.
j. The **pronator ridge** is a short, variably expressed ridge on the distal quarter of the shaft. It is located anteromedially and is the origin for the *pronator quadratus muscle*.
k. The **styloid process** is the sharp, distal-most projection of the ulna. It is set on the posteromedial corner of the bone. Its end gives attachment to the *ulnar collateral ligament* of the wrist. It is separated from the remainder of the head by a deep groove or pit, the fovea.
l. The **extensor carpi ulnaris groove** is adjacent to the styloid process, located proximolaterally to it. It houses the *tendon of the extensor carpi ulnaris muscle*, a dorsiflexor and adductor of the hand at the wrist.
m. The **radial** (**circumferential**) **articulation** is the distal, lateral, round articulation that conforms to the ulnar notch of the radius in the same way that the radial head conforms to the radial notch of the proximal ulna.

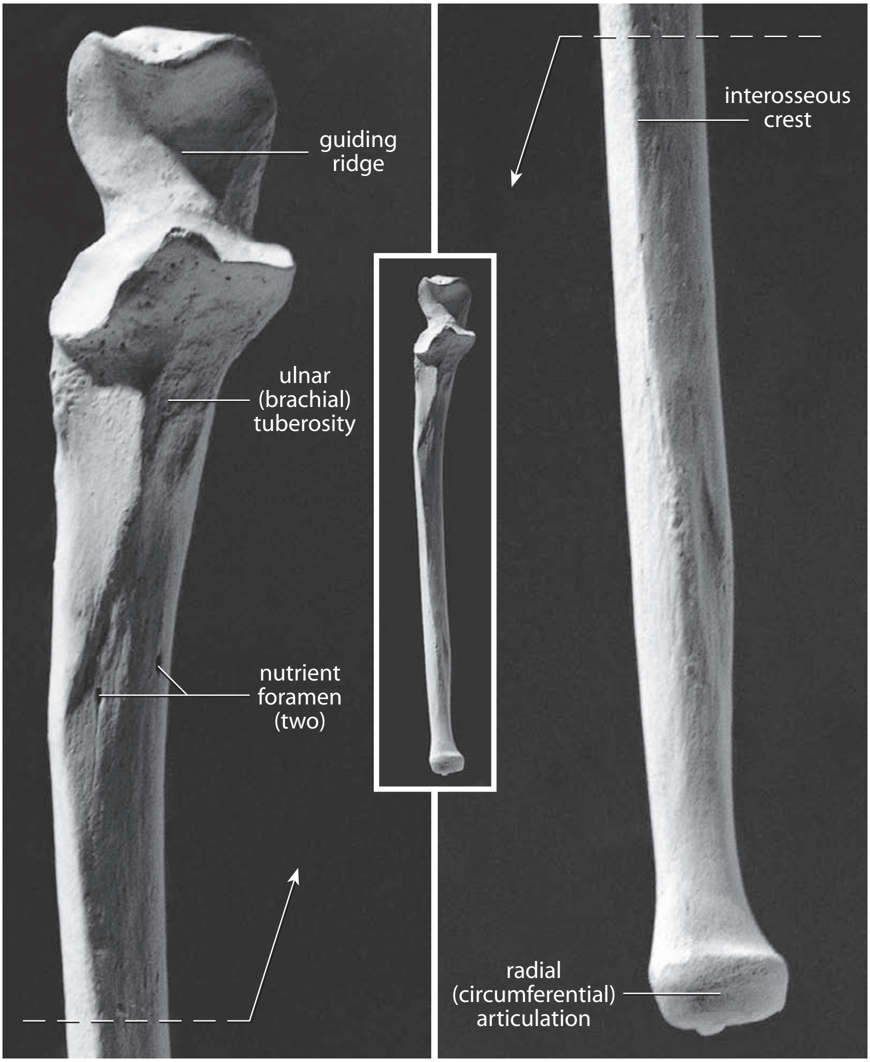


Figure 12.13 **Right ulna, anterior**. *Left*, proximal end; *right*, distal end. Natural size.

12.3.2 Growth (Figure 12.7)

The ulna ossifies from three centers: the shaft, the olecranon process, and the distal end.

12.3.3 Possible Confusion

The ulnar proximal and distal ends are diagnostic, but isolated shafts could be mis-

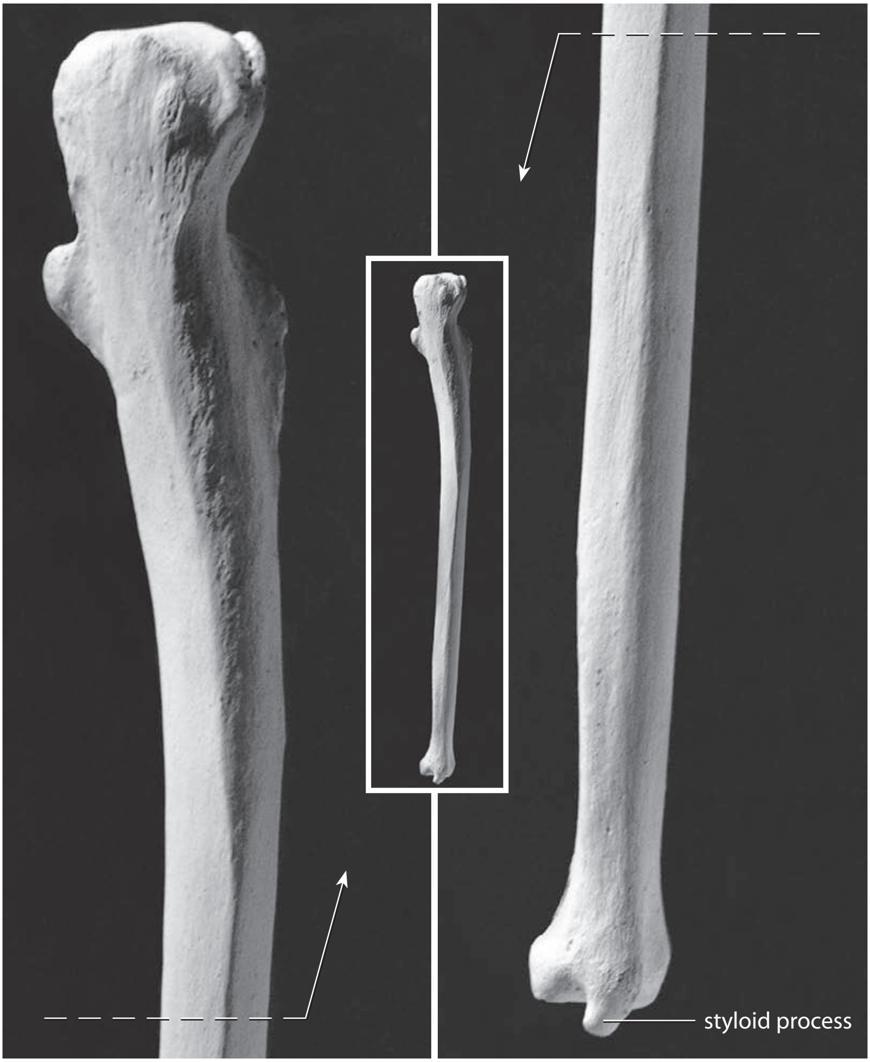


Figure 12.14 **Right ulna, posterior.** *Left*, proximal end; *right*, distal end. Natural size.

taken for radial or fibular shafts.

- The radial shaft is more triangular, or teardrop-shaped, in cross section with two rounded corners and one sharp corner. Radial shafts do not taper distally as the less regular ulnar shaft does.
- The fibular shaft is much more irregular in cross section, with multiple sharp corners.
- See the description of the radius shaft for further details.

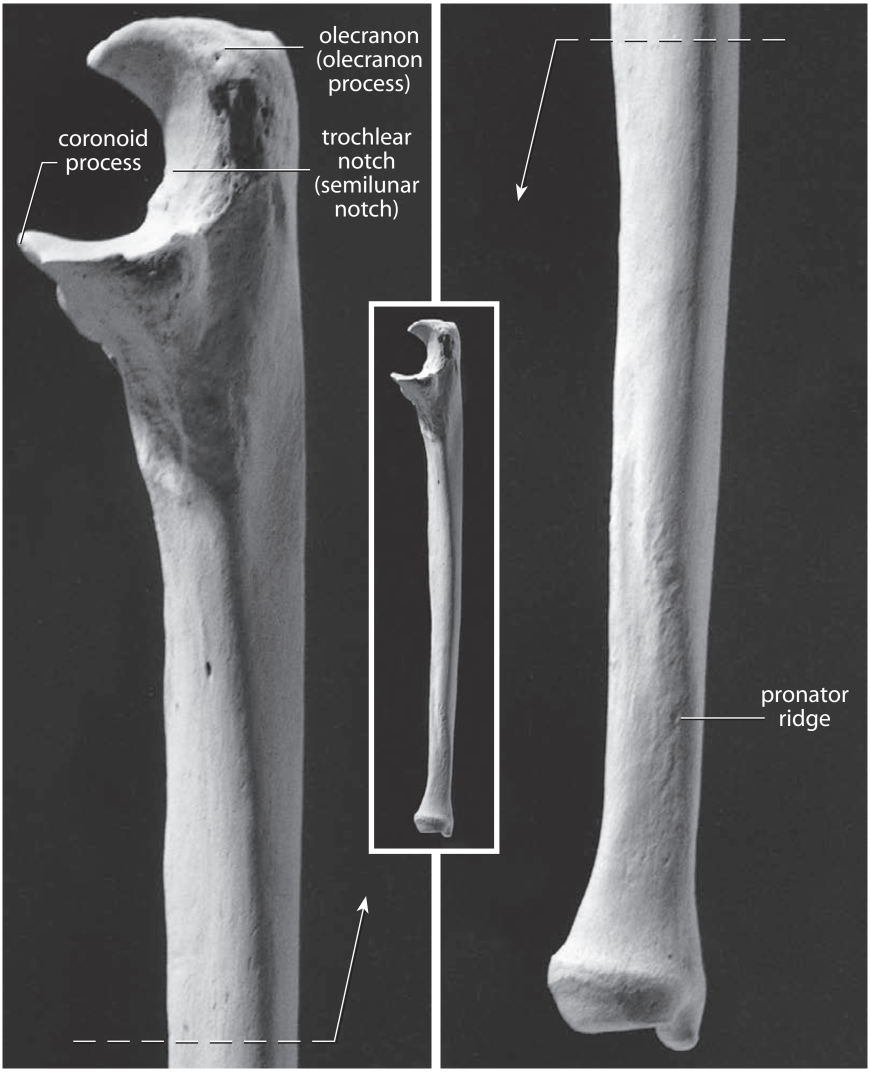


Figure 12.15 **Right ulna, medial.** *Left*, proximal end; *right*, distal end. Natural size.

12.3.4 Siding

- For an intact ulna, the olecranon process is proximal and posterior, the radial notch is lateral, and the interosseous crest is lateral.
- For an isolated proximal end, use the same criteria given earlier for an intact ulna. Note also that the brachial tuberosity is medially displaced.
- For an isolated shaft segment, the shaft tapers distally, and the nutrient foramen exits the bone distally and is located on the anterior shaft surface. The interosse-

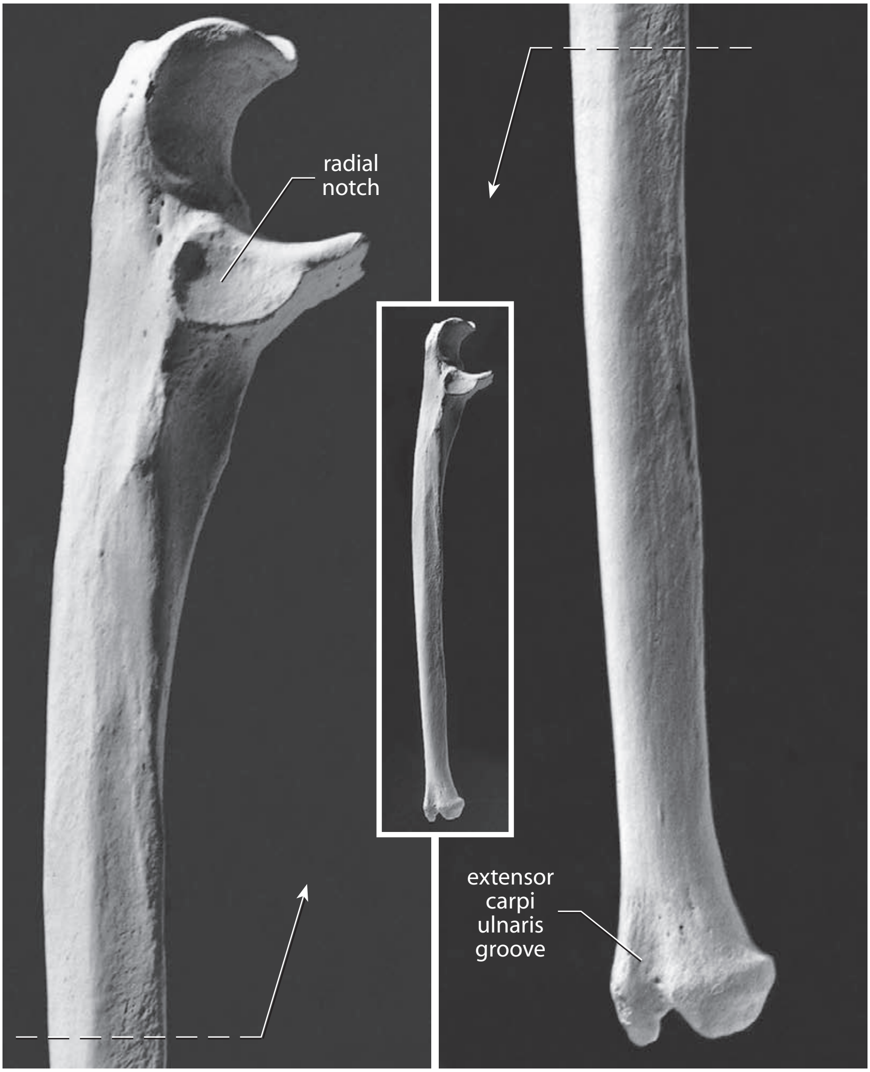


Figure 12.16 **Right ulna, lateral.** *Left*, proximal end; *right*, distal end. Natural size.

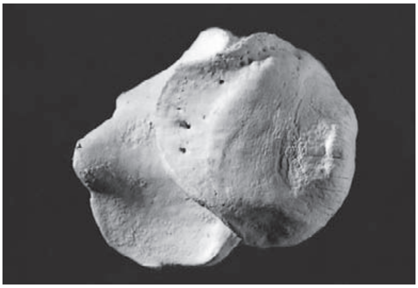


Figure 12.17 **Right ulna, proximal.** Lateral is up, anterior is toward the left. Natural size.

Figure 12.18 **Right ulna, distal**. Anterior is down, lateral is toward the right. Natural size.

ous crest is lateral. The shaft surface anterior to the crest is more hollowed proximally but this may flatten distally. At midshaft and distally, the surface posterior to the interosseous crest may display a narrow groove that is variable in expression.

- For an isolated distal end, the styloid process is posterior, and the groove for the *extensor carpi ulnaris* is lateral to the process.

Chapter 13

Hand: Carpals, Metacarpals, & Phalanges

The hand is a complex structure that represents the tetrapod's distal limb segment. It is the modified end of the ancestral fish fin, a structure based on jointed bony rays. In the generalized reptilian hand, a set of small wrist bones (carpals) forms the foundation for five digits. Each digit is composed of one large proximal segment (a metacarpal) and a chain of additional bones (the phalanges). Digital reduction and modification have occurred in a great variety of mammals, from the wings of bats to the single toes of modern horses. Humans have retained the generalized pattern of five digits. There are a total of twenty-seven bones in each human hand, eight carpal bones arranged in two rows, followed distally by a single row of five metacarpals. Farther distally, there is a single row of five proximal phalanges, a single row of four intermediate phalanges, and a single row of five distal, or terminal, phalanges.

In addition to the twenty-seven major hand bones, there are small bones called **sesamoid bones** that lie within tendons of the hand. These are not usually recovered and are rarely studied by osteologists, who should nevertheless always be alert to

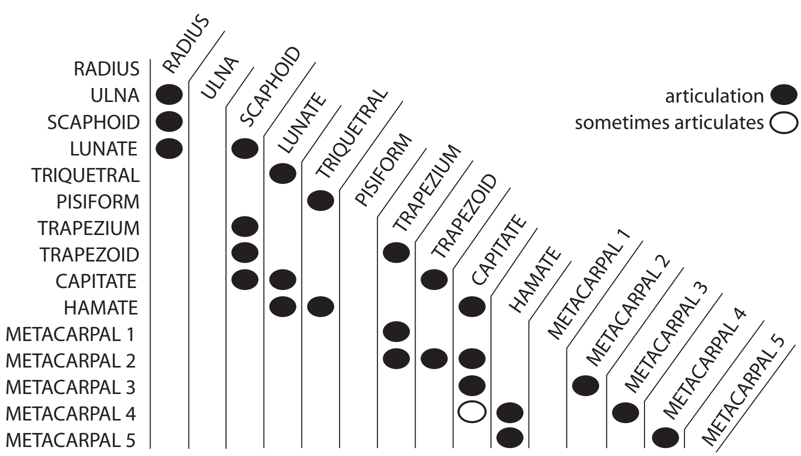


Figure 13.1 Articulation of bones in the adult human wrist and hand.

Figure 13.2 **Right hand, palmar (anterior).** Small sesamoid bones not included. Natural size.

Figure 13.3 **Right hand, dorsal** (**posterior**). Small sesamoid bones not included. Natural size.

their presence as they are of considerable functional significance. In the hand, a pair of sesamoids is usually found on the palmar aspect of the first metacarpal head. Figures 13.1–13.3 summarize and illustrate articulations within the hand.

Elements of the hand skeleton are described in three categories: the **carpals**, the **metacarpals**, and the **hand phalanges**. In the carpal region of the hand, as in the tarsal region of the foot, a variety of different names have been applied to each bone as anatomical nomenclature has evolved through the years. For readers curious about this history, O'Rahilly (1989) provides a good summary.

Before analyzing the various elements that make up the hand, it is useful to note the importance of anatomical nomenclature in the study of the hand. In dealing with elements of the hand, it is easy to become confused by the terms "anterior," "posterior," "medial," and "lateral" because these terms can only be applied when the specimen is in proper anatomical position. For this reason, it is useful to supplement the directional terms when possible, using the following sets of synonyms:

- anterior = palmar
- posterior = dorsal
- medial = ulnar = little finger side
- lateral = radial = thumb side

The term **ray** is often applied to each finger, or toe, including the phalanges and metacarpal of the digit. By convention, the thumb ray, or **pollex**, is identified as ray number 1. The index finger is ray 2, the middle finger is ray 3, the ring finger is ray 4, and the little finger is ray 5.

For hand and foot elements, it is often easiest to use memory-based, or positional, "tools" in order to side the bone quickly. The text provides a set of these tools but also employs standard anatomical techniques to side each bone. Many of the positional techniques detailed here are adopted from Bass (1995).

13.1 Carpals (Figures 13.4–13.15)

The eight bones of the adult wrist are often described as cubical in shape with six surfaces, but this is a misleading characterization. Each bone has a unique, diagnostic shape. For this reason, identification is straightforward. An introduction to the functional anatomy of the wrist facilitates study of the individual wrist elements. The palmar surface of the carpus, or wrist, bears four major projections. The hook of the hamate and the pisiform underlie the medial edge of the palm at the base of metacarpal 5 (MC 5). The scaphoid tubercle and crest of the trapezium underlie the lateral edge of the palm, at the base of the thumb metacarpal (MC 1). In life there is a fibrous band stretched transversely between these carpal elevations. This band, the *flexor retinaculum*, creates a **carpal tunnel** through which *flexor tendons* of the wrist pass.

The carpals are divided into a proximal row incorporating (from radial to ulnar) the **scaphoid**, the **lunate**, the **triquetral**, and the **pisiform**. The scaphoid and lunate both articulate with the radius. The distal row of carpals, again from radial to ulnar, is composed of the **trapezium** (**greater multangular**), the **trapezoid** (**lesser multangular**), the **capitate**, and the **hamate**.

13.1.1 Scaphoid (Figure 13.4)

The scaphoid bone (also known as the hand navicular) is shaped like a boat, with a major concave surface for the head of the capitate and a major convex surface that articulates with the distal radius. One of the largest carpal bones, it is the most lateral and proximal carpal, interposed between the radius and the trapezium, at the base of the thumb. The **tubercle** is a blunt, nonarticular projection adjacent to the hollowed capitate facet. It is one of four attachments for the *flexor retinaculum*, a fibrous band across the wrist.

- **Anatomical siding**. The concave articular surface houses the capitate head and is therefore distal. The tubercle is on the palmar surface and is lateral (toward the thumb).
- **Positional siding**. Hold the concave (capitate) facet toward you and the tubercle up. The tubercle leans toward the side from which the bone comes.

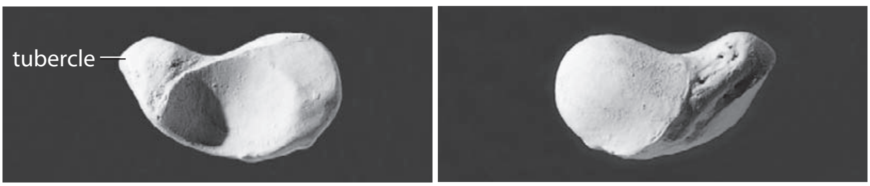


Figure 13.4 **Right scaphoid. Palmar is up.** View from the capitate (*left*); view from the radius (*right*). Natural size.

13.1.2 Lunate (Figures 13.5–13.6)

The lunate is shaped in the form of a crescent moon. The deeply concave surface articulates with the capitate, and the large, broad articulation opposite this shares the distal radial articular surface with the scaphoid.

- **Anatomical siding**. The radial facet is proximal, and the capitate facet is distal. The long, narrow, crescent-shaped facet on the flat surface of the bone articulates

Figure 13.5 **Right lunate.** Dorsal is up. View from the capitate. Natural size.

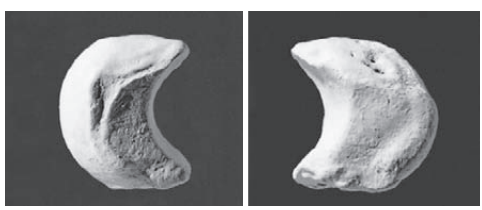


Figure 13.6 **Right lunate.** Palmar is up. View from the scaphoid (*left*); view from the triquetral (*right*). Natural size.

laterally (on the thumb side) with the scaphoid. The remaining facet, for the triquetral, is displaced dorsally. The largest nonarticular surface is palmar.

- **Positional siding**. Place the flat side on the table and the most concave facet toward you. The remaining facet rises up and toward the side from which the bone comes.

13.1.3 Triquetral (Figures 13.7–13.8)

The triquetral is the third bone from the thumb side in the proximal carpal row. It has three main articular surfaces (hence its name). The bone is distinguished from the trapezoid by its pisiform articulation, a single, circular, isolated, and elevated facet.

- **Anatomical siding.** The smallest of the three major articular surfaces is for the pisiform, on the palmar, medial surface of the bone. The largest facet is for the hamate and is distal. The lunate facet is lateral to, but continuous with, this facet.
- **Positional siding.** Hold the common edge between the two largest facets toward you and vertically. When the third facet (for the pisiform) is up, this facet points toward the side from which the bone comes.

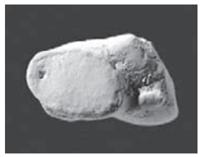


Figure 13.7 **Right triquetral.** Lateral is up. Palmar view. Natural size.

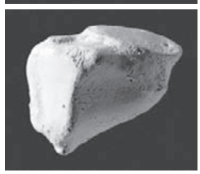


Figure 13.8 **Right triquetral.** Palmar is up. View from the hamate. Natural size.

13.1.4 Pisiform (Figures 13.9–13.10)

The pisiform bone is pea-shaped, with one side flattened by the triquetral articular facet. The nonarticular body is an attachment point for the *flexor retinaculum*. The pisiform is the smallest of the carpals. Because it develops within a tendon, it is actually a sesamoid bone. There are other, much smaller sesamoid bones found embedded in flexor tendons, for example, at some metacarpophalangeal and interphalangeal joints.

- **Anatomical siding.** The nonarticular body of the pisiform underlies the ulnar corner of the base of the palm. The morphological variation of the bone makes siding accurate in only about 85–90% of all cases.
- **Positional siding.** Hold the facet toward you and turn the bone until the bulk of the nonarticular surface that is visible in this view is up. The groove and the bulk of this visible surface is displaced toward the side from which the bone comes.

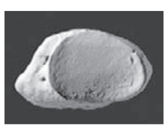


Figure 13.9 **Right pisiform.** Distal is toward the left. View from the triquetral. Natural size.

Figure 13.10 **Right pisiform.** The triquetral facet is up and faces the left (dorsal). View from the proximal, palmar hamate end (lateral). Natural size.

13.1.5 Trapezium (Greater Multangular) (Figure 13.11)

The trapezium is an irregularly sided bone of medium size. It is distinguished by its largest facet, a saddle-shaped articular surface for the base of MC 1 (thumb), and by a long, raised, narrow tubercle, or crest.

- **Anatomical siding.** The bone has an elongate, proximodistally oriented crest, or tubercle, on its palmar surface. This is an attachment point for the *flexor retinaculum*. The groove adjacent to this tubercle is medial (toward the center of the hand). The thumb articulation is distal and faces laterally.
- **Positional siding.** Place the bone on a flat surface with the tubercle on top and away from you, and the concave facets on either side. The groove adjacent to the tubercle is on the side from which the bone comes.

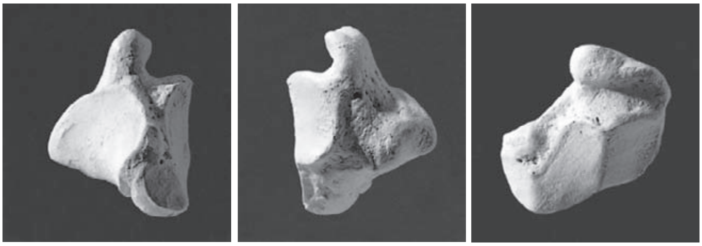


Figure 13.11 **Right trapezium.** Palmar is up. View from the MC 2 base (*left*); view from the lateral scaphoid end (*center*); view from the scaphoid-trapezoid boundary (from medial) (*right*). Natural size.

13.1.6 Trapezoid (Lesser Multangular) (Fig. 13.12)

The trapezoid is boot-shaped. It is the smallest carpal bone in the distal row. It articulates distally with the base of MC 2.

- **Anatomical siding.** The largest nonarticular surface is dorsal, and its most pointed corner is proximal and lateral (on the thumb side). Just palmar to this corner there is a sharp ridge where the lateral, more convex articular facet for the trapezium meets the proximal, more concave articular facet for the scaphoid.
- **Positional siding.** Place the "sole" of the boot on the table, with the narrow, V-shaped space between the articular facets (or the largest articular double facet) toward you. The toe of the boot then points toward the side from which the bone comes.

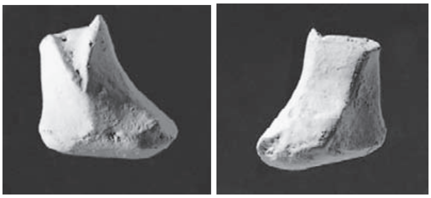


Figure 13.12 **Right trapezoid.** Palmar is up. View from the distal-most trapezium (*left*); view from the capitate-scaphoid boundary (from proximal) (*right*). Natural size.

13.1.7 Capitate (Figures 13.13–13.14)

The capitate is a large carpal bone that articulates distally with the bases of MC 3, MC 2, and (sometimes) MC 4. Its distal end is therefore squared off, while the proximal end is rounded. The **head** (Figure 13.13) of the capitate is the rounded end of the bone that articulates proximally with the hollow formed by the lunate and scaphoid. The **base** (Figure 13.13) of the capitate is the more squared-off end that articulates distally most directly with the base of MC 3.

- **Anatomical siding.** Proximally the head articulates in the hollow formed by the lunate and scaphoid. The largest, flattest nonarticular surface is dorsal. The more concave surface of the head is for the hamate and is thus medial (on the little finger side).
- **Positional siding.** When the head is up and the base rests on the table, place the long, narrow articulation that runs up one side of the bone (from the base to the head) toward you. This articulation is on the side from which the bone comes.

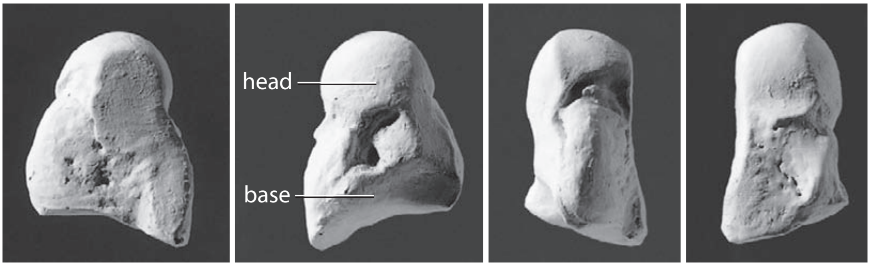


Figure 13.13 **Right capitate.** Proximal is up. View from hamate (*left*); view from the scaphoid and trapezoid (from lateral) (*middle left*); palmar view (*middle right*); dorsal view (*right*). Natural size.

Figure 13.14 **Right capitate.** Palmar is up. View from the MC 3 base. Natural size.

13.1.8 Hamate (Figure 13.15)

The hamate is the carpal bone with the **hamulus** (Figure 13.15) or hook-shaped, nonarticular projection on the palmar surface. This projection is the fourth attachment point for the *flexor retinaculum.*

- **Anatomical siding.** The bone articulates distally with the bases of MC 4 and MC 5 via a double facet at the base of the hamulus. The hamulus is placed on the distal, palmar surface of the bone and is medial, hooking over the edge of the carpal tunnel in this position.

- **Positional siding.** Place the flat nonarticular surface down with the hook and the two adjacent metacarpal facets away from you. The hook leans toward the side from which the bone comes.

13.1.9 Growth

The carpal bones each ossify from a single center.

13.1.10 Possible Confusion

Because of their small size and compact construction, the identification of fragmentary carpal bones is not usually called for. If the hand has been carefully collected, intact bones are usually available. Each of the carpal bones is distinctive and impossible

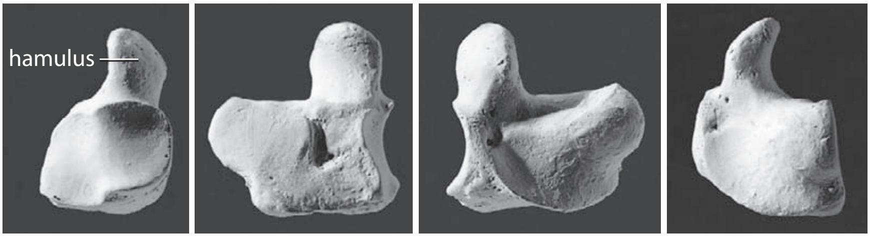


Figure 13.15 **Right hamate.** Palmar is up. View from the MC 4 and MC 5 bases (*left*); view from the capitate (*middle left*); view fromt he triquetral (*middle right*); view from the lunate (*right*). Natural size.

to confuse with another. Confusion of the adult carpal bones with the tarsal bones is improbable because the former are all smaller than the latter and the shapes are all distinctive.

Many skeletons, especially those from archeological contexts, have incomplete hands because of postmortem disturbance of the skeleton (for instance, burrowing rodents) before excavation. These animals often move smaller skeletal elements during their burrowing activities. During archeological excavation, very small bones, such as the sesamoids, pisiform, and terminal phalanges, are sometimes lost if care and fine screening are not employed in recovery.

13.2 Metacarpals (Figures 13.16–13.20)

The metacarpals are numbered MC 1 (the thumb) through MC 5 (the little finger), according to the five rays of the hand. They are all tubular bones, with round distal articular surfaces (**heads**) and more rectangular proximal ends (**bases**). They are iden-

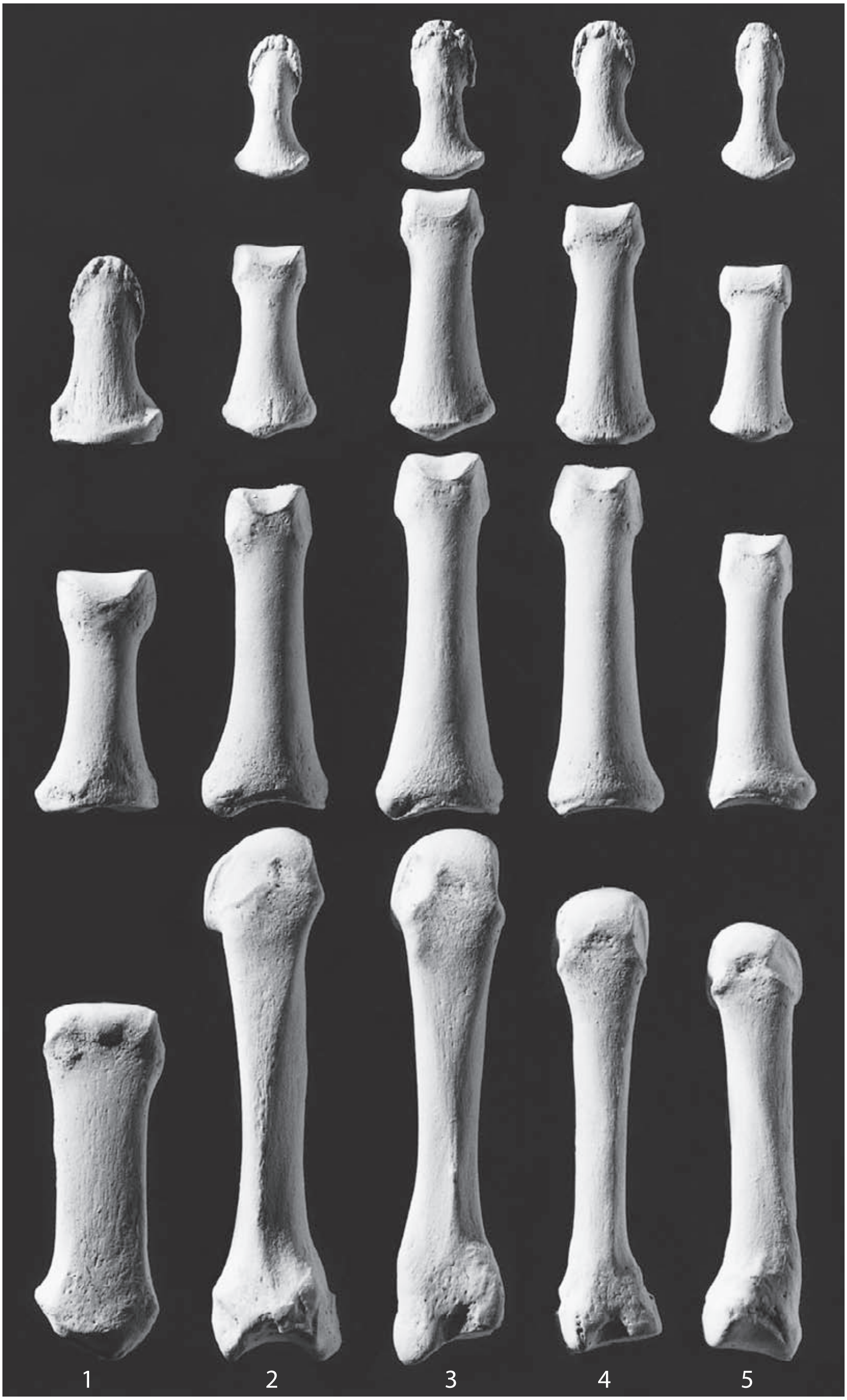


Figure 13.16 **Right hand, dorsal** (posterior). Rays 1–5, showing the metacarpals and the proximal, intermediate, and distal hand phalanges. Distal is up, lateral is toward the left. Natural size.

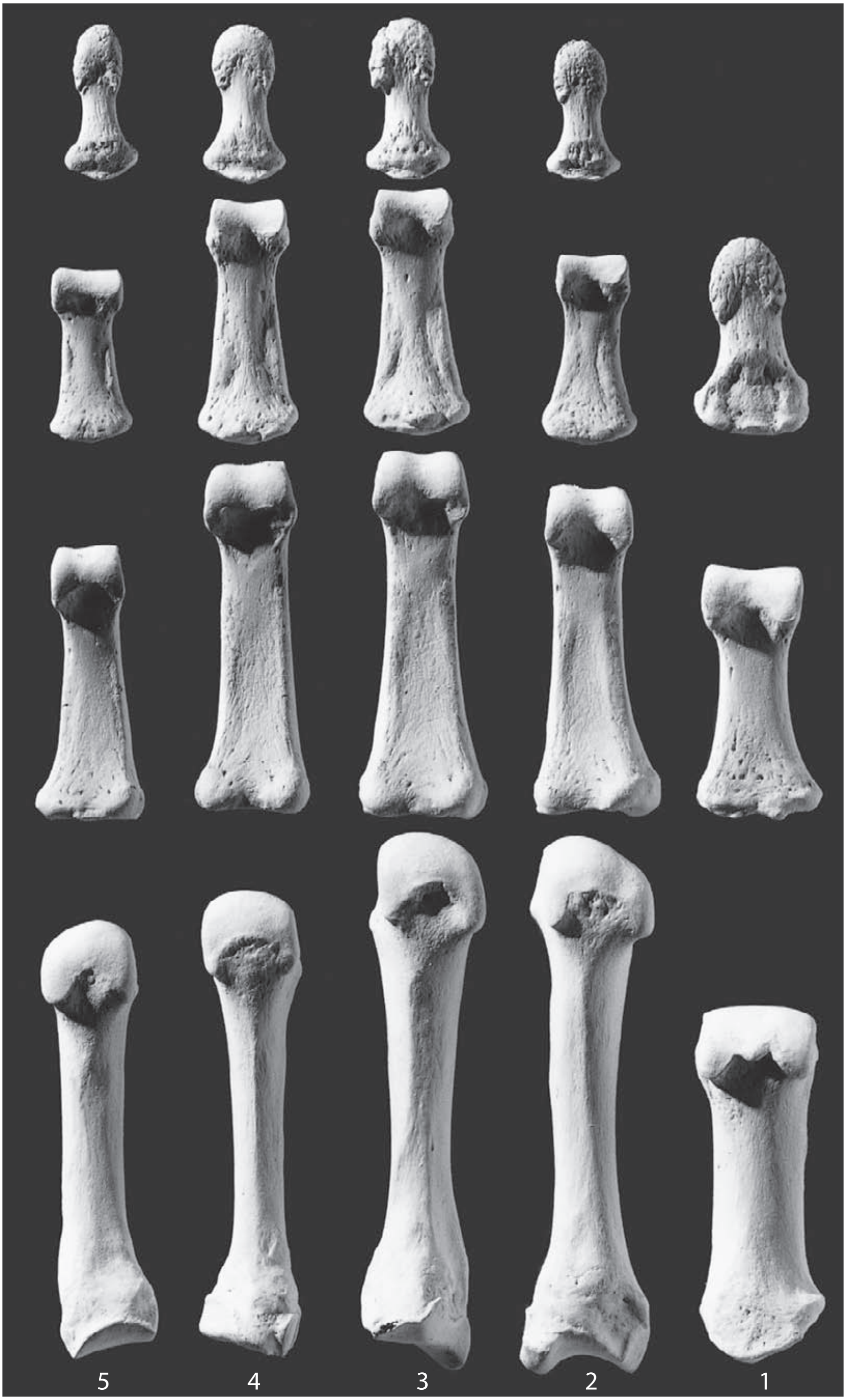


Figure 13.17 **Right hand, palmar** (anterior). Rays 1–5, showing the metacarpals and the proximal, intermediate, and distal hand phalanges. Distal is up, lateral is toward the right. Natural size.

HAND

tified and sided most effectively according to the morphology of the bases.

The bases of the metacarpals articulate with their neighbors in positions 2 – 5. All four of the carpals in the distal row articulate with one or more metacarpal bases: the trapezium with MC 1 and MC 2, the trapezoid with MC 2, the capitate with MC 2 and MC 3 (and sometimes MC 4), and the hamate with MC 4 and MC 5.

13.2.1 First Metacarpal (Thumb)

The first metacarpal is the shortest metacarpal, broader and more robust in its shaft than the others. Its single proximal articular surface is saddle-shaped, corresponding to the facet on the trapezium.

- **Siding.** The maximum palmar projection of the bone at the base is always toward the medial side. Therefore, in a proximal view, imagine dividing the saddle-shaped proximal facet into medial and lateral portions. The medial portion of the articular surface is always smaller. The lateral palmar surface of the shaft is larger and more excavated than the medial palmar surface. Viewed dorsally, with the distal end up, the axis of maximum length is skewed basally toward the side the bone is from.

13.2.2 Second Metacarpal

The second metacarpal is normally the longest metacarpal, at the base of the index finger. The base presents a long, curved, blade-like wedge that articulates with the trapezoid, capitate, trapezium, and MC 3.

- **Siding.** The most proximal part of the base is a broad, blade-like, medially positioned wedge that bears the articulation for MC 3.

13.2.3 Third Metacarpal

The third metacarpal lies at the base of the middle finger. It is the only metacarpal with a sharp projection, the **styloid process**, at its base. It articulates with the capitate and MC 2 and MC 4 at the base.

- **Siding.** The styloid process is on the lateral, or MC 2, side of the bone.

13.2.4 Fourth Metacarpal

The fourth metacarpal lies at the base of the ring finger and is shorter and more gracile than MC 2 or MC 3. It has a fairly square base with three or four articular facets. It articulates (at its base) with the capitate (sometimes), hamate, MC 3, and MC 5.

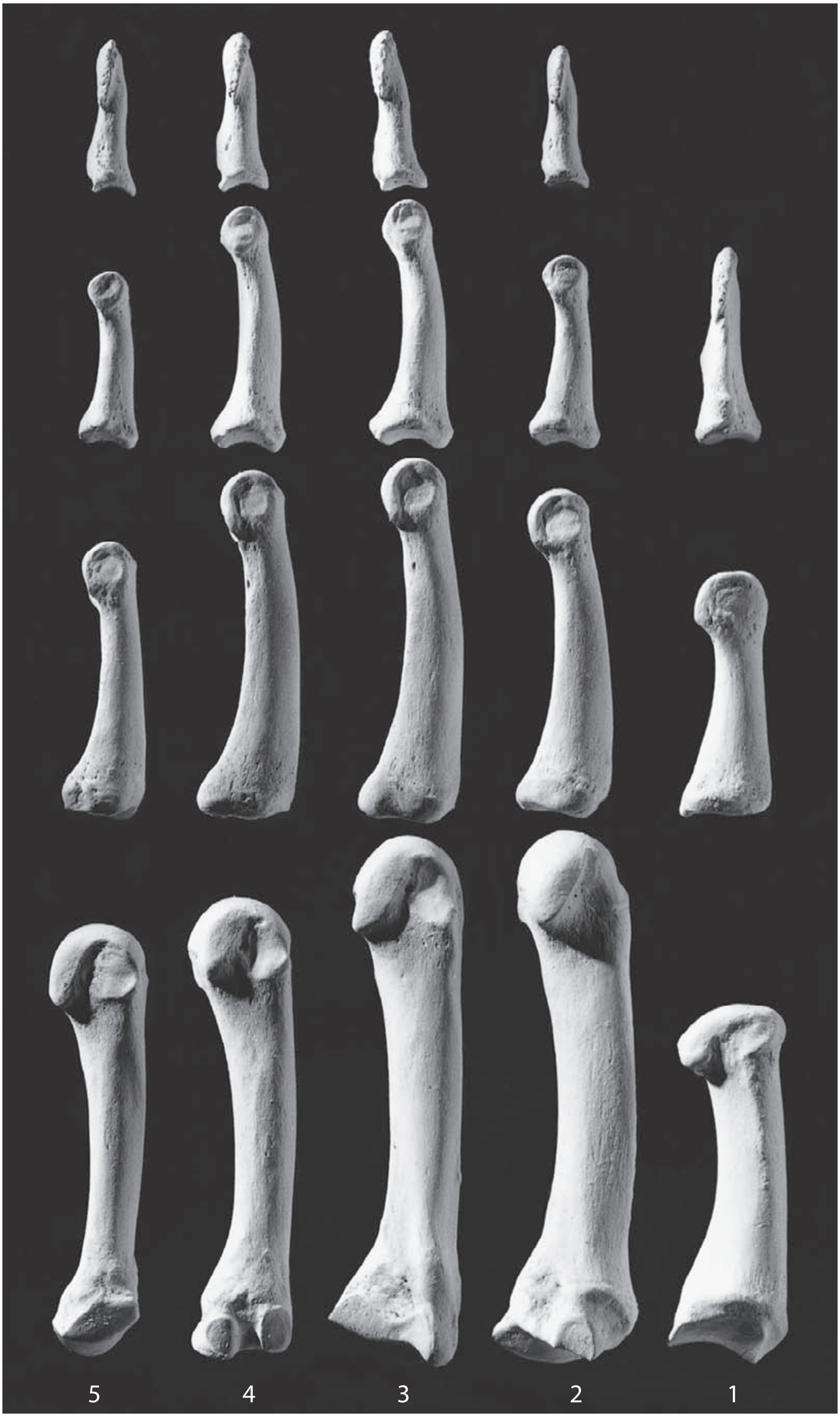


Figure 13.18 **Right hand, lateral.** Rays 1–5, showing the metacarpals and the proximal, intermediate, and distal hand phalanges. Natural size.

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Figure 13.19 **Right metacarpals, medial.** Natural size.

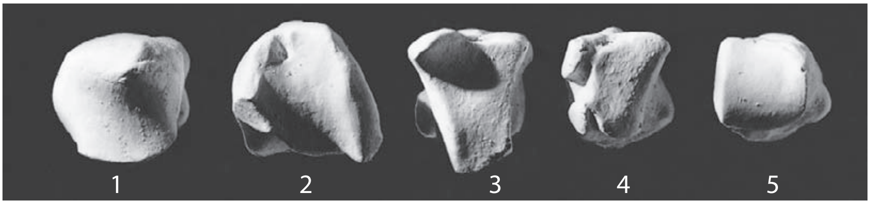

Figure 13.20 **Right metacarpal bases, proximal.** Dorsal is up, lateral is toward the left. Natural size.

- **Siding.** The proximal and medial basal facets share a common, right-angle articular edge.

13.2.5 Fifth Metacarpal

At the base of the little finger, the fifth metacarpal is the thinnest and shortest of the nonpollical metacarpals. It bears only two basal facets: one for the hamate and one for MC 4.

- **Siding.** The nonarticular side of the base faces medially, away from MC 4.

13.2.6 Growth (Figure 13.21)

Each metacarpal except MC 1 ossifies from two centers: a primary one for the shaft

Figure 13.21 Metacarpal growth. The pairs of immature metacarpals are shown here in anterior (palmar) view, with ray 1 on the left and ray 5 on the right. They are from one-year-old and six-year-old individuals. Natural size.

and the base, and a secondary one for the distal extremity (the head). The thumb metacarpal has a separate center for its base (but none for its distal extremity).

13.2.7 Possible Confusion

Metacarpals 2–5 are stouter than metatarsals 2–5. Metacarpal shafts are larger in diameter relative to length and are not as straight and slender as metatarsal shafts. Metacarpal heads are more rounded than the mediolaterally compressed metatarsal heads.

13.2.8 Siding

In siding the metacarpals, the bases are always proximal, and the palmar shaft surfaces are always more concave than the dorsal surfaces in lateral view. Features of the base are used to side metacarpals as outlined in the preceding sections.

13.3 Hand Phalanges (Figures 13.16–13.18)

The phalanges are all shorter than metacarpals, lack rounded heads, and are anteroposteriorly flattened in their shafts. The thumb phalanges are shorter and squatter than the others, and the thumb lacks an intermediate phalanx. The expanded proximal end of each phalanx is the **base**. The distal end is the **head** (proximal or intermediate phalanges) or the **distal tip** (tuft; distal phalanges only). The nonarticular tubercles adjacent to the metacarpal heads and the phalangeal joints are attachment points for the *collateral ligaments*.

Dorsal surfaces of the hand phalanges are smooth and rounded. The palmar surfaces, in contrast, are flat and more roughened, especially along either side of the **shaft**, where raised ridges mark attachment sites for the *fibrous flexor sheaths*, tissues that prevent the *flexor tendons* from "bow stringing" away from the bones as the fingers are flexed.

13.3.1 Proximal Hand Phalanges

Each proximal hand phalanx displays a single, concave proximal (basal) articular facet for the metacarpal head. The proximal thumb phalanx is readily recognizable by its short, stout appearance.

13.3.2 Intermediate Hand Phalanges

Each intermediate hand phalanx displays a double proximal articular facet for the head of the proximal phalanx, and each also has a distal articular facet. The thumb ray bears only two phalanges, lacking a morphologically intermediate phalanx.

13.3.3 Distal Hand Phalanges

Each distal hand phalanx displays a double proximal articular facet for the head of the intermediate phalanx. The terminal end of each has a nonarticular pad, the **distal phalangeal tuberosity**. The thumb phalanx is readily recognizable because of its short, stout appearance. The dorsal surfaces of these phalanges are more rounded, and the palmar surfaces are more rugose.

13.3.4 Growth

Hand phalanges each ossify from two centers: a primary one for the shaft and distal end, and a secondary one for the base.

13.3.5 Possible Confusion

Hand phalanges have shafts whose palmar surfaces are flattened, forming a half-circle in cross section. Foot phalanx shafts are circular in cross section.

13.3.6 Siding

For siding hand and foot phalanges it is best to work with whole specimens and comparative materials, particularly *in vivo* radiographs.

Chapter 14

Pelvic Girdle: Sacrum, Coccyx, & Os Coxae

The bony structure at the base of the front limbs is the shoulder girdle and the one at the base of the hind limbs is the pelvic girdle. The pelvic girdles of terrestrial vertebrates are connected to the vertebral column and are much larger than their homologs in fish. These adaptations are required for weight-bearing and muscle attachment in the terrestrial forms. In early land-dwelling vertebrates, the right and left limb girdles joined dorsally with the sacral vertebrae to form a bony ring around the rear of the trunk. This is still the basic form in the tetrapod pelvis.

The adult human bony pelvis is composed of four main elements: the right and left **os coxae** and the **sacrum** and **coccyx**. The sacrum and coccyx are part of the axial skeleton and are actually variably fused vertebrae. The bony pelvis functions to support and protect the abdominal and pelvic organs. In addition, it anchors muscles of the abdomen and leg. Unlike the shoulder girdle, which is a movable platform, the pelvic girdle is firmly fixed to the axial skeleton via its vertebral element, the sacrum.

14.1 **Sacrum** (Figures 14.1–14.4)

14.1.1 Anatomy

The sacral vertebrae fuse during adolescence into one immobile, wedge-shaped bone, the sacrum. This bone is typically formed from five segments, but may have as few as four or as many as six. The sacrum is located at the base of the vertebral column. It articulates bilaterally with the two ossa coxa and inferiorly with the small coccyx.

a. The **promontory** is the anterior midline projection of the sacral plateau. The sacral plateau is the flat, anterosuperiorly inclined surface of the sacrum that articulates with the terminal, or most inferior, lumbar vertebra.
b. The **alae**, or "wings," sweep laterally from the first sacral element. They articulate with the posteromedial surface of the os coxae.
c. The **sacroiliac joint** (**auricular surface**) is the articulation between the sacrum and the os coxae. This articular surface is best seen in lateral aspect. The articulation is the most immobile synovial joint in the body. The "ear-shaped" surface

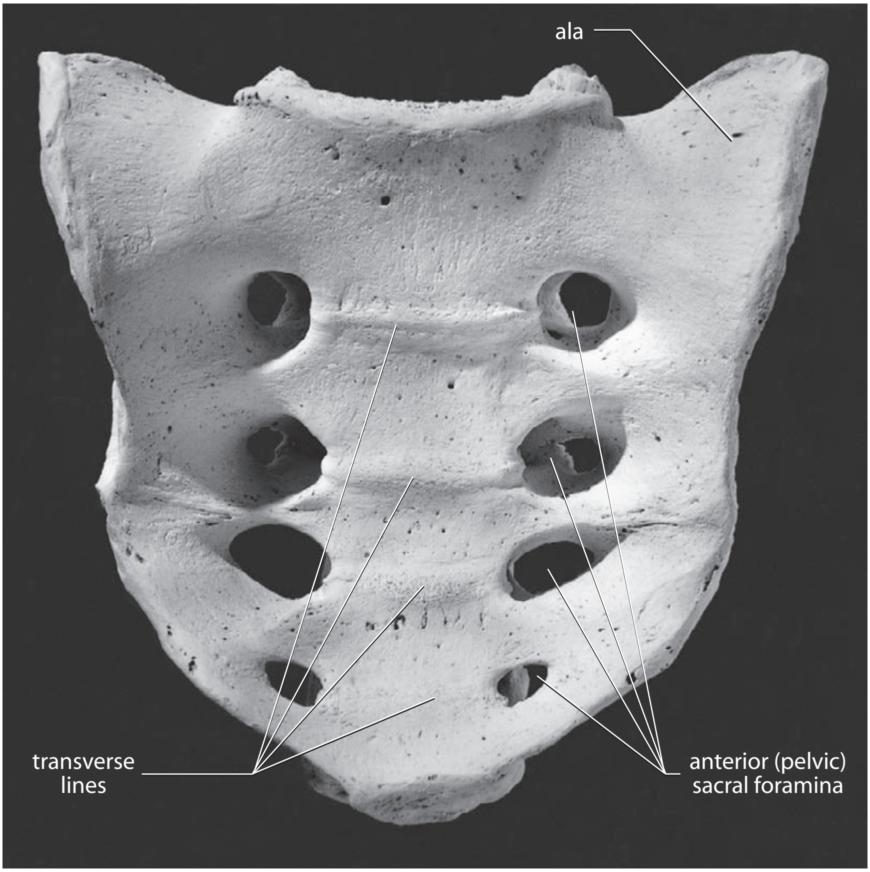

Figure 14.1 **Sacrum, anteroinferior view.** Natural size.

articulates with the auricular surface of the os coxae.

d. The **anterior** (**pelvic**) **sacral foramina** are openings in the concave anterior surface of the sacrum through which the *sacral nerves* pass.
e. The **transverse lines** are horizontal ridges on the concave anterior sacral surface that mark the edges of the fused sacral vertebrae.
f. The **superior articular facets** of the sacrum articulate with facets on the inferior articular processes of the most inferior lumbar vertebra.
g. The **dorsal wall** of the sacrum is a rough, irregular, variable plate of bone made up of the ossified laminae and articular processes of the fused sacral vertebrae.
h. The **median crest** (**spine**) is the highly variable midline projection of the dorsal wall composed of fused spines of the sacral vertebrae.

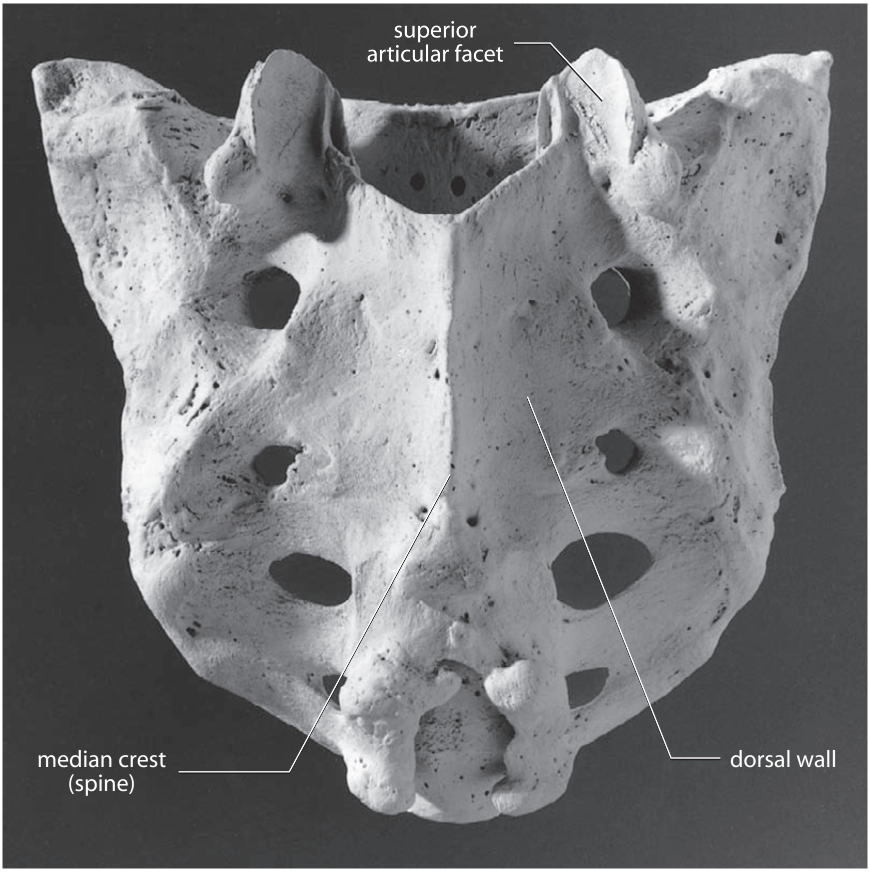

Figure 14.2 **Sacrum, posterosuperior view.** Natural size.

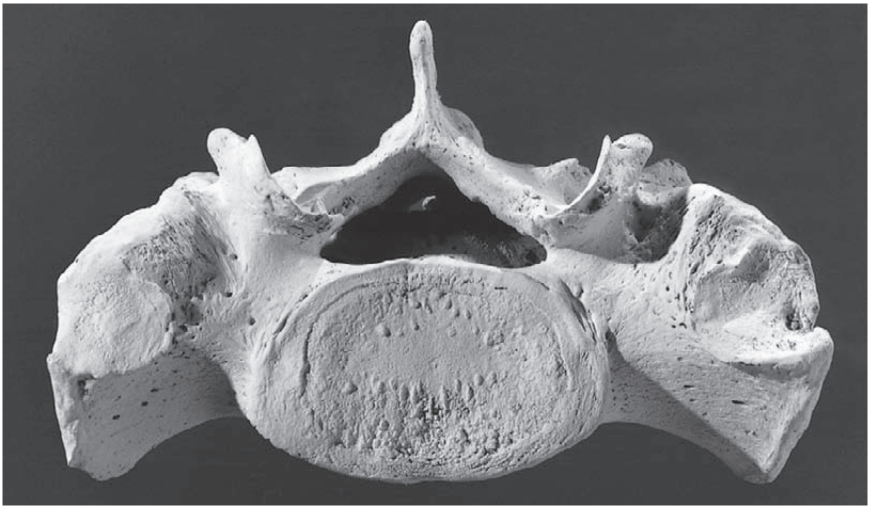

Figure 14.3 **Sacrum, anterosuperior view.** Posterior is up. Note the laterally placed facets for the sacralized L-5 of this individual. Natural size.

PELVIC GIRDLE

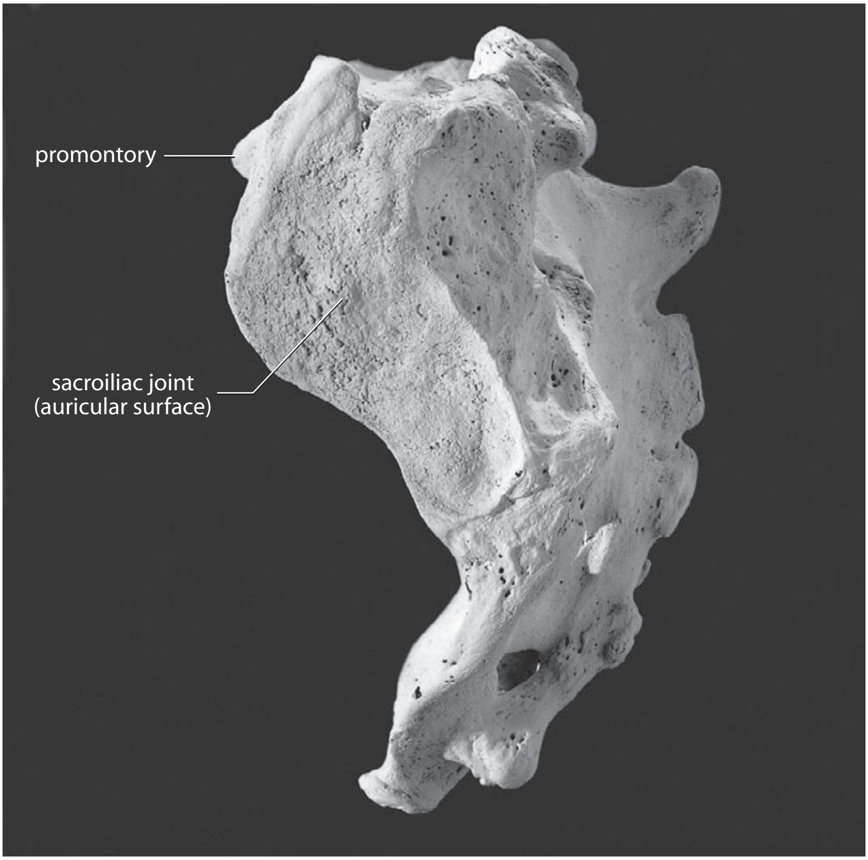

Figure 14.4 **Sacrum, left lateral.** Anterior is toward the left. Natural size.

14.1.2 Growth

The sacrum ossifies from many separate centers in individuals with five sacral vertebrae. Each sacral body develops from a primary center with two epiphyseal plates. Corresponding arches ossify from two centers each, and an additional pair of costal elements form the anterolateral projections of each sacral vertebra. Two epiphyseal plates form at each sacroiliac articular region, one forming the auricular surface and one forming the lateral margin inferior to this. See Figure 9.7.

14.1.3 Possible Confusion

- The promontory region might be mistaken for a lumbar vertebra when fragmented. Lumbars, however, lack attached alae.

- The auricular surface might be mistaken for a fragment of os coxae when broken. However, the sacral auricular surface has virtually no adjacent outer bone surface surrounding it as the os coxae does.

14.1.4 Siding

When fragmentary, parts of the sacrum can be sided as follows:

- The anterior sacral surface is smooth and concave, with transverse lines.
- The size of sacral vertebrae diminishes inferiorly.
- The auricular (sacroiliac) surface is lateral, and the apex of this V-shaped feature is anterior.

14.2 Coccyx (Figures 14.5 –14.6)

The coccyx, the vestigial tail, is highly variable in shape, with three to five (most often four) variably fused segments. The rudimentary vertebrae of the coccyx have articular and transverse processes superiorly, but they lack pedicles, laminae, and spinous processes. The sacral articulation is via the superior coccygeal body as well as a relatively large pair of tubercles called the **cornua** (Figure 14.6). The latter are rudimentary articular processes that contact the sacrum. The coccyx may fuse with the sacrum late in life.

As with the sacrum, the individual vertebral elements of the coccyx decrease in size inferiorly, and horizontal lines of fusion can be seen between adjacent coccygeal vertebrae. The coccyx serves to anchor pelvic muscles and ligaments.

Figure 14.5 **Coccyx, anterior.** Superior is up. Natural size.

Figure 14.6 **Coccyx, posterior.** Superior is up. Natural size.

14.3 Os Coxae (Figures 14.7–14.10)

14.3.1 Anatomy

Unlike many bones that gain their names because of perceived similarities to common objects, the os coxae resembles no common object and thus has earned the informal name **innominate** — the "bone with no name." The os coxae differs in males and females, with its anatomy representing a compromise between the demands of locomotion and birthing. The os coxae is a part of the bony pelvis and is formed ontogenetically from three different parts, the **ilium**, **ischium**, and **pubis**, which fuse in early adolescence. Anatomical orientation of the os coxae is accomplished by placing the hip socket laterally and the ilium superiorly; this allows the plane of the **pubic symphysis** (the only place where right and left os coxae nearly meet) to define the sagittal plane.

The features identified here occur on both the surfaces and the edges of the os coxae. Many of the features are visible from different views of the bone. When correctly oriented, the anterior superior iliac spine should be in the same paracoronal plane as the most anterior point on the pubis.

a. The **ilium** is the thin, blade-like portion superior to the hip socket.
b. The **ischium** is the massive, blunt, posteroinferior part of the bone that one sits on.
c. The **pubis** is the anteroinferior part of the bone that approaches the opposite os coxae at the midline.
d. The **acetabulum** is the laterally facing, hemispherical hollow that forms the socket of the hip, which articulates with the head of the femur.
e. The **acetabular fossa**, or notch, is the nonarticular surface within the acetabulum. It is the attachment point for the *ligamentum teres*, a ligament that limits femoral mobility and accompanies the vessel that supplies blood to the femoral head.
f. The **lunate surface** is the crescent-shaped articular surface within the acetabulum where the femoral head actually articulates.
g. The **iliac pillar** (**acetabulo-cristal buttress**) is the bony thickening, or buttress, located vertically above the acetabulum on the lateral iliac surface. This pillar extends to the superior margin of the ilium.
h. The **iliac** (**cristal**) **tubercle** is the thickening at the superior terminus of the iliac pillar.
i. The **iliac crest** is the superior border of the ilium. It is S-shaped when viewed superiorly. Many of the *abdominal muscles* originate on the crest.
j. **Gluteal lines** are rough, irregular lines that demarcate the attachment of the *gluteal muscles* on the lateral surface of the ilium. They vary from prominent to imperceptible between individuals and across their paths. The *inferior gluteal line* is a horizontal line just superior to the acetabulum. The **anterior gluteal line** is a line that curves posteroinferiorly through the fossa posterior to the iliac pillar. The **posterior gluteal line** is more vertically placed, near the posterior edge of the ilium. The *gluteus minimus muscle* originates between the inferior and anterior lines, and the *gluteus medius muscle* arises between the anterior and posterior lines. The *gluteus maximus muscle* originates posterior to the posterior gluteal line. The first two gluteal muscles, *minimus* and *medius*, are abductors and medial rotators of

the femur at the hip, and the *gluteus maximus* is a lateral rotator, an extensor, and an abductor of the femur at the hip.

k. The **anterior superior iliac spine** is located, according to its name, at the anterior end of the iliac crest. It anchors the *sartorius muscle* and the *inguinal ligament*.
l. The **anterior inferior iliac spine** is a blunt projection on the anterior border of the os coxae, just superior to the acetabulum. It is the origin of the straight head of the *rectus femoris muscle,* a flexor of the thigh at the hip, and an extensor of the knee. Its lower extent serves as the attachment site for the *iliofemoral ligament*.
m. The **posterior superior iliac spine** is the posterior terminus of the iliac crest. It is an attachment for part of the *gluteus maximus muscle*, an extensor, lateral rotator, and abductor of the femur at the hip.
n. The **posterior inferior iliac spine** is a sharp projection just posteroinferior to the auricular surface. It partially anchors the *sacrotuberus ligament*, which serves to bind the sacrum to the os coxae.
o. The **greater sciatic notch** is the wide notch just inferior to the posterior inferior iliac spine. The *piriformis muscle*, a lateral rotator of the thigh at the hip, and the nerves leaving the pelvis for the lower limb pass through this notch. Cortical bone in the os coxae is thickest in this area.
p. The **ischial spine** for attachment of the *sacrospinous ligament* is located just inferior to the greater sciatic notch.
q. The **lesser sciatic notch** is the notch between the ischial spine superiorly and the rest of the ischium inferiorly. The *obturator internus muscle*, a lateral rotator and sometimes abductor of the femur at the hip, passes through this notch.
r. The **ischial tuberosity** is the blunt, rough, massive posteroinferior corner of the os coxae. It anchors the extensor muscles of the thigh at the hip, including the *semitendinosus*, *semimembranosus*, *biceps femoris* (*long head*), and *quadratus femoris*.
s. The **auricular surface** is the ear-shaped sacral articulation on the medial surface of the ilium.
t. The **iliac tuberosity** is the roughened surface just posterosuperior to the auricular surface. It is the attachment site for *sacroiliac ligaments*.
u. The **preauricular sulcus** is a variable groove along the anteroinferior edge of the auricular surface.
v. The **iliac fossa** is the smooth hollow on the medial surface of the iliac blade.
w. The **arcuate line** is an elevation that sweeps anteroinferiorly across the medial surface of the os coxae from the apex of the auricular surface toward the pubis.
x. The **iliopubic** (**iliopectineal**) **eminence** marks the point of union of the ilium and the pubis just lateral to the arcuate line.
y. The **iliopubic** (**superior pubic**) **ramus** connects the pubis to the ilium at the acetabulum.
z. The **ischiopubic** (**inferior pubic**) **ramus** is the thin, flat strip of bone connecting the pubis to the ischium.
aa. The **pubic symphysis** is the near-midline surface of the pubis where the two ossa coxa most closely approach. In life it is nearly occluded by the *obturator membrane*.
bb. The **obturator foramen** is the large foramen encircled by the two pubic rami and the ischium. In life it is mostly closed by a membrane across it.
cc. The **obturator groove (sulcus)** is the wide groove on the medial surface of the

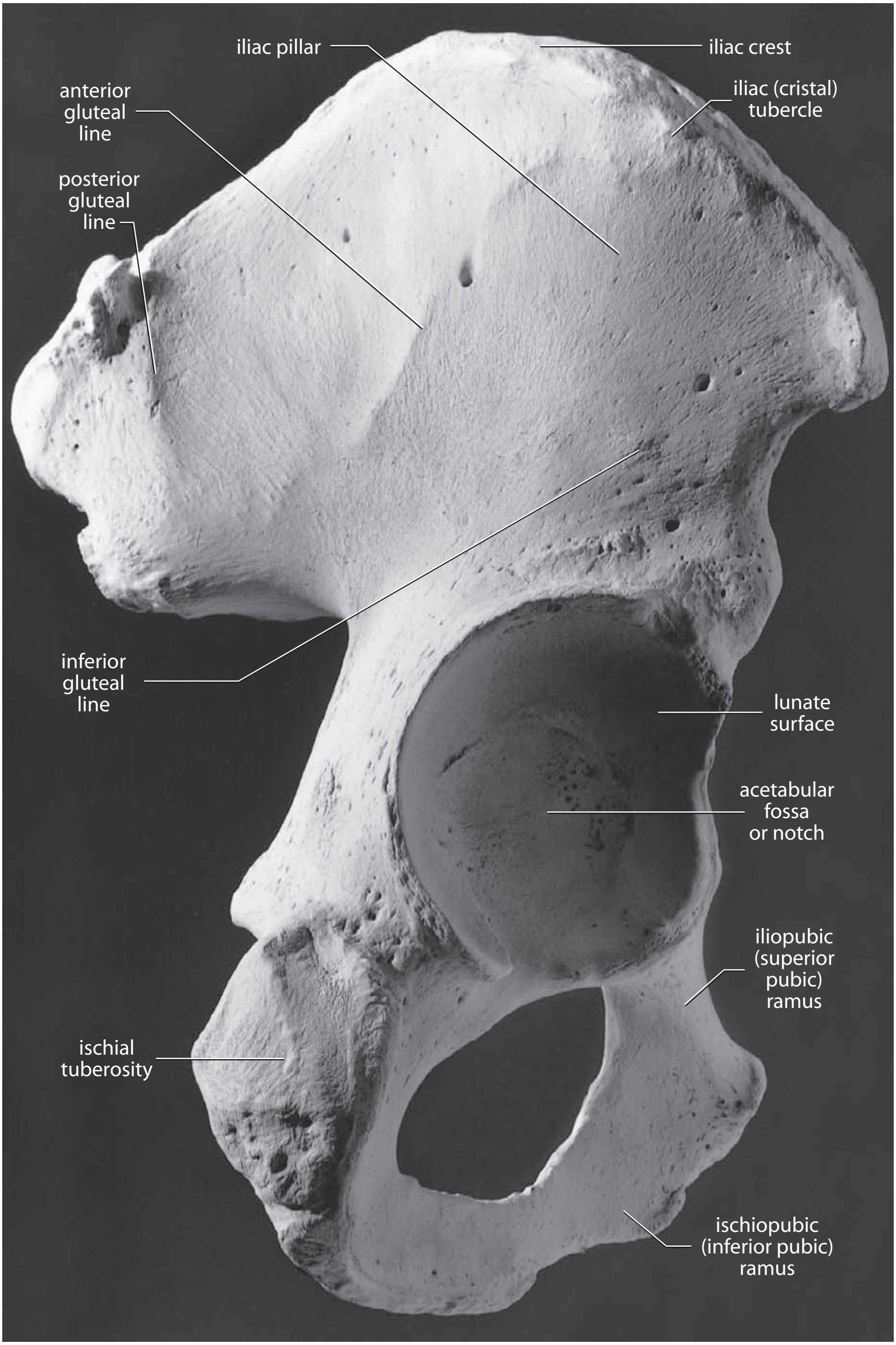

Figure 14.7 **Right os coxae, lateral.** Natural size.

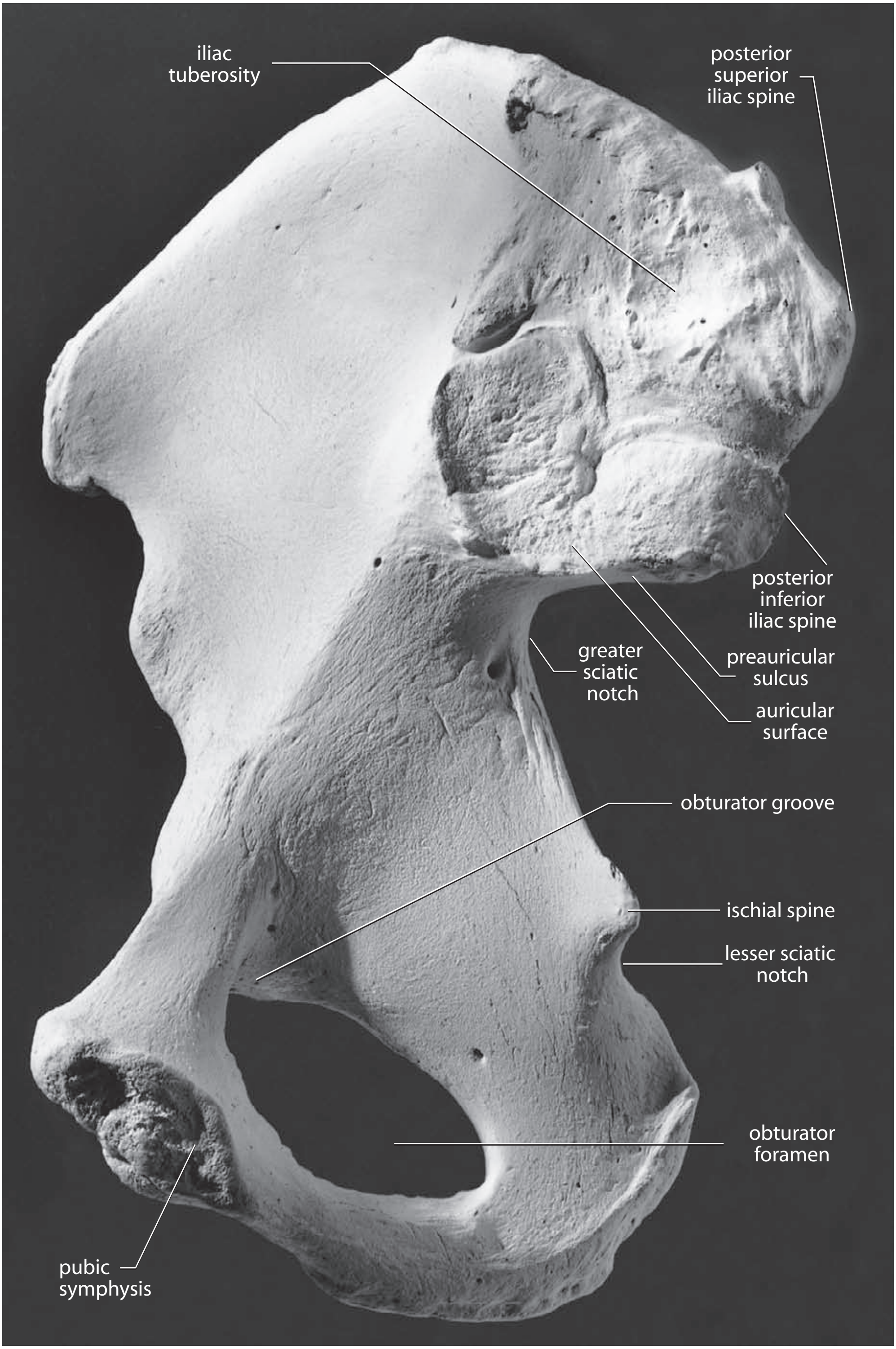

Figure 14.8 **Right os coxae, medial.** Natural size.

PELVIC GIRDLE

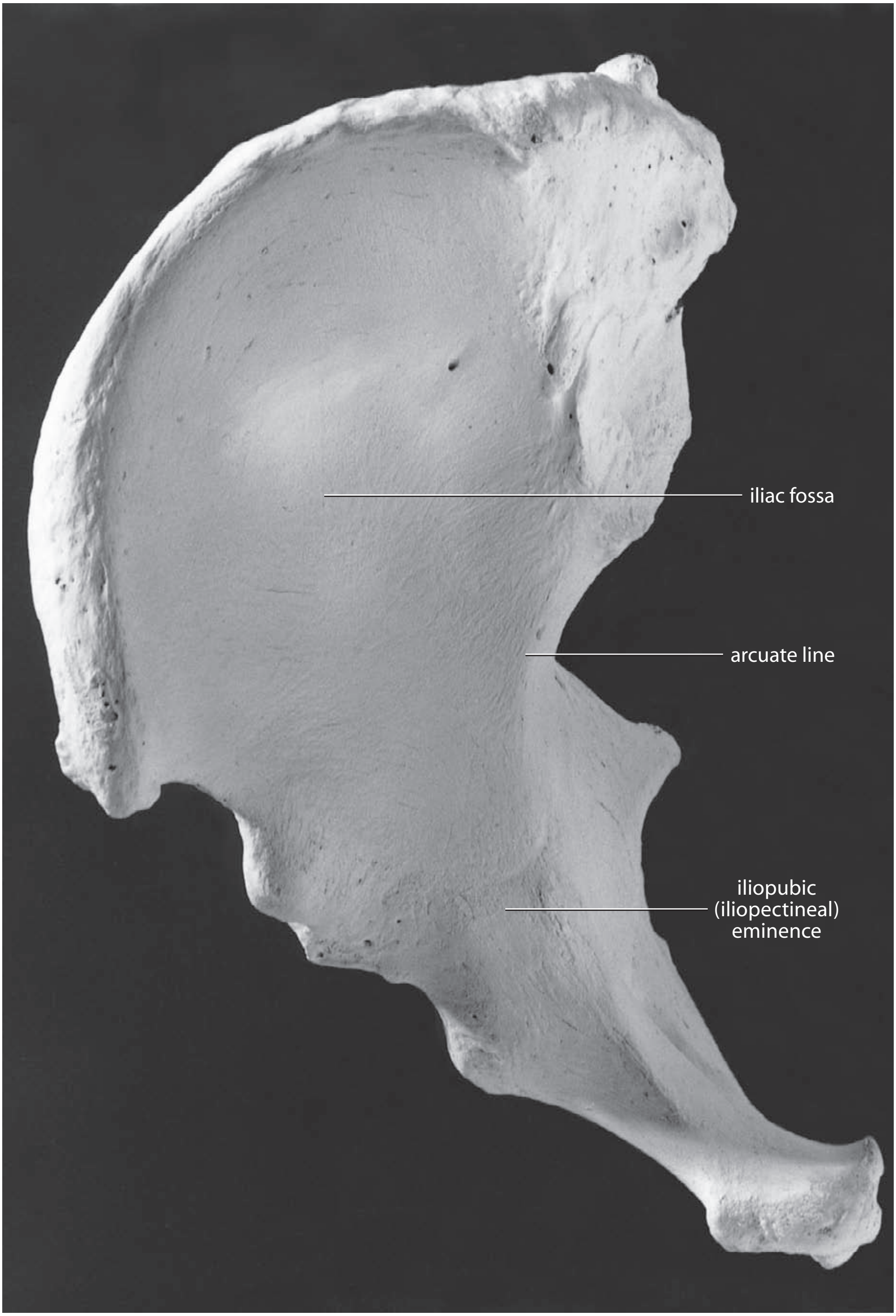

Figure 14.9 **Right os coxae, anterosuperior view.** Anterior is down. Natural size.

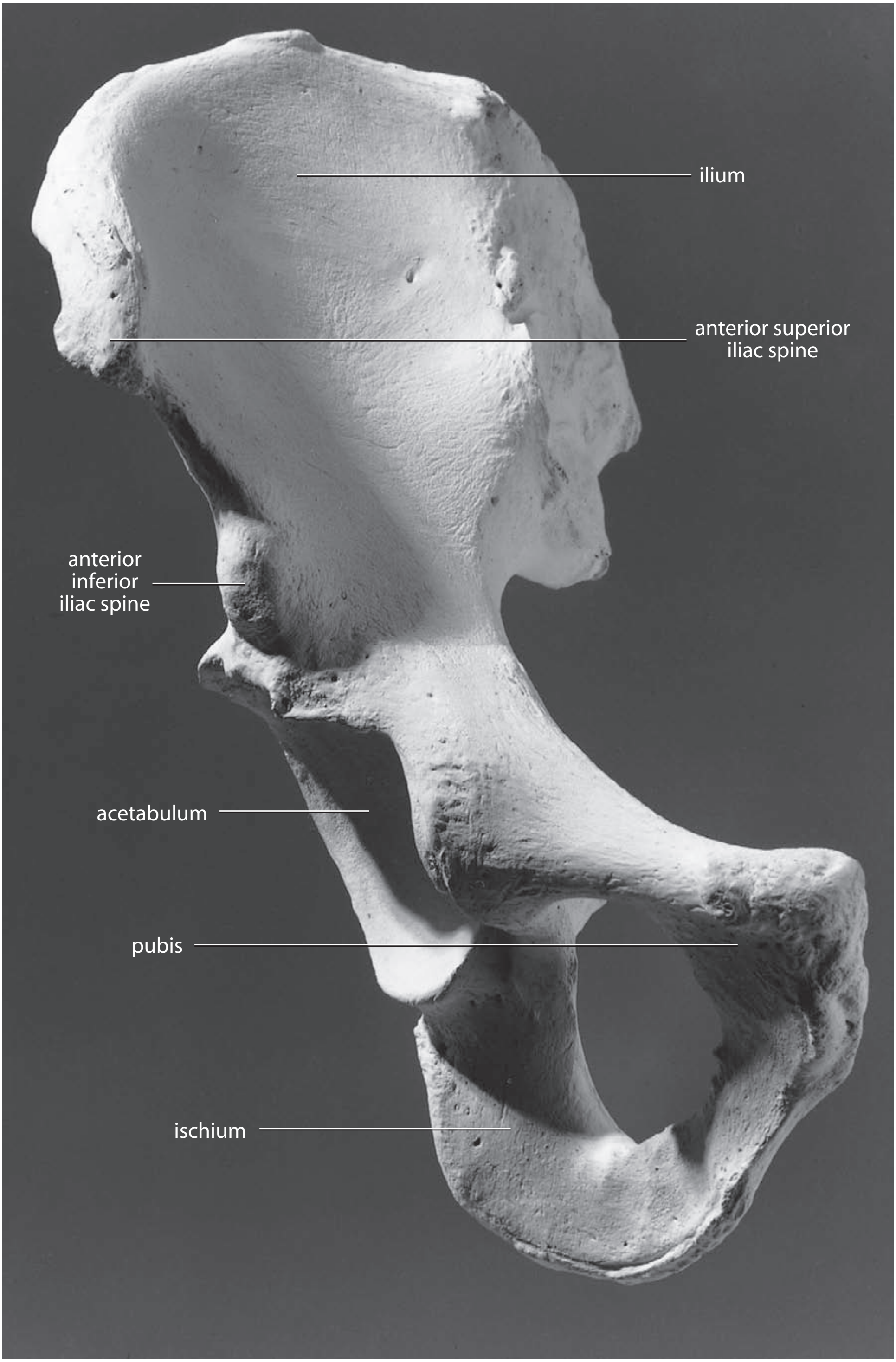

Figure 14.10 **Right os coxae, anterior.** Natural size.

PELVIC GIRDLE

iliopubic ramus, at the superolateral corner of the obturator foramen. The *obturator vessels* and *nerve* pass through this groove.

14.3.2 Growth (Figure 14.11)

There are three primary and five secondary centers of ossification in each os coxae. The ilium, ischium, and pubis form the primary centers, fusing around the acetabulum. The ilium has one secondary center at the anterior inferior spine and one across the iliac crest. The pubis has one center at the symphysis (the "ventral rampart"), and the ischium has one at the tuberosity that extends along the inferior pubic ramus. The eighth center ("os cotyledon") is located in the depth of the acetabulum.

14.3.3 Possible Confusion

- Fragmentary iliac blades might be mistaken for cranial or scapular fragments. The cranial bones are, however, of more uniform thickness. They have cortices of about equal thickness around the diploë.
- Scapular blades are thinner than iliac blades and display subscapular ridges.
- Fragmentary auricular areas could be mistaken for sacra, but in the latter bone there are attached alae, and the adjacent surfaces have no evidence of sacroiliac roughening or sciatic notches.

14.3.4 Siding

When intact, the os coxae is easily sided because the pubis is anterior, the iliac crest is superior, and the acetabulum is lateral. When fragmentary, various parts of the os coxae can be sided as follows:

- For isolated pubic regions, the ventral surface is rough, the dorsal surface is smooth and convex, the symphysis faces the midline, and the superior pubic ramus is more robust than the inferior pubic ramus.
- For isolated ischial regions, the thicker ramus faces the acetabulum. The thinner ramus is therefore anteroinferior. The surface of the ischial tuberosity faces posterolaterally.
- For isolated iliac blades, the iliac pillar is lateral and is anteriorly displaced. The auricular surface and related structures are posterior and medial.
- For isolated iliac crests, the iliac tubercle is anterior and lateral, and the lateral surface anterior to it is more concave than the surface posterior to it. The crest sweeps posteromedially from this point until it reaches the level of the anterior edge of the auricular surface and turns laterally.
- For isolated acetabula, the acetabular notch is inferior and faces slightly anteriorly. The inferior end of the "c" made by the lunate surface is broader and more blunt than the superior end. The ischial ramus is posterior, and the superior pu-

Figure 14.11 **Os coxae growth.** The three elements of the os coxae, shown here in lateral view, are from a one-year-old (*left*) and a six-year-old (*right*). Natural size.

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bic ramus is anterior. The ilium is superior.

- For isolated auricular surfaces, the auricular surface is posterior on the ilium and faces medially. Its apex points anteriorly, and the roughened surface for the sacroiliac ligaments is posterosuperior. The greater and lesser sciatic notches are posteroinferior.

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Chapter 15

Leg: Femur, Patella, Tibia, & Fibula

The evolution of the leg mirrors that of the arm as described in Chapter 12. The single thigh bone, the **femur**, is the serial homolog of the upper arm bone, the humerus. Likewise, the lower bones of the leg, the **tibia** and **fibula**, are serial homologs of the radius and ulna. The largest sesamoid bone in the body, the **patella**, lies at the knee joint. The bipedal locomotor mode practiced by hominids has resulted in major specializations of the leg bones.

15.1 Femur (Figures 15.1–15.6)

15.1.1 Anatomy

The femur is the longest, heaviest, and strongest bone in the body. It supports all of the body's weight during standing, walking, and running. Because of its strength and density, it is frequently recovered in forensic, archeological, and paleontological contexts. The femur is a particularly valuable bone because of the information it can provide on the stature of an individual (see Chapter 19).

The femur articulates with the acetabulum of the os coxae. Distally, it articulates with the patella and the proximal tibia. The leg's actions at the hip include medial and lateral rotation, abduction, adduction, flexion, and extension. At the knee, motion is far more restricted, confined mostly to flexion and extension. Although the main knee action is that of a sliding hinge, this joint is one of the most complex in the body.

a. The **head** is the rounded proximal part of the bone that fits into the acetabulum. It constitutes more of a sphere than the hemispherical humeral head.
b. The **fovea capitis** is the small, nonarticular depression near the center of the head of the femur. It receives the *ligamentum teres* from the acetabular notch of the os coxae.
c. The **neck** of the femur connects the head with the shaft.
d. The **greater trochanter** is the large, blunt, nonarticular prominence on the lateral, proximal part of the femur. It is the insertion site for the *gluteus minimus* (an-

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terior aspect of the trochanter) and *gluteus medius muscles* (posterior aspect), both major abductors of the thigh and stabilizers of the hip. Their origins are on the broad, flaring iliac blade of the os coxae. These muscles are crucial in stabilizing the trunk when one leg is lifted from the ground during bipedal locomotion.

e. The **intertrochanteric line** is a variable, fairly vertical, roughened line that passes between the lesser and greater trochanters on the anterior surface of the base of the neck of the femur. Superiorly, this line anchors the *iliofemoral ligament*, which is the largest ligament in the human frame. It acts to strengthen the *joint capsule* of the hip.

f. The **trochanteric fossa** is the pit excavated into the posteromedial wall of the greater trochanter. This pit is for insertion of the *tendon of obturator externus*, a muscle that originates around and across the membrane that stretches across the obturator foramen of the os coxae. This muscle acts to rotate the thigh laterally at the hip. Just above its insertion, the medial tip of the greater trochanter receives several hip muscles: the *superior* and *inferior gemelli*, the *obturator internus*, and the *piriformis*. The latter two are important abductors, and all of these muscles can rotate the femur laterally.

g. The **obturator externus groove** is a shallow depression aligned laterally and superiorly across the posterior surface of the femoral neck. In hominids, erect posture brings the *tendon of the obturator externus muscle* into contact with the posterior surface of the femoral neck, creating the groove.

h. The **lesser trochanter** is the blunt, prominent tubercle on the posterior femoral surface just inferior to the point where the neck joins the shaft. This is the point of insertion of the *iliopsoas tendon* (the common *tendon of the iliacus muscle*, originating in the iliac fossa, and the *psoas major muscle*, originating from the lumbar vertebrae and their disks). These muscles are major flexors of the thigh at the hip.

i. The **intertrochanteric crest** is the elevated line on the posterior surface of the proximal femur between the greater and lesser trochanters. It passes from superolateral to inferomedial. Just above its midpoint is a small tubercle (the **quadrate tubercle**), which is the site of insertion of the *quadratus femoris muscle*, a lateral rotator of the femur.

j. The **gluteal line**, or **tuberosity**, is a long, wide, roughened, posterolaterally placed feature that extends from the base of the greater trochanter to the lip of the linea aspera (see later). It can be a depression or it can assume the form of a true tuberosity. If the latter is present, it is often referred to as the **third trochanter**. It is the insertion for part of the *gluteus maximus muscle*, an extensor, abductor, and lateral rotator of the thigh at the hip that originates on the posterior half of the os coxae, the sacrum, and the coccyx.

k. The **spiral line**, spiraling inferior to the lesser trochanter, connects the inferior end of the intertrochanteric line with the medial lip of the linea aspera. It is the origin of the *vastus medialis muscle*, a part of the *quadriceps femoris muscle*, a knee extensor that inserts on the anterior tibia via the patella.

l. The **pectineal line** is a short, curved line that passes inferolaterally from the base of the lesser trochanter, between the spiral line and gluteal tuberosity. It is the insertion of the *pectineus muscle*, which originates from the pubic part of the os coxae and acts to adduct, laterally rotate, and flex the thigh at the hip.

m. The **femoral shaft** is the long section between the expanded proximal and distal ends of the bone.
n. The **linea aspera** is the long, wide, roughened, and elevated ridge that runs along the posterior shaft surface. It collects the spiral, pectineal, and gluteal lines proximally and divides into the supracondyloid ridges distally. The linea aspera is a primary origin site for the *vastus muscles* and the primary insertion site of the adductors (*longis*, *brevis*, and *magnus*) of the hip.
o. The **nutrient foramen** is located about midshaft level on the posterior surface of the bone, adjacent to or on the linea aspera. This foramen exits the bone distally.
p. The **medial supracondylar line** (**ridge**) is the inferior, medial extension of the linea aspera, marking the distal, medial corner of the shaft. It is fainter than the lateral supracondylar ridge.
q. The **lateral supracondylar line** (**ridge**) is the inferior (distal), lateral extension of the linea aspera. It is more pronounced than the medial supracondylar ridge.
r. The **popliteal surface** is the wide, flat, triangular area of the posterior, distal femur. It is bounded by the condyles inferiorly and by the supracondylar lines medially and laterally.
s. The **lateral condyle** is the large, protruding, articular knob on the lateral side of the distal femur.
t. The **lateral epicondyle** is the convexity on the lateral side of the lateral condyle. It is an attachment point for the *lateral collateral ligament* of the knee. Its upper surface bears a facet that is an attachment point for one head of the *gastrocnemius muscle*, a flexor of the knee and plantarflexor of the foot at the ankle.
u. The **popliteal groove**, a smooth hollow on the posterolateral side of the lateral condyle, is a groove for the *tendon of the popliteus muscle*. This muscle inserts on the posterior tibial surface and is a medial rotator of the tibia at the knee.
v. The **medial condyle** is the large, articular knob on the medial side of the distal femur. Its medial surface bulges away from the axis of the shaft. The medial condyle extends more distally than the lateral condyle.
w. The **medial epicondyle** is the convexity on the medial side of the medial condyle. It is a point of attachment for the *medial collateral ligament* of the knee.
x. The **adductor tubercle** is a variable, raised tubercle on the medial supracondylar ridge just superior to the medial epicondyle. It is an attachment point for the *adductor magnus*, a muscle originating on the lower edge of the ischiopubic ramus and ischial tuberosity. This muscle adducts the thigh at the hip.
y. The **intercondylar fossa**, or **notch**, is the nonarticular, excavated surface between the distal and posterior articular surfaces of the condyles. Within the fossa are two facets that are the femoral attachment sites of the *anterior* and *posterior cruciate ligaments*, a pair of crossed ligaments linking the femur and tibia. These ligaments strengthen the knee joint.
z. The **patellar surface** is a notched, articular area on the anterior surface of the distal femur, over which the patella glides during flexion and extension of the knee. The lateral surface of this notch is elevated, projecting more anteriorly than the medial boundary of the notch. This helps prevent lateral dislocation of the patella during full extension of the knee.

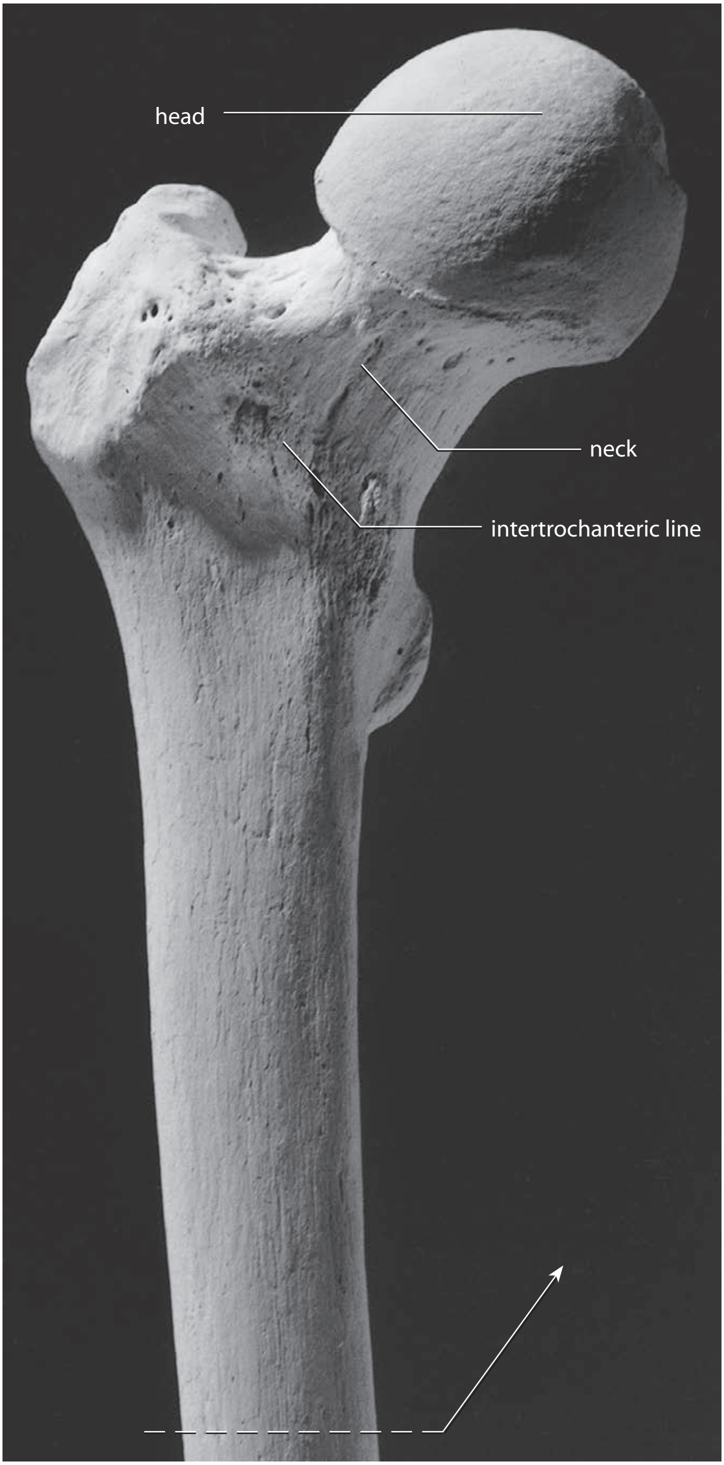

Figure 15.1a **Right femur, anterior.** *Above*, proximal end; *opposite*, distal end; *middle*, mid-shaft. Natural size.

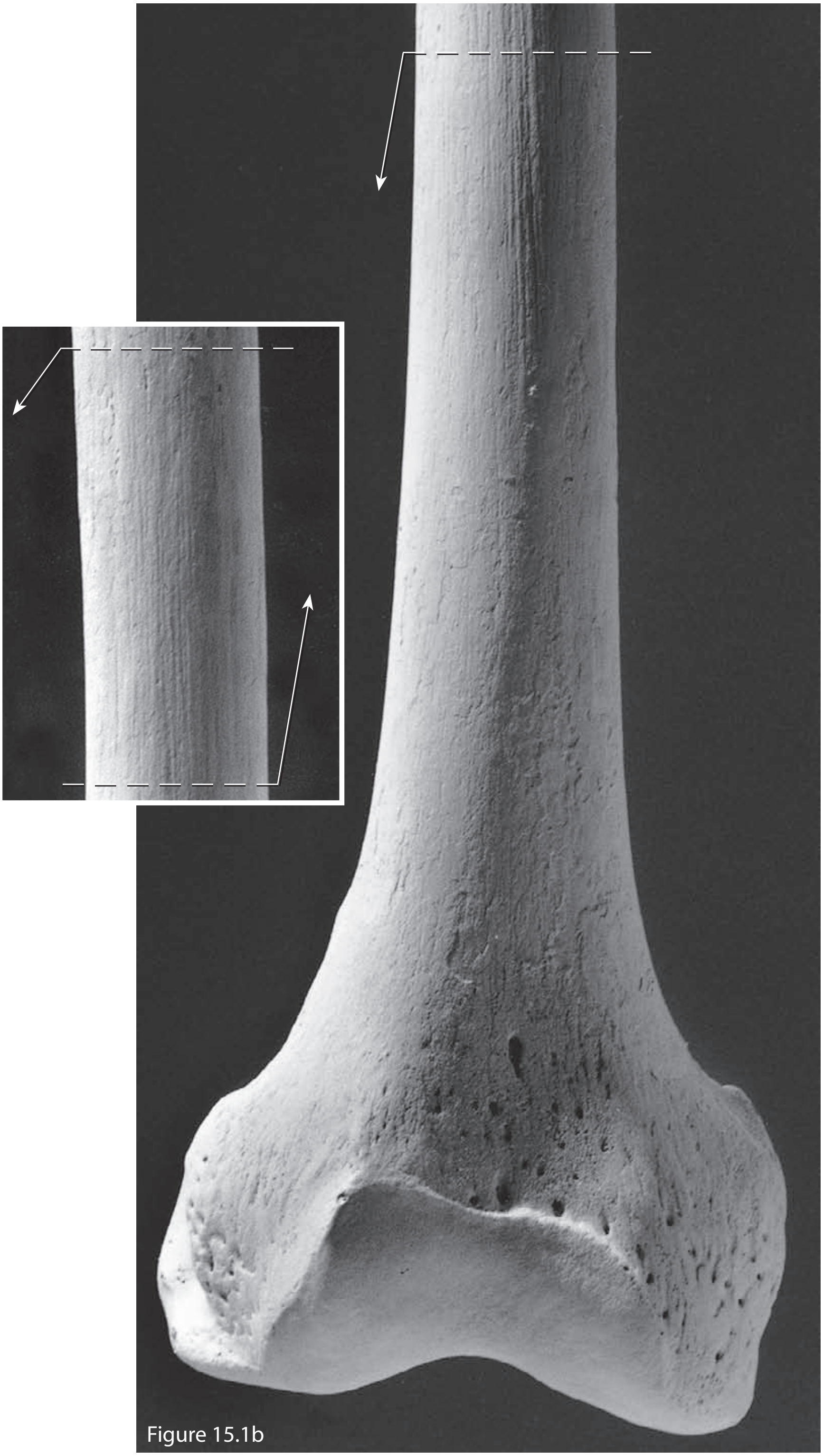

Figure 15.1b

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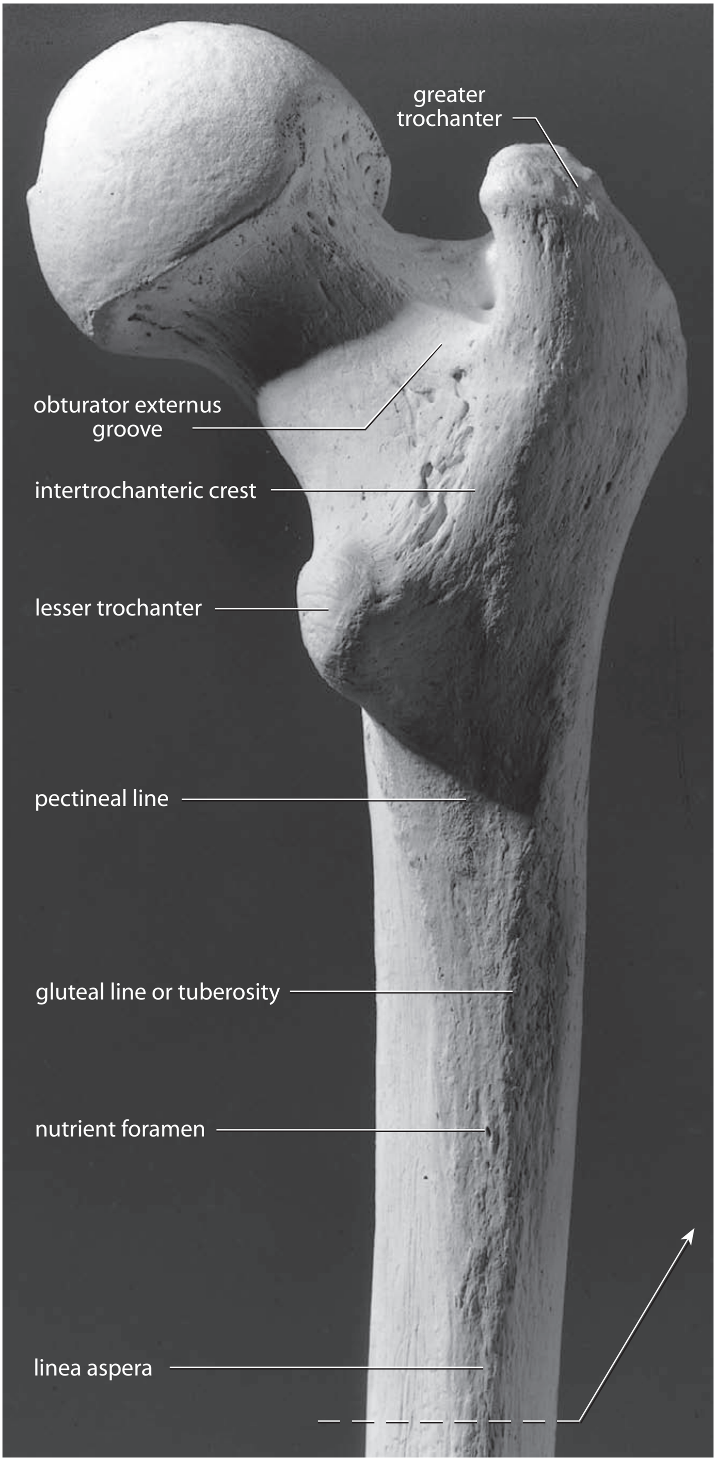
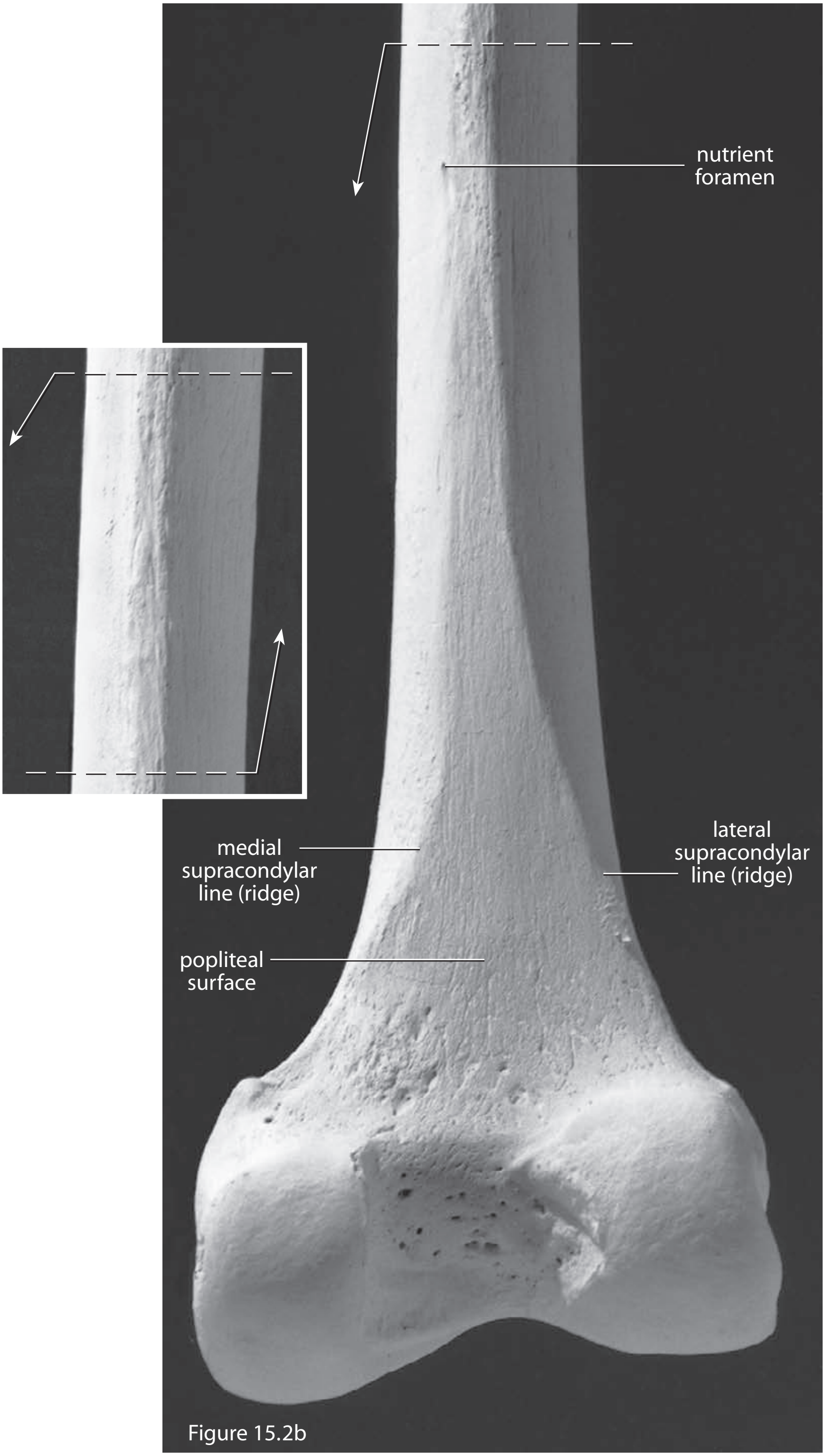


Figure 15.2a **Right femur, posterior.** *Above*, proximal end; *opposite*, distal end; *middle*, mid-shaft. Natural size.


nutrient
foramen
medial
supracondylar
line (ridge)
lateral
supracondylar
line (ridge)
popliteal
surface
Figure 15.2b

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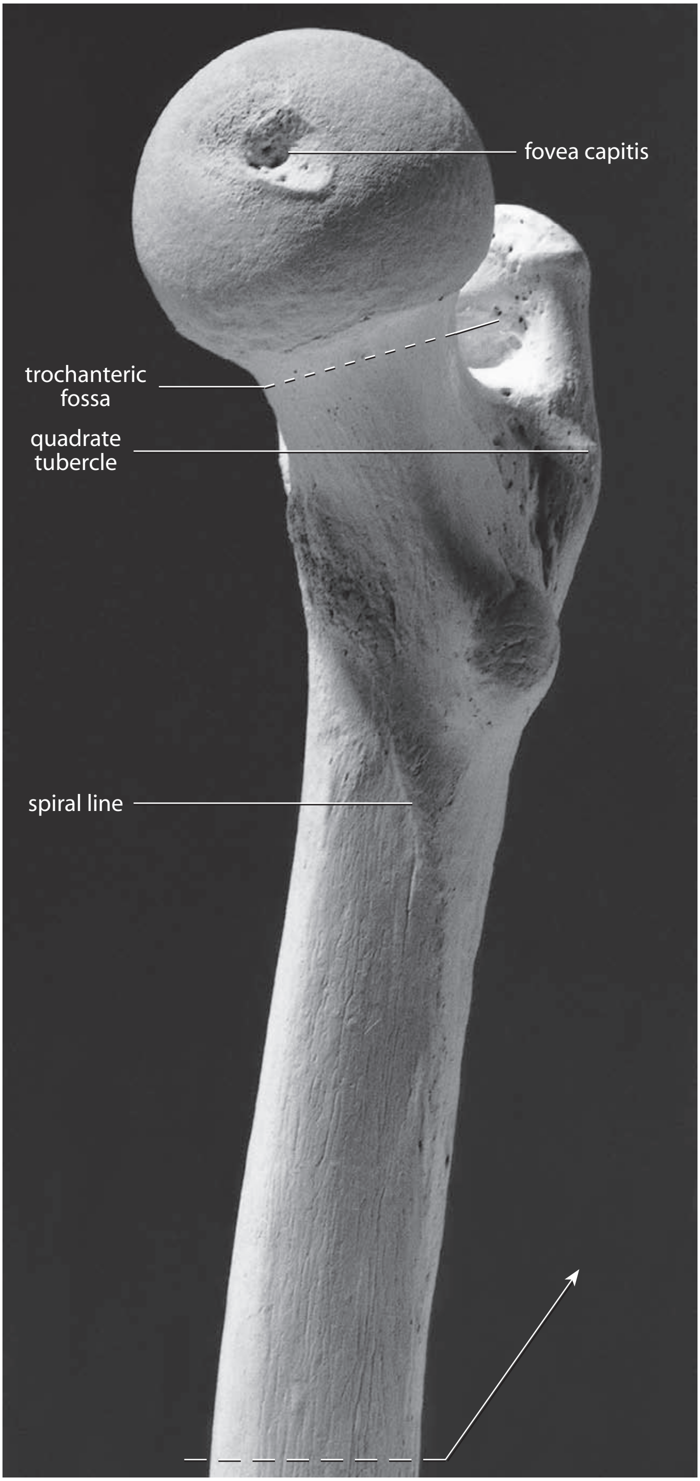

Figure 15.3a **Right femur, medial.** *Above*, proximal end; *opposite*, distal end; *middle*, mid-shaft. Natural size.

Figure 15.3b

Figure 15.4a **Right femur, lateral.** *Above*, proximal end; *opposite*, distal end; *middle*, mid-shaft. Natural size.

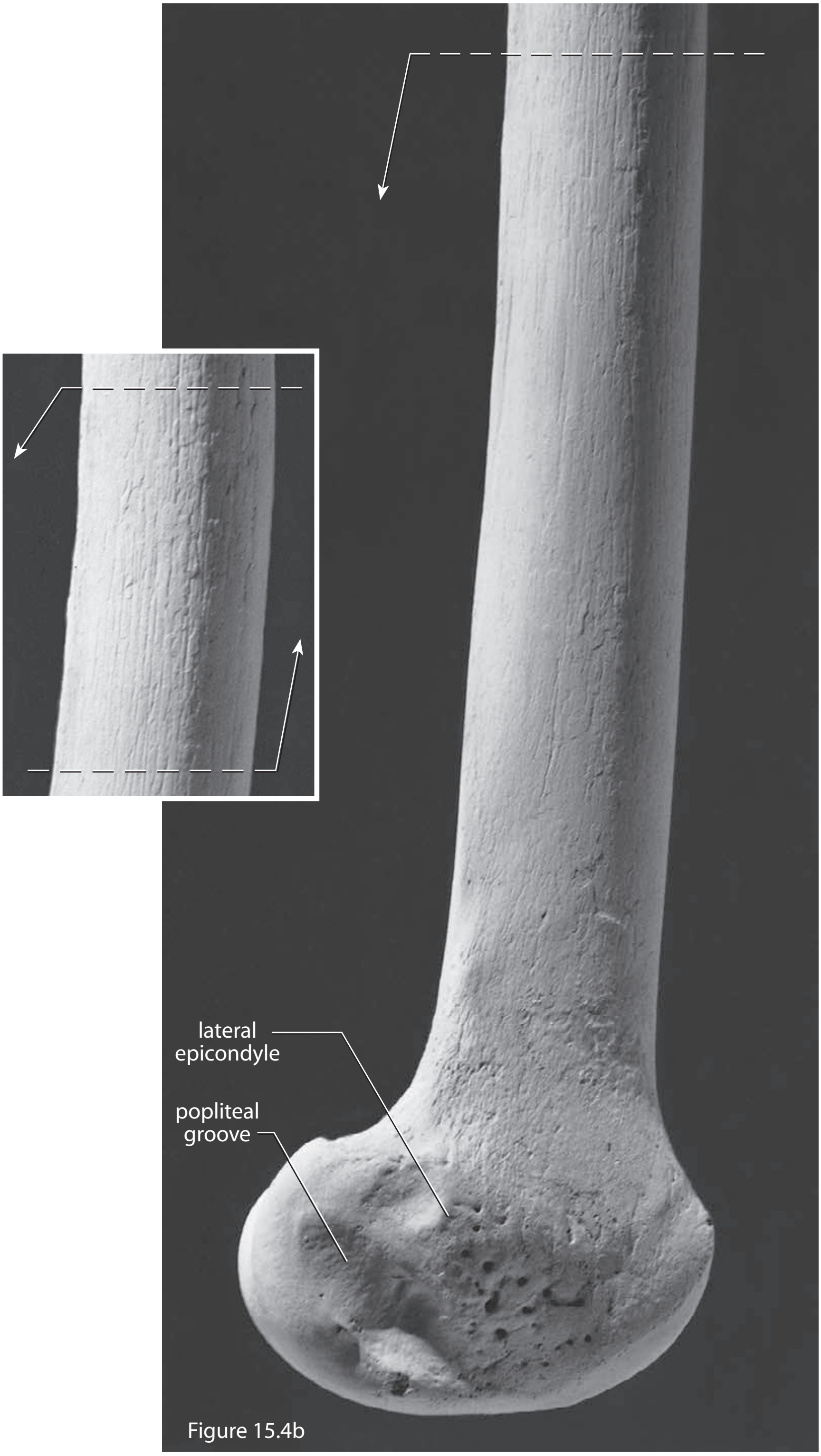

Figure 15.4b

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Figure 15.5 **Right femur, proximal**. Posterior is up, lateral is toward the left. Natural size.

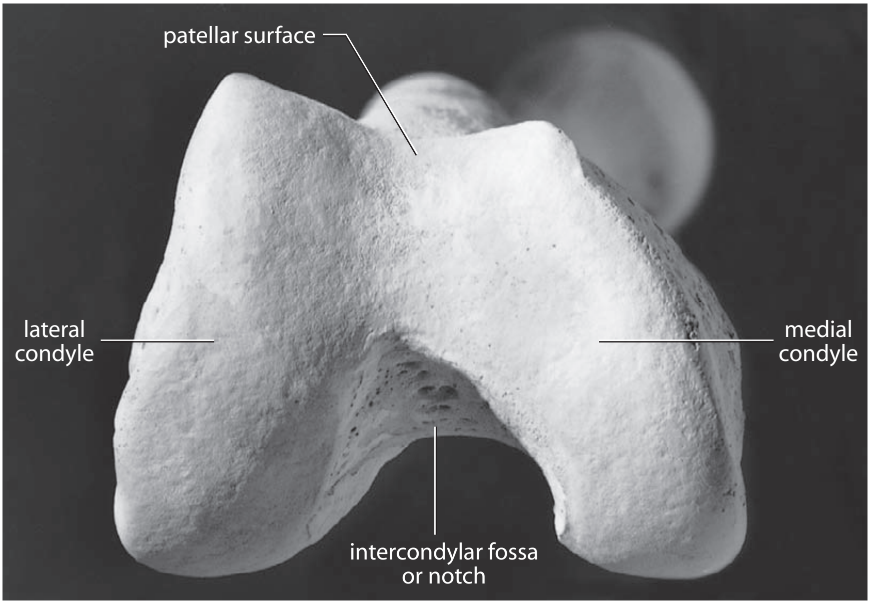

Figure 15.6 **Right femur, distal.** Anterior is up, lateral is toward the left. Natural size.

15.1.2 Growth (Figure 15.7)

The femur ossifies from five centers: one for the shaft, one for the head, one for the distal end, and one for each trochanter.

15.1.3 Possible Confusion

Neither intact femora nor femoral fragments are easily confused with other bones.

- The femoral head has a fovea and is a more complete sphere than the humeral head.
- The femoral shaft is larger, has a thicker cortex, and is rounder in cross section than any other shaft. It has only one sharp corner, the linea aspera.

15.1.4 Siding

- For intact femora or proximal ends, the head is proximal and faces medially. The lesser trochanter and linea aspera are posterior.
- For isolated femoral heads, the fovea is medial and displaced posteriorly and inferiorly. The posteroinferior head–neck junction is more deeply excavated than the anterosuperior junction.
- For proximal femoral shafts, the nutrient foramen opens distally, and the linea aspera is posterior and thins inferiorly. The gluteal tuberosity is superior and faces posterolaterally.
- For femoral midshafts, the nutrient foramen opens distally, the bone widens distally, and the lateral posterior surface is usually more concave than the medial posterior surface.
- For distal femoral shafts, the shaft widens distally and the lateral supracondylar ridge is more prominent than the medial. The medial condyle extends more distally than the lateral.
- For femoral distal ends, the intercondylar notch is posterior and distal, and the lateral border of the patellar notch is more elevated. The lateral condyle bears the popliteal groove, and the medial condyle bulges away from the line of the shaft. Relative to the shaft axis, the lateral condyle extends more posteriorly than the medial. The medial condyle extends more distally than the lateral because in anatomical position the femur angles beneath the body.

Figure 15.7 **Femoral, tibial, and fibular growth.** The pairs of immature femora (*top*), tibiae (*middle*), and fibulae (*bottom*), shown here in posterior view, are from a one-year old and a six-year-old. Distal ends are to the left. Natural size.

Figure 15.8 **Right patella, anterior.** Superior is up; lateral is toward the left. Natural size.

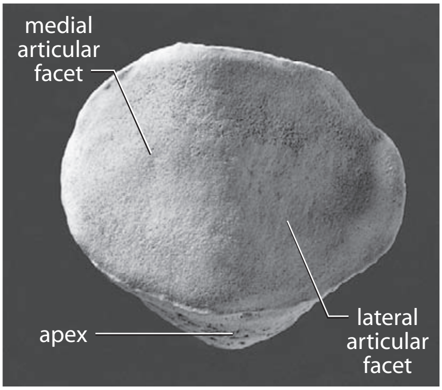

Figure 15.9 **Right patella, posterior.** Superior is up; lateral is toward the right. Natural size.

15.2 Patella (Figures 15.8–15.9)

15.2.1 Anatomy

The patella, the largest sesamoid bone in the body, articulates only with the patellar surface of the distal femur (patellar notch). The patella rides in the *tendon of the quadriceps femoris*—the largest muscle of the thigh and the primary extensor of the knee. The patella functions to protect the knee joint, to lengthen the lever arm of the quadriceps, and to increase the area of contact between the *patellar ligament* and the femur.

a. The **apex** of the patella is the nonarticular point on the bone. It points distally.
b. The **lateral articular facet** for the distal femur faces posteriorly and is the largest part of the large articular surface of the patella.
c. The **medial articular facet** for the distal femur faces posteriorly and is smaller than the lateral articular facet.

15.2.2 Growth

The patella ossifies from a single center.

15.2.3 Possible Confusion

This bone might be mistaken for an os coxae fragment, but only in a very fragmentary state. The acetabulum of the os coxae is strongly hollowed, as opposed to the much flatter articular surface of the patella.

15.2.4 Siding

- **Anatomical siding**. The patella is triangular in shape. Its thin, pointed apex is distal, and the thicker, blunter end is proximal. The lateral articular facet, which articulates with the lateral condyle of the femur, is the larger of the two facets.
- **Positional siding**. Place the apex away from you and the articular surface on the table. The bone falls toward the side from which it comes.

15.3 Tibia (Figures 15.10–15.15)

15.3.1 Anatomy

The tibia is the major weight-bearing bone of the lower leg. It articulates proximally with the distal femur, twice laterally with the fibula (once proximally and once distally), and distally with the talus.

a. The **tibial plateau** is the proximal tibial surface on which the femur rests. It is divided into two articular sections, one for each femoral condyle. In life there are fibrocartilagenous rings around the periphery of these articular facets, the *medial* and *lateral menisci*.
b. The **medial condyle** is the medial part of the tibial plateau. Its femoral articulation is oval, with the long axis oriented anteroposteriorly. Its lateral edge is straight.
c. The **lateral condyle** is the lateral part of the tibial plateau. Its femoral articulation is smaller and rounder than the medial articulation.
d. The **intercondylar eminence** is the raised area on the proximal tibial surface between articular facets.
e. The **medial intercondylar tubercle** forms the medial part of the intercondylar eminence.
f. The **lateral intercondylar tubercle** forms the lateral part of the intercondylar eminence. The anterior and posterior *cruciate ligaments* and the anterior and posterior extremities of the *menisci* insert into the nonarticular areas between the condyles, which are just anterior and posterior to the medial and lateral intercondylar tubercles, respectively.
g. The **superior fibular articular facet** is located on the posteroinferior edge of the lateral condyle.
h. The **tibial tuberosity** is the rugose area on the anterior surface of the proximal tibia. Its superior part is smoothest and widest. The patellar ligament of the *quadriceps femoris muscle*, a major lower leg extensor at the knee, inserts here.
i. The tibial **shaft** is the fairly straight segment of the tibia between the expanded proximal and distal ends.
j. The **soleal** (**popliteal**) **line** crosses the proximal half of the posterior tibial surface from superolateral to inferomedial. The line demarcates the inferior boundary of the *popliteus muscle* insertion. This muscle is a flexor and medial rotator of the tibia and originates from the popliteal groove on the lateral femoral condyle. The line itself gives rise to the *popliteus fascia* and *soleus muscle*, a plantarflexor of

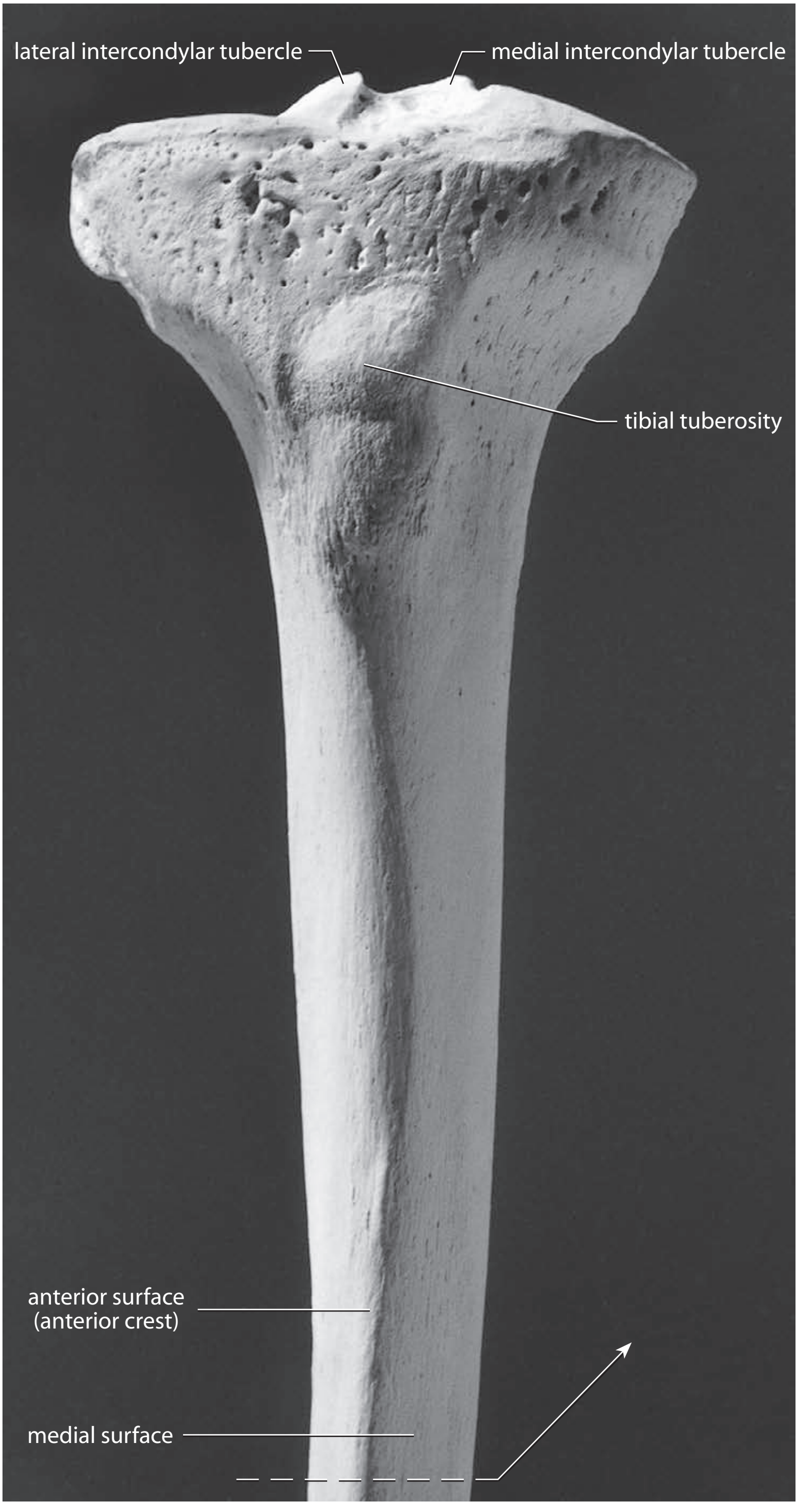

Figure 15.10a **Right tibia, anterior.** *Above*, proximal end; *opposite*, distal end. Natural size.

Figure 15.10b

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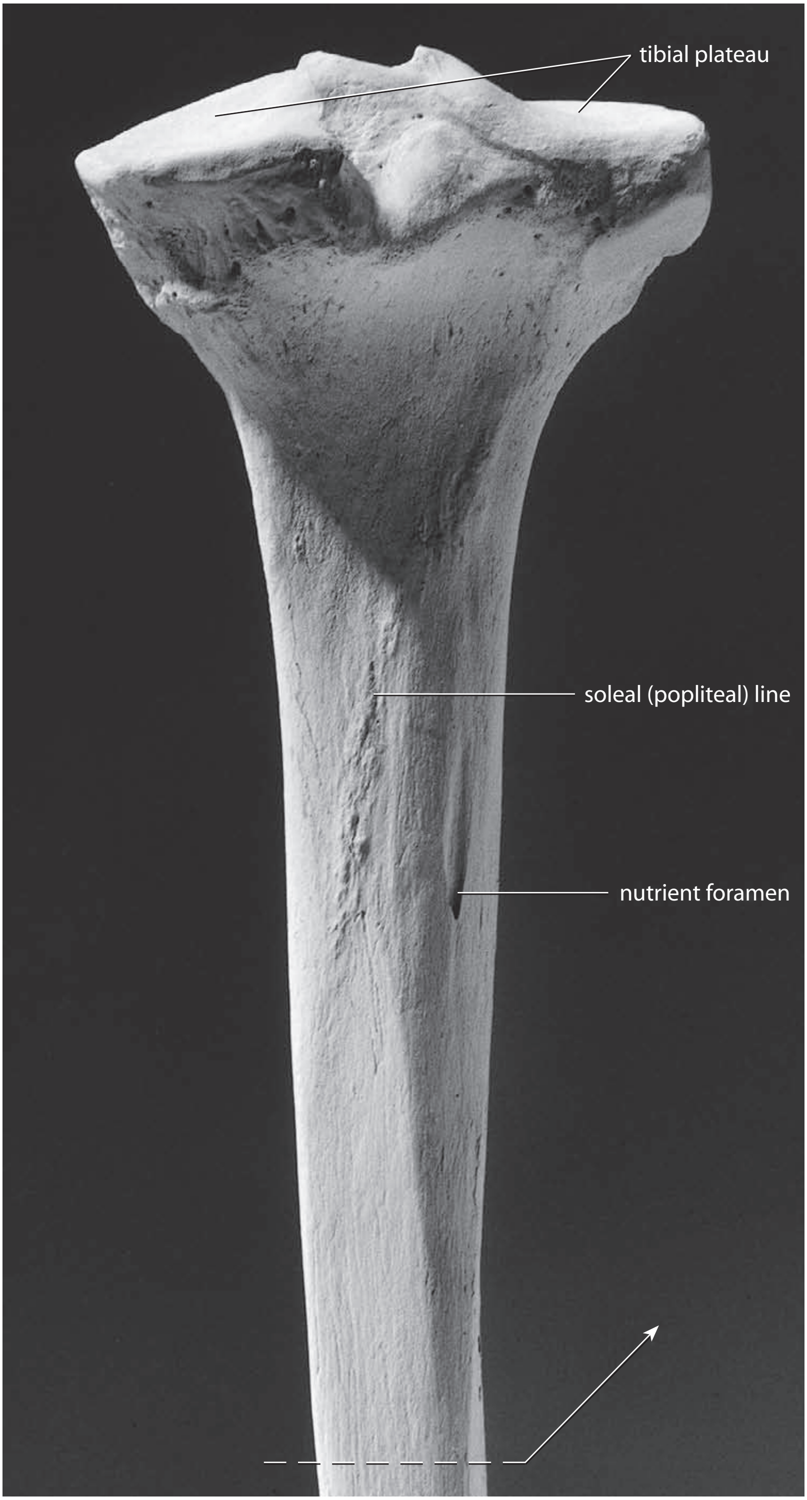


Figure 15.11a **Right tibia, posterior.** *Above*, proximal end; *opposite*, distal end. Natural size.

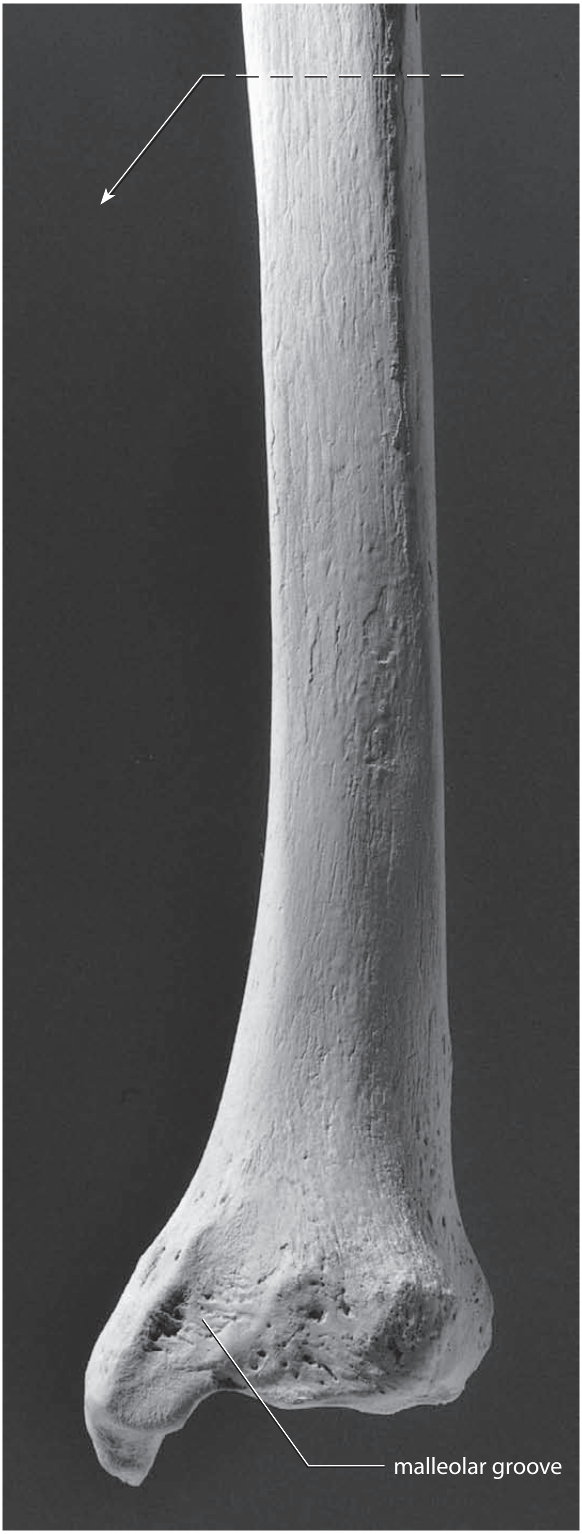


Figure 15.11b

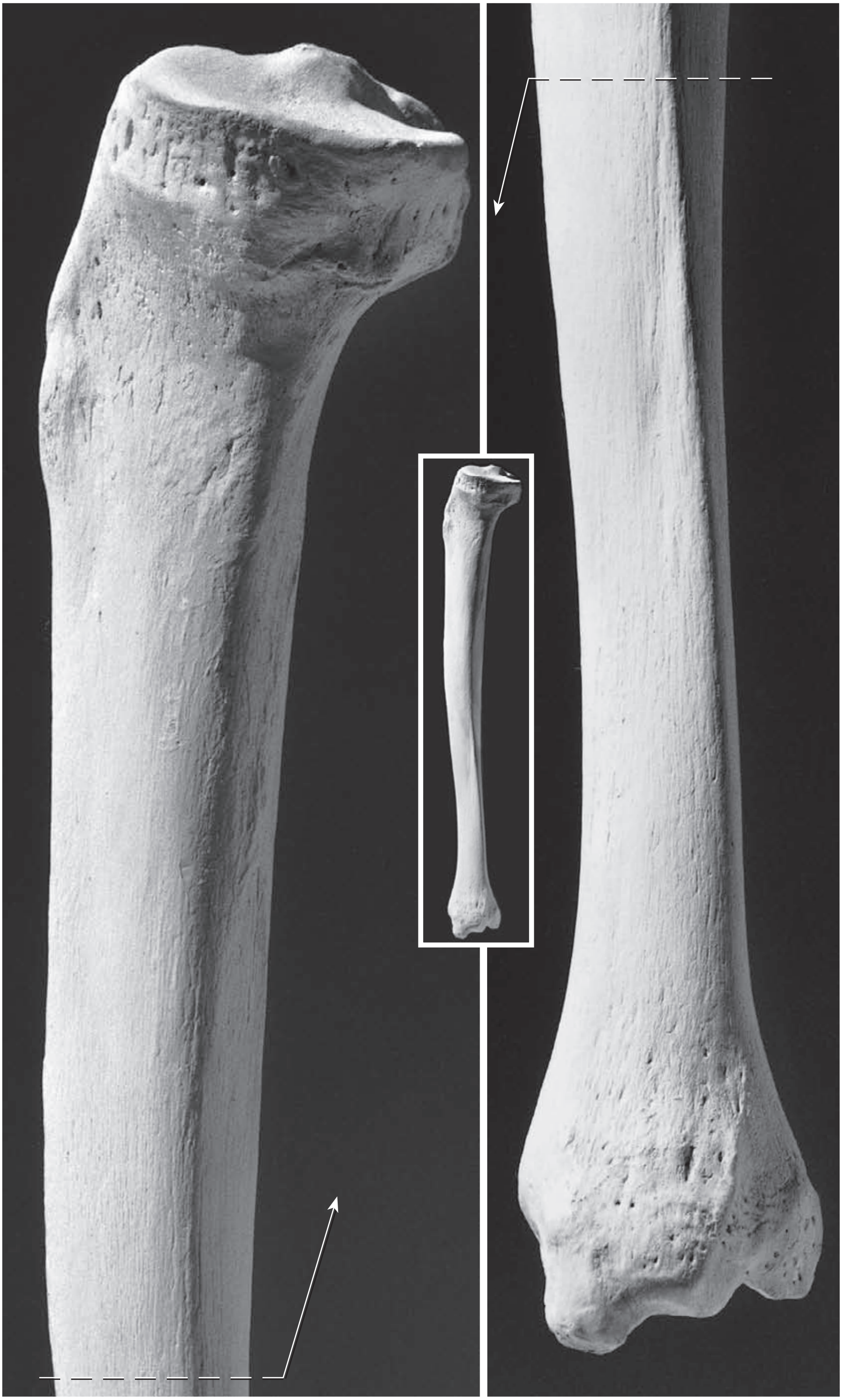


Figure 15.12 **Right tibia, medial**. *Left*, proximal end; *right*, distal end. Natural size.

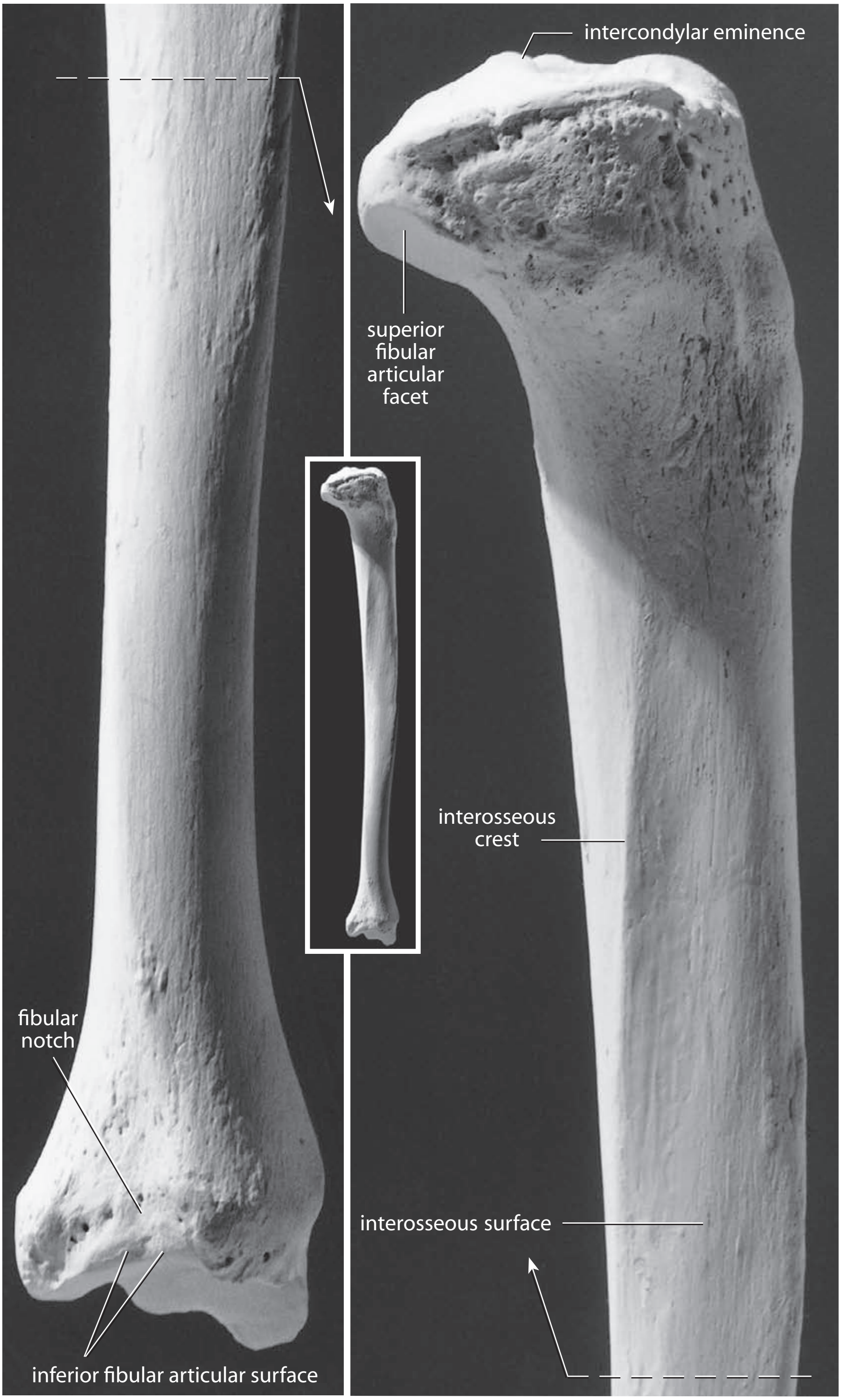


Figure 15.13 **Right tibia, lateral.** *Left*, distal end; *right*, proximal end. Natural size.

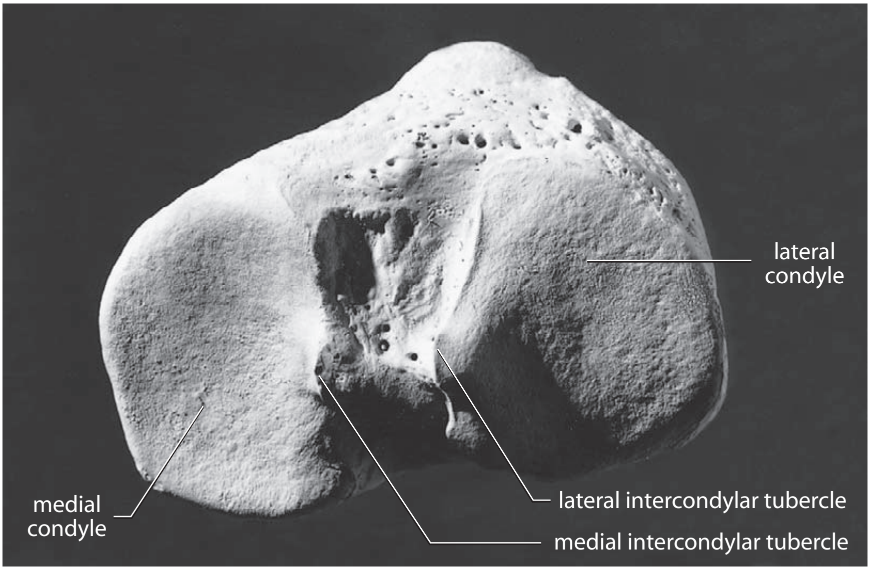


Figure 15.14 **Right tibia, proximal.** Anterior is up, lateral is toward the right. Natural size.


Figure 15.15 **Right tibia, distal.** Anterior is up, lateral is toward the left. Natural size.

the foot at the ankle.

k. The **nutrient foramen** is just inferolateral to the popliteal line. It is a large foramen that exits the bone proximally.
l. The **anterior surface** (**anterior crest**) of the shaft forms the anterior edge of the "shin."
m. The **medial surface** of the shaft forms the medial edge of the "shin" of the lower leg. This subcutaneous border is the widest tibial shaft surface.
n. The **interosseous surface** of the shaft is lateral, opposite the fibula. It is the most concave of the three tibial surfaces.
o. The **interosseous crest** is the lateral crest of the shaft, which faces the fibula. It is the attachment area for the *interosseous membrane*, a sheet of tissue that functions to bind the tibia and fibula together and to compartmentalize lower leg muscles into anterior and posterior groups, just as its serial homolog does in the forearm.
p. The **medial malleolus** is the projection on the medial side of the distal tibia that forms the subcutaneous medial knob at the ankle. Its lateral surface is articular, for the talar body.
q. The **fibular notch** is the distolateral corner of the tibia. It is a triangular nonarticular area for the thick, short interosseous *tibiofibular ligament*. This ligament binds the distal tibia and fibula together as a unit at this syndesmosis. The proximal ankle, or **talocrural**, joint is formed by the tightly bound distal tibia and fibula, which articulate with the superior, medial, and lateral talar surfaces.
r. The **inferior fibular articular surface** is a thin articular surface for the fibula, which faces laterally at the base of the fibular notch.
s. The **malleolar groove** on the posterior aspect of the medial malleolus transmits the *tendons of the tibialis posterior* and *flexor digitorum longus muscles*, plantarflexors.

15.3.2 Growth (Figure 15.7)

The tibia ossifies from three centers: one for the shaft and one for each end of the bone. Separate centers for the tibial tuberosity sometimes occur.

15.3.3 Possible Confusion

- The triangular tibial cross section differentiates fragments of this bone from the femur or the much smaller humerus. The tibial shaft is much larger than radial or ulnar shafts.
- Proximal and distal ends of the tibia are diagnostic, and the only possibility of confusion arises in mistaking a segment of the proximal articular surface for the body of a vertebra. The articular surface of the tibia is much denser and smoother than the articular surface of a vertebral body.

15.3.4 Siding

- For an intact tibia, the tibial tuberosity is proximal and anterior. The medial malleolus is on the distal end and is medial.

- For the proximal tibia, the tibial tuberosity is anterolateral, the fibular articulation is placed posterolaterally, and the lateral femoral articular surface is smaller, rounder, and set laterally. The intercondylar eminence is set posteriorly, and the axis of the nonarticular strip on the plateau runs from anterolateral to posteromedial. This strip is wider anteriorly than posteriorly. The intercondylar eminence has a more concave medial border and a more evenly sloping lateral border.
- For fragments of shaft, the entire shaft tapers distally, and the interosseous crest is lateral and posterior. The medial surface is the widest and faces anteriorly. The nutrient foramen is posterior and exits proximally. The cortex is thickest at midshaft.
- For the distal end, the malleolus is medial and its distal-most projection is anterior. Grooves for the plantarflexor tendons are posterior. The fibular notch is lateral, and the interosseous crest runs toward its anterior surface. The margin of the articular surface for the superior talus is grooved on the anterior surface but not the posterior surface.

15.4 Fibula (Figures 15.16–15.21)

15.4.1 Anatomy

The fibula is a long, thin bone that lies lateral to the tibia, articulating twice with it and once with the talus. Although this bone plays only an indirect role in the knee joint, serving to anchor ligaments, it plays a key role in forming the lateral border of the ankle joint. The fibula bears very little weight, not even touching the femur at its superior end.

a. The **head** is the swollen proximal end of the fibula, more massive and less mediolaterally flattened than the distal end. It is the attachment point for the *biceps femoris muscle* (a flexor and lateral rotator at the knee) and the *lateral collateral ligament* of the knee.
b. The **styloid process** is the most proximal projection of the bone, forming the posterior part of the head.
c. The **proximal fibular articular surface** is a round, flat, medially oriented surface that corresponds to a similar surface on the lateral proximal tibia.
d. The fibular **shaft** is the long, thin, fairly straight segment of the bone between the expanded proximal and distal ends.
e. The **interosseous crest** is an elevated crest that runs down the medial, slightly anteriorly facing surface of the shaft. Attached to it is the *interosseous membrane*, a fibrous sheet that binds the fibula and tibia and divides the lower leg musculature into anterior and posterior compartments.
f. The **nutrient foramen** opens proximally on the posteromedial surface, at about midshaft level. The cross section of the fibular shaft can be extremely variable in this region.
g. The **lateral malleolus** is the inferiormost (distalmost) projection of the fibula. Its lateral, nonarticular surface is subcutaneous, forming the lateral knob of the

ankle.

h. The **malleolar** (**distal**) **articular surface** is a flat, medially facing, triangular surface whose apex faces inferiorly. The surface articulates with the lateral surface of the talus.
i. The **malleolar fossa** is located just posterior to the distal articular surface. It is the attachment site of the *transverse tibiofibular* and *posterior talofibular ligaments*, which strengthen the ankle joint.
j. The **fibular (peroneal) groove**, for *tendons of the fibularis (peroneus) longus* and *fibularis (peroneus) brevis muscles*, marks the posterior surface of the distal fibula. These muscles plantarflex and evert the foot at the ankle, originating in the leg and inserting at the bases of the first (*longus*) and fifth (*brevis*) metatarsals.

15.4.2 Growth (Figure 15.7)

The fibula, like the tibia, ossifies from three centers: one for the shaft and one for each end.

15.4.3 Possible Confusion

The proximal and distal fibular ends are distinctive and are rarely confused with other bones.

- The distal end is flattened along the plane of the articular facet, whereas the proximal end of the fifth metatarsal, for which a distal fibular end might be mistaken, has two facets and is flattened perpendicular to the planes of each.
- Fibular shafts are thin, straight, and usually quadrilateral (sometimes triangular), with sharp crests and corners. Thus, they are thus more irregular in cross section than either radial or ulnar shafts.

15.4.4 Siding

- For an intact fibula, the articular surfaces for the tibia are medial, the head is proximal, the flattened end is distal, and the malleolar fossa is posterior.
- For the proximal end, the styloid process is lateral, proximal, and displaced posteriorly. The articular surface faces medially and is also displaced posteriorly. The neck is roughest laterally.
- For the shaft, try to use intact specimens for comparison. The nutrient foramen opens proximally. The sharpest crest on the triangular proximal end is the interosseous crest. This expands downshaft to a rough, flattened surface. The distal aspect of the shaft is marked by a line diverging from the trend of the interosseous crest in the direction of the side from which the bone comes.
- For the distal end, the malleolar fossa is always posterior, and the articular facet is always medial, with its apex pointed inferiorly.

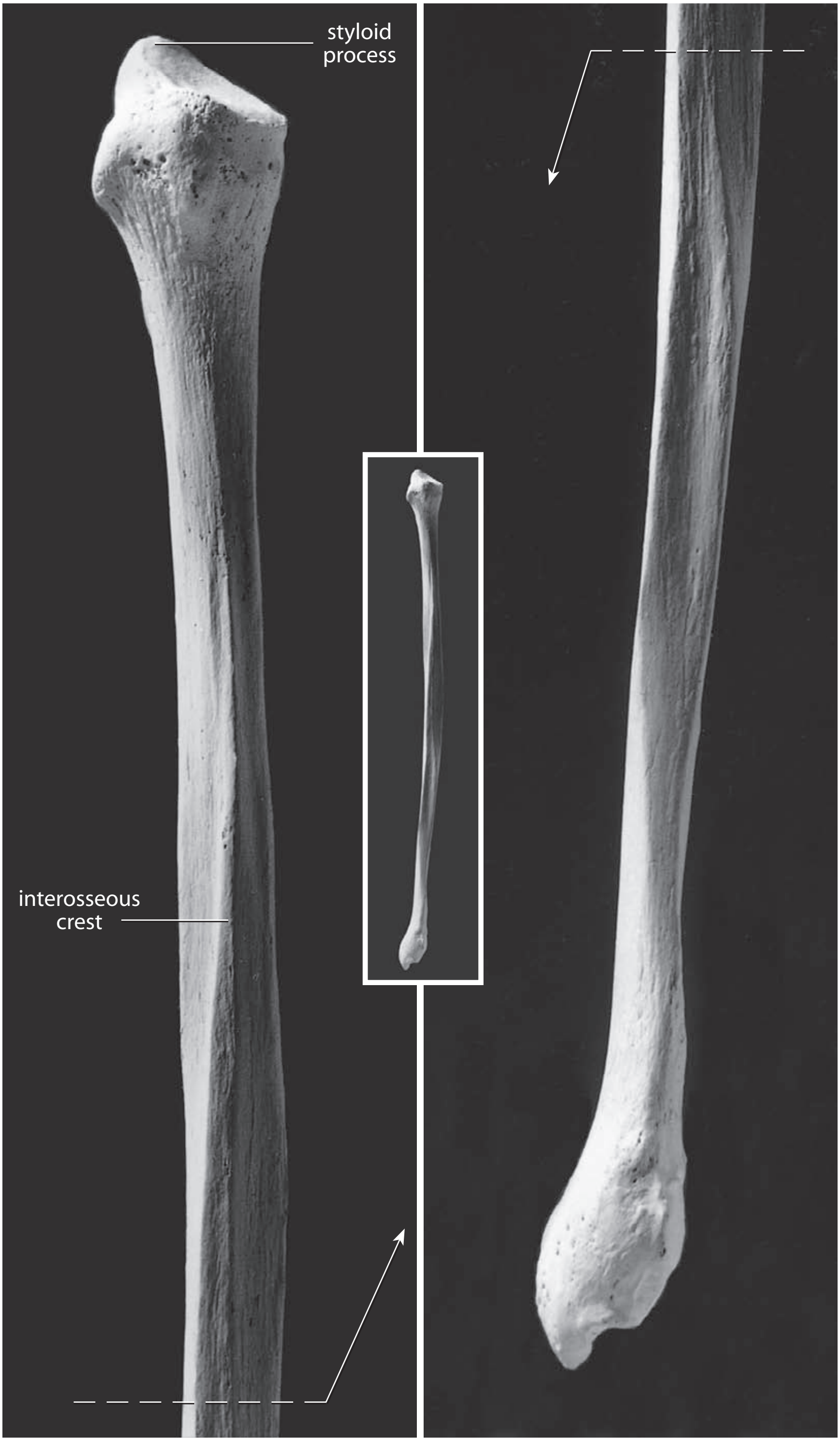


Figure 15.16 **Right fibula, anterior.** *Left*, proximal end; *right*, distal end. Natural size.

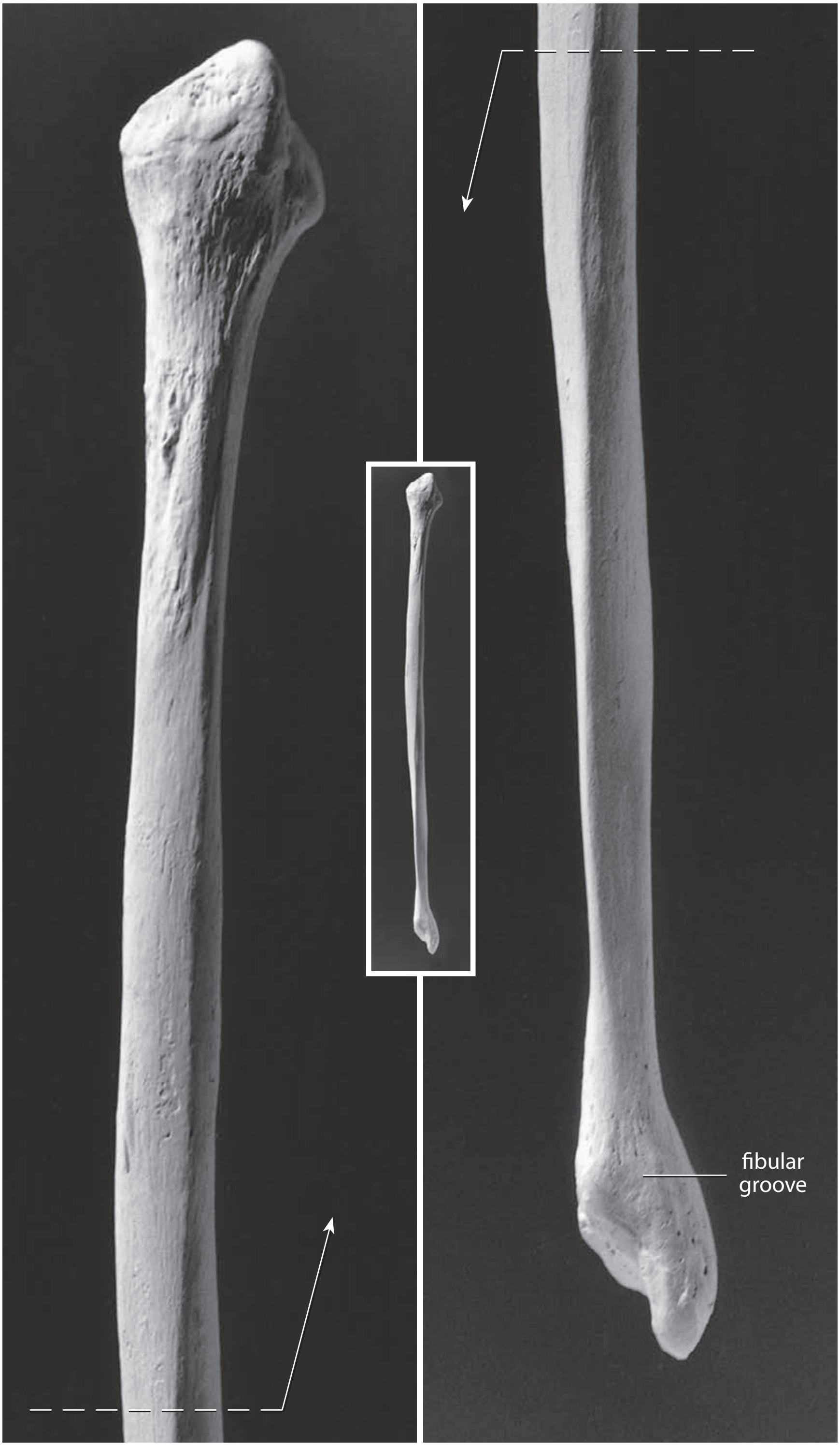


Figure 15.17 **Right fibula, posterior.** *Left*, proximal end; *right*, distal end. Natural size.

LEG

Figure 15.18 **Right fibula, medial.** *Left*, proximal end; *right*, distal end. Natural size.

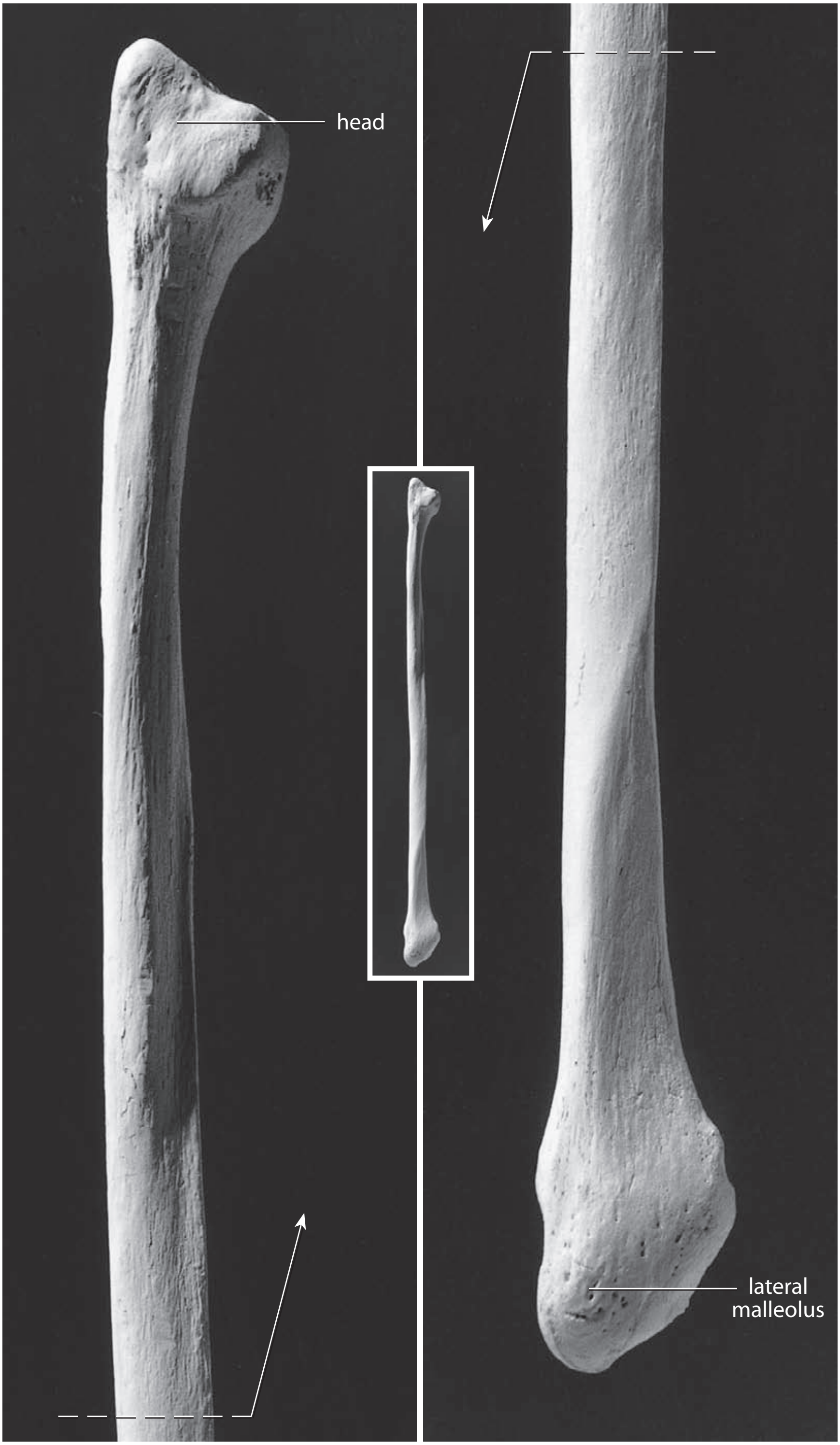


Figure 15.19 **Right fibula, lateral.** *Left*, proximal end; *right*, distal end. Natural size.

LEG

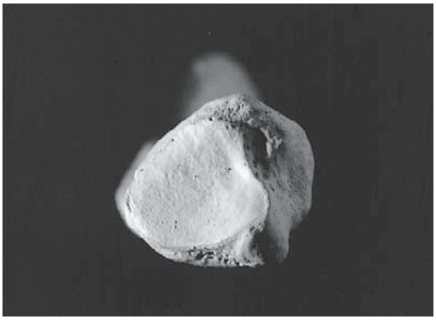


Figure 15.20 **Right fibula, proximal.** Anterior is up; lateral is toward the right. Natural size.

Figure 15.21 **Right fibula, distal.** Posterior is up; lateral is toward the right. Natural size.

Chapter 16

Foot: Tarsals, Metatarsals, & Phalanges

The bones of the foot are obvious serial homologs of the hand bones. The deep evolutionary history of foot elements is similar to that described for those of the hand in Chapter 13. There are a total of twenty-six bones in each human foot, one less than in each hand. Of the seven tarsal bones, two occupy a proximal row, four occupy a distal row, and one is centered between rows. The tarsals are followed distally by a single row of five metatarsals. Farther distally, there is a single row of five proximal phalanges, a single row of four intermediate phalanges, and a single row of five distal, or terminal, phalanges.

In addition to these twenty-six, as with the hand, there are small sesamoid bones that lie within tendons of the foot. In the foot, a pair of sesamoids is usually found below the head of the first metatarsal. Figures 16.1–16.4 summarize and illustrate articulations within the foot. Elements of the foot skeleton can be divided into three segments: the **tarsals**, **metatarsals**, and **phalanges**.

It is convenient to apply specific directional terms to the foot. **Plantar** refers to the sole of the foot, its inferior surface in standard anatomical position. **Dorsal** is the

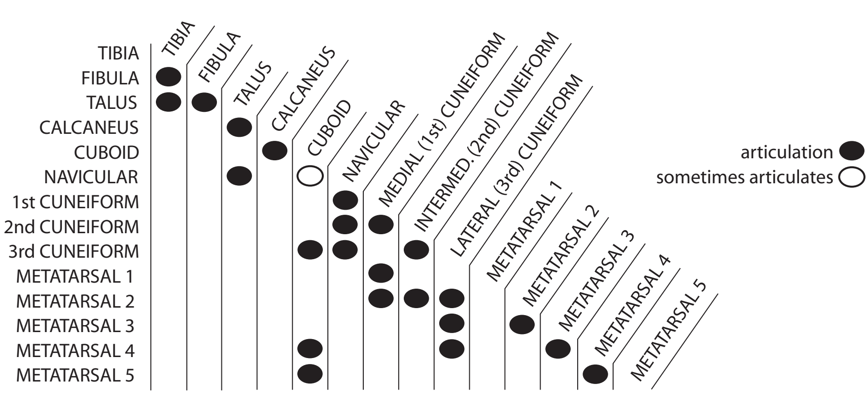


Figure 16.1 Articulation of bones in the adult human ankle and foot.

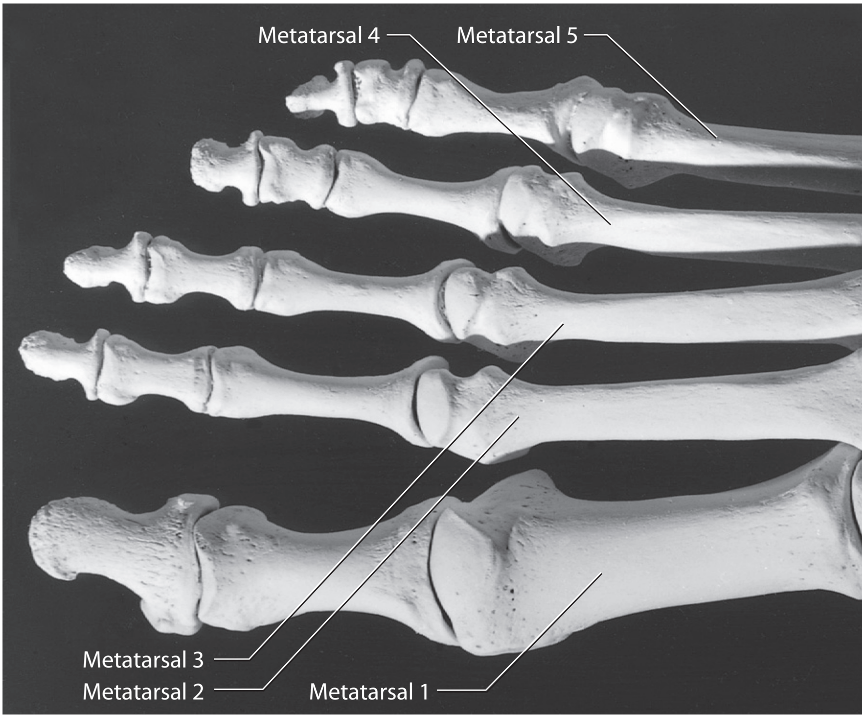
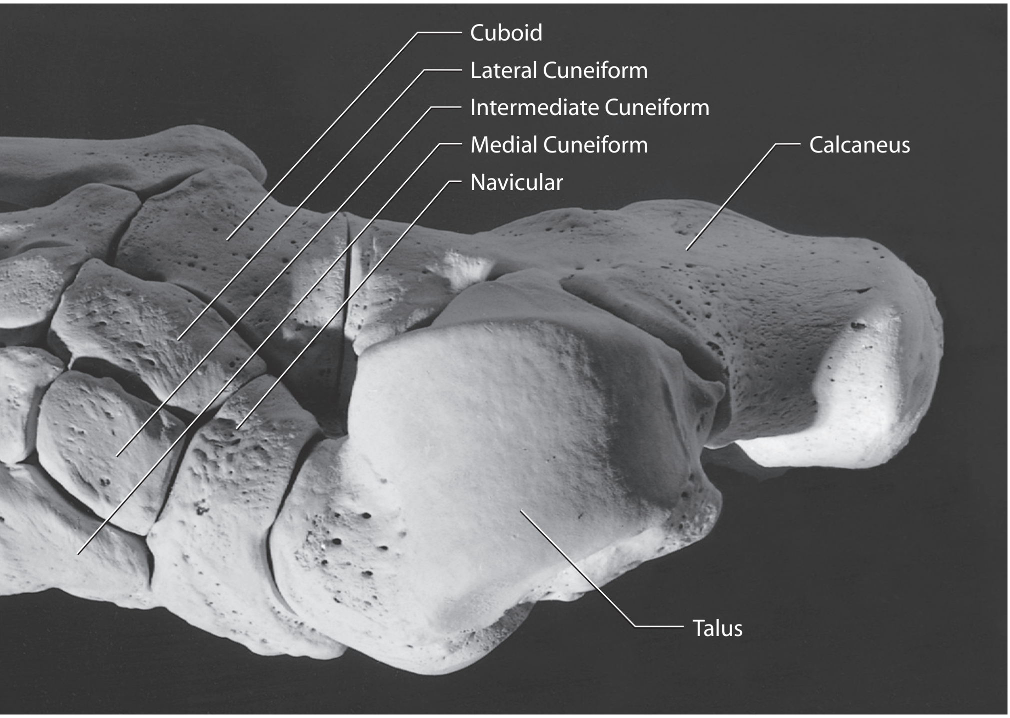


Figure 16.2 **Right foot, dorsal (superior).** Sesamoid bones not included. Natural size.


Figure 16.3 **Right foot, plantar (inferior).** Sesamoid bones not included. Natural size.


Cuboid
Lateral Cuneiform
Intermediate Cuneiform
Medial Cuneiform
Navicular
Calcaneus
Talus

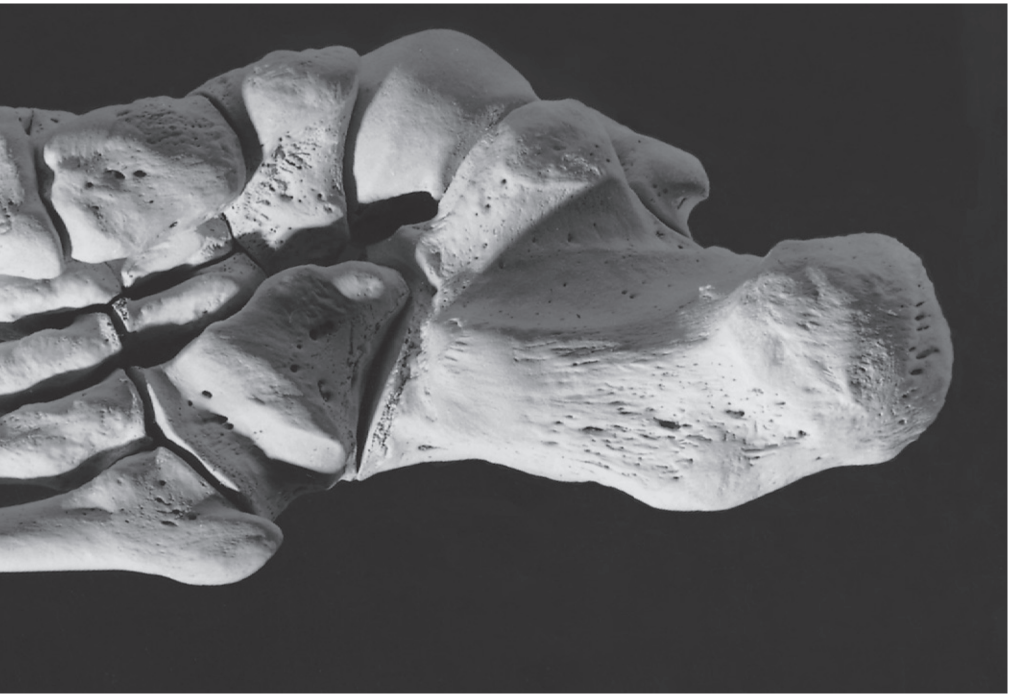


Figure 16.4a **Right foot, lateral.** Sesamoid bones not included. Natural size.

Figure 16.4b **Right foot, medial.** Sesamoid bones not included. Natural size.

opposite, superior surface. **Proximal** (posterior) is toward the tibia, **distal** (anterior) is toward the toe tips, and the distal-most phalanges are referred to as "terminal." In addition, the big toe is sometimes called the **hallux**, and its ray is identified as ray 1. Other rays are numbered as in the hand.

The human foot has changed dramatically during its evolution from a grasping organ to a structure adapted to bipedal locomotion. Most of the mobility, flexibility, and grasping abilities of the foot have been lost in humans as the foot adapted to shock absorption and propulsion.

16.1 Tarsals

The seven tarsals combine with the five metatarsals to form the longitudinal and transverse arches of the foot. The **talus** articulates superiorly with the distal tibia and fibula at the ankle joint. The **calcaneus** forms the heel of the foot, supports the talus, and articulates anteriorly with the **cuboid**, the third largest tarsal bone. The metatarsals articulate proximally with the cuboid and three **cuneiforms**. The seventh tarsal, the **navicular**, is interposed between the head of the talus and these cuneiforms.

16.1.1 Talus (Figures 16.5–16.6)

The talus is called the **astragalus** in other animals. It is the second largest of the tarsals and is situated between the tibia and fibula superiorly and the calcaneus inferiorly. No muscles attach to this bone. It rests atop the calcaneus and articulates distally with the navicular. It forms the lower member of the **talocrural joint**. Talar variation is illustrated in Figure 4.1.

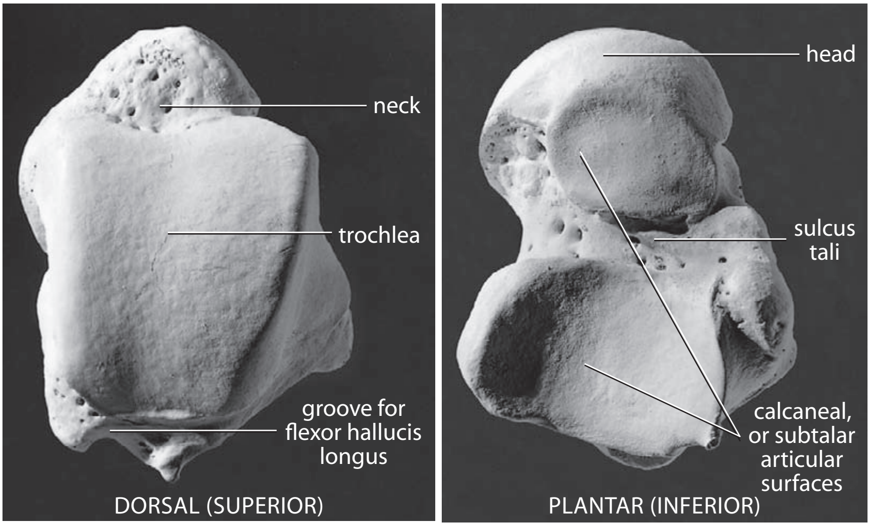


Figure 16.5 **Right talus.** Distal is up. Natural size.

a. The **head** is the rounded, convex, distal articular surface of the talus. It fits into the hollow of the navicular.
b. The **body** is the squarish bulk of the bone posterior to the talar neck.
c. The **trochlea** is the saddle-shaped articular surface of the body. Its sides are the lateral and medial **malleolar surfaces**, which articulate with the fibula and tibia, respectively.
d. The **neck** connects the head of the talus to the body. Occasionally there are small articular facets on the neck, formed by contact with the anterior surface of the distal tibia during strong dorsiflexion of the foot at the ankle (or talocural) joint. These facets are called squatters' facets.
e. The **groove for flexor hallucis longus** is the short, nearly vertical groove on the posterior surface of the talar body. It is so named because it transmits the tendon of this muscle, a calf muscle that plantarflexes the foot and hallux.
f. The **calcaneal** or **subtalar articular surfaces** on the inferior aspect of the talus are usually three in number and variable in shape.
g. The **sulcus tali** is a deep groove between the posterior and the middle calcaneal articular surfaces.

- **Anatomical siding.** The saddle-shaped articular surface for the distal tibia is superior, and the talar head is anterior. The larger malleolar surface (for the fibula) is lateral.
- **Positional siding.** The head is medial when viewed from above and aligns with the hallux.

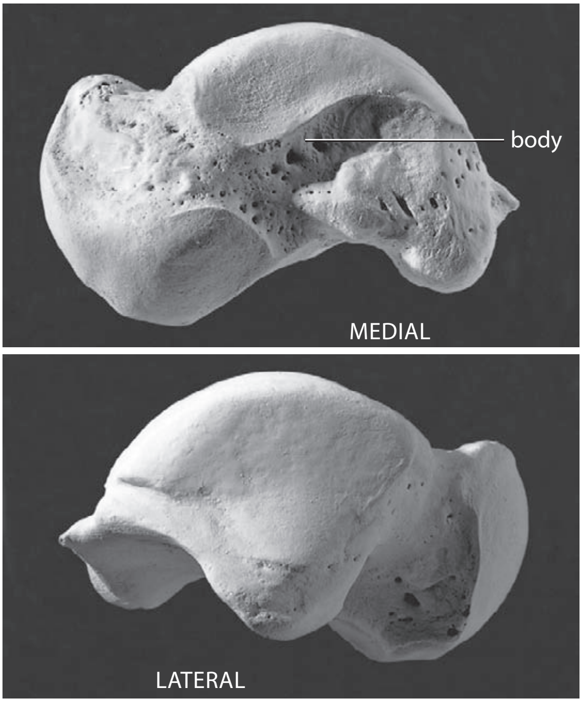


Figure 16.6 **Right talus.** Dorsal is up. Natural size.

16.1.2 Calcaneus (Figures 16.7–16.9)

The calcaneus, or "heel bone," is the largest of the tarsal bones and the largest bone of the foot. It is located inferior to the talus and articulates anteriorly (distally) with the cuboid.

a. The **calcaneal tuber** is the large, blunt, nonarticular, posterior process of the heel. It is the insertion point of the *calcaneal*, or *Achilles', tendon*. Contraction of the *gastrocnemius* and *soleus* calf muscles causes plantarflexion of the foot, with the calcaneal tuber serving as a lever arm that uses the talar body as its fulcrum.
b. The **lateral** and **medial processes**, on the plantar portion of the calcaneal tuberosity, serve to anchor several *intrinsic muscles* of the foot. The lateral process is much smaller than the medial.
c. The **sustentaculum tali** is the shelf on the medial side of the calcaneus. It supports the talar head.
d. The **sustentacular sulcus** (**groove**), just inferior to the sustentaculum, is a pronounced groove. The *tendon of the flexor hallucis longus muscle*, a plantarflexor of the big toe, travels through this groove. It is continuous posterosuperiorly with the groove on the posterior extremity of the talus.
e. The **fibular (peroneal) tubercle** is a rounded projection low on the lateral surface of the calcaneal body. It is closely associated with *tendons of the fibularis (peroneus) longus* and *brevis muscles*. These muscles plantarflex and evert the foot,

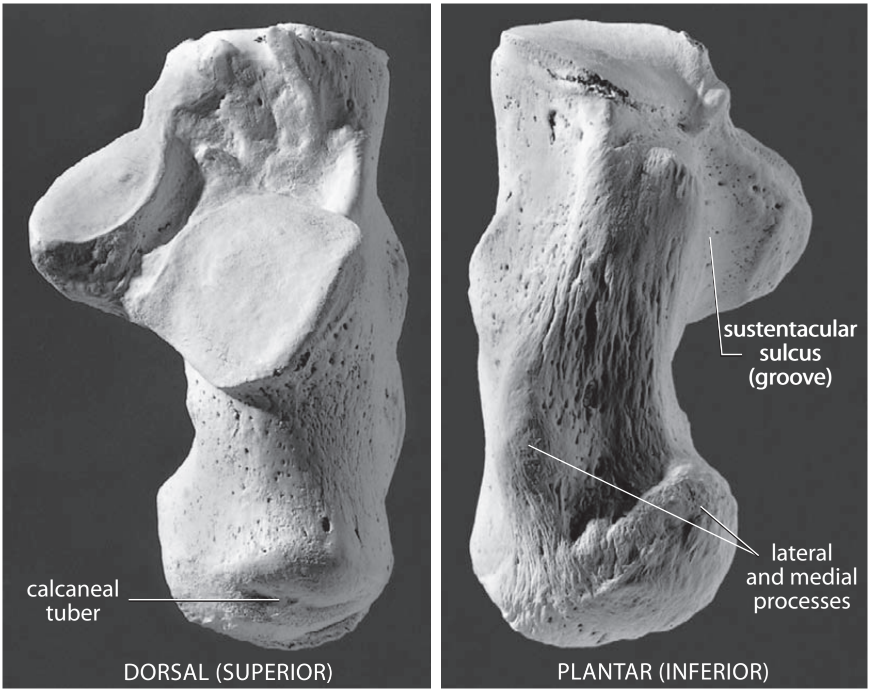


Figure 16.7 **Right calcaneus.** Distal is up. Natural size.

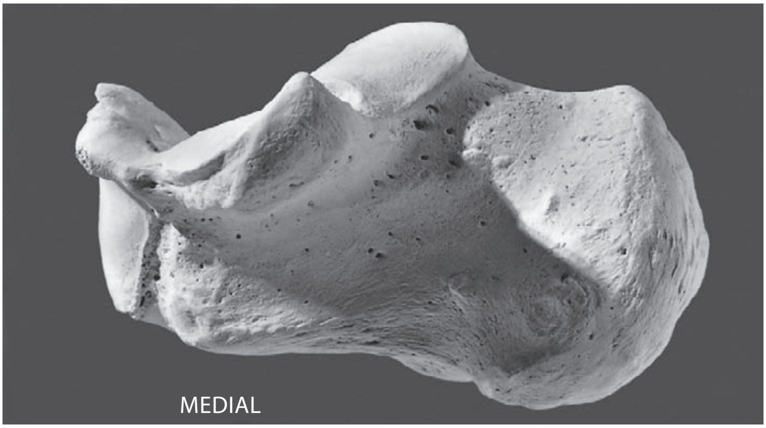
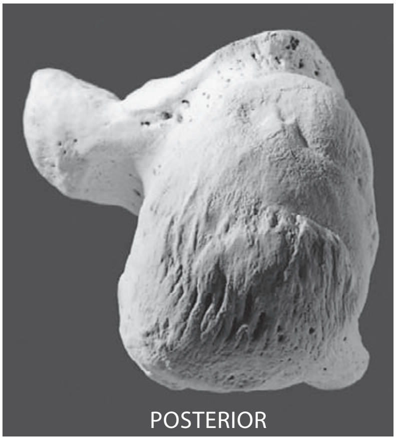


Figure 16.8 **Right calcaneus.** (*above* and *right*) Dorsal is up. Natural size.



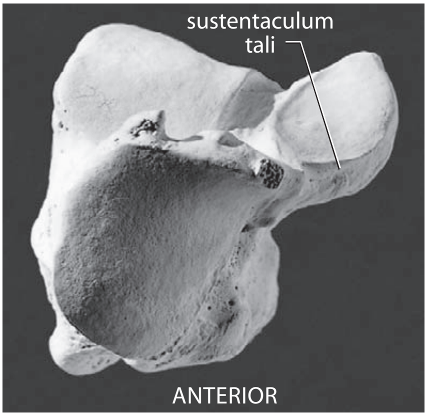
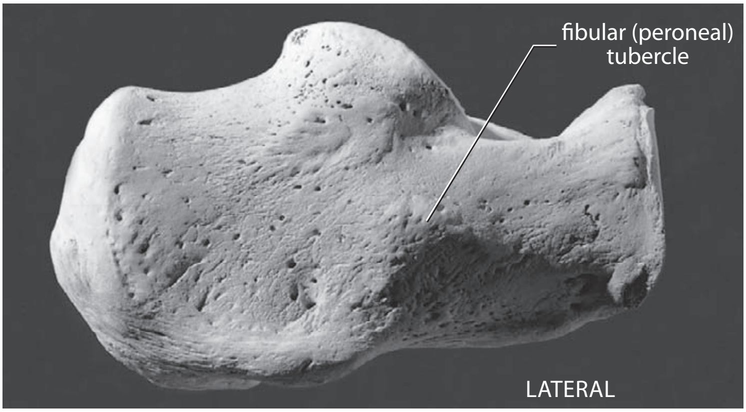


Figure 16.9 **Right calcaneus.** (*left* and *below*) Dorsal is up. Natural size.



inserting on the base of the first and fifth metatarsals, respectively.

- **Possible confusion.** It is not possible to confuse an intact calcaneus with another bone. A broken calcaneal body might sometimes be mistaken for a section of femoral greater trochanter, but the only articular surface on the proximal femur is the spherical head.
- **Anatomical siding.** The tuberosity is posterior and the inferior surface is nonarticular. The sustentaculum tali projects medially, inferior to the talar head.
- **Positional siding.** With the heel away from you and the articular surfaces up, the shelf projects to the side from which the bone comes.

16.1.3 Cuboid (Figures 16.10–16.11)

The cuboid bone sits on the lateral side of the foot, sandwiched between the calcaneus and the fourth and fifth metatarsals, articulating with the navicular and third cuneiform. It is recognized by its large size and projecting, pointed, proximal articular surface. It is the most cuboidal, or cube-shaped, of the tarsal bones. The **cuboid tuberosity** (Figure 16.10) is a large tuberosity on the inferolateral surface of the bone. The

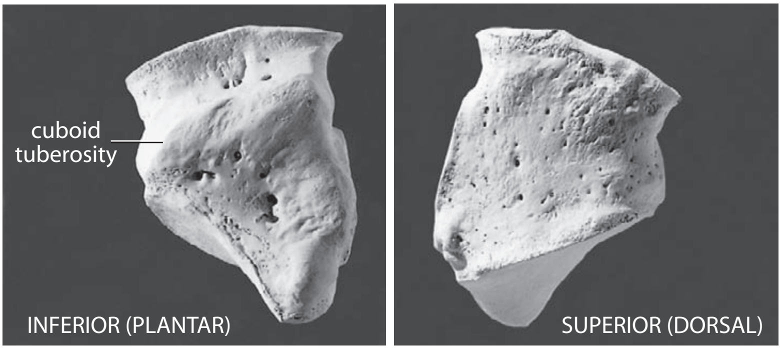


Figure 16.10 **Right cuboid.** Distal is up. Natural size.

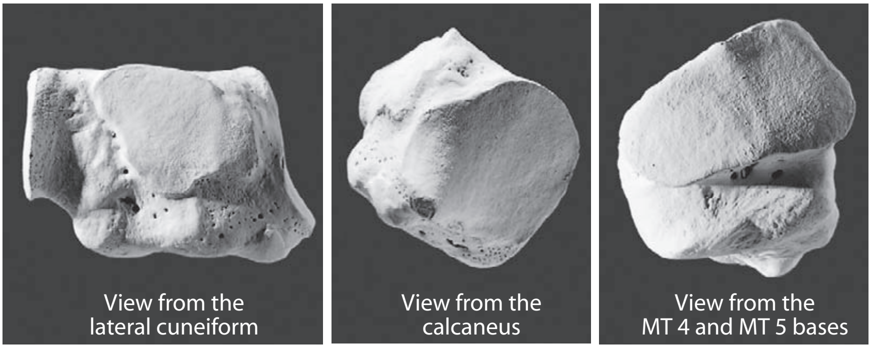


Figure 16.11 **Right cuboid.** Dorsal is up. Natural size.

tendon for the fibularis (peroneus) longus muscle enters the foot via the groove adjacent to this tuberosity.

- **Anatomical siding.** The wide, flat nonarticular surface is superolateral, and the pointed calcaneal facet is proximal. The tuberosity is inferolateral. There is an articulation on the medial, but not on the lateral surface.
- **Positional siding.** Look directly at the flat nonarticular surface. With the calcaneal facet toward you, the tuberosity projects laterally on the side from which the bone comes.

16.1.4 Navicular (Figures 16.12–16.13)

The navicular is named for the strongly concave proximal surface that articulates with the head of the talus. On the distal surface, the navicular has a large facet divided by two ridges. These demark the articular planes of the three cuneiforms. In addition, the navicular often articulates with a corner of the cuboid. The **tubercle** (Figure 16.12) of the navicular is a large, blunt projection on the medial side of the bone. This tubercle is the main insertion of the *tibialis posterior muscle*, a plantarflexor of the foot and toes.

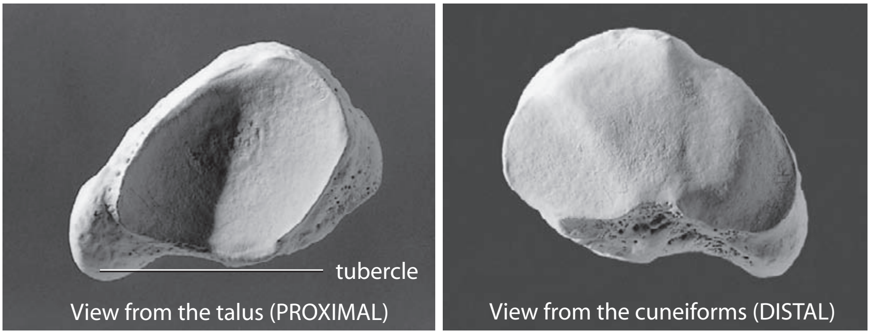


Figure 16.12 **Right foot navicular.** Dorsal is up. Natural size.

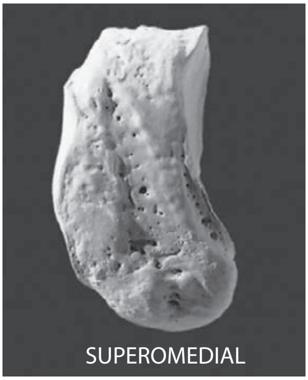


Figure 16.13 **Right foot navicular.** Distal is toward the left. Natural size.

- **Possible confusion.** Although generally similar in gross shape, this bone is much larger than the scaphoid and has a flat side with three facets.
- **Anatomical siding.** The concave talar facet is proximal. The large, flat nonarticular surface is dorsal, and the tubercle is medial.
- **Positional siding.** Hold the bone by the base of the tubercle, with the concave articular surface facing you and the flat nonarticular side up. The tip of the tubercle points toward the side from which the bone comes.

16.1.5 Medial (First) Cuneiform (Figure 16.14)

The first cuneiform is the largest of three cuneiforms. It sits between the navicular and the base of the first metatarsal, articulating with these as well as with the second cuneiform and the base of the second metatarsal (MT 2). It is less wedge-shaped than the other cuneiforms and is distinguished by the kidney-shaped facet for the base of the first metatarsal.

- **Anatomical siding.** The longest, kidney-shaped articular surface is distal, its long axis vertical. The broad, rough, nonarticular surface is medial, and the lateral facet for the intermediate cuneiform is superior. The proximal facet for the navicular is concave.
- **Positional siding.** Place the large, kidney-shaped articular facet away from you and orient its long axis vertically, with the smaller, more concave navicular facet toward you. With the bone resting on its blunter end, the only other facet is near the top (superolateral) and faces toward the side from which the bone comes.

16.1.6 Intermediate (Second) Cuneiform (Figure 16.15)

The intermediate cuneiform is the smallest of three cuneiforms. It is located between the navicular and the second metatarsal. In addition, it articulates on either side with the first and third cuneiforms.

- **Anatomical siding.** The nonarticular dorsal surface of the bone is broadest, and the bone wedges inferiorly, participating in the transverse arch of the foot. The proximal articular surface is usually the most concave (for the navicular). The lateral edge of this facet (proximal, lateral corner of the bone) is concave in profile. The lateral facet is bilobate.
- **Positional siding.** Place the flat, nonarticular surface up and the concave facet away from you. The outline of the superior (dorsal) surface is a square whose most projecting corner points towards the side from which the bone comes.

16.1.7 Lateral (Third) Cuneiform (Figure 16.16)

The lateral cuneiform is intermediate in size between the other cuneiforms. It is located in the center of the foot, articulating distally with the second, third, and fourth

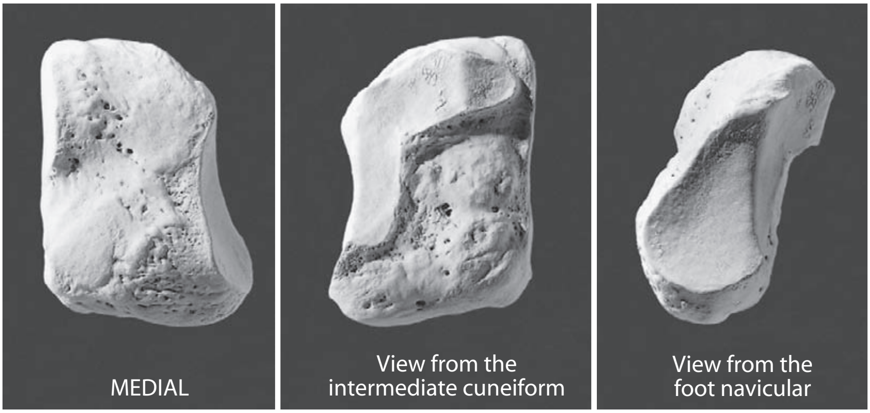


Figure 16.14 **Right medial (first) cuneiform.** Dorsal is up. Natural size.

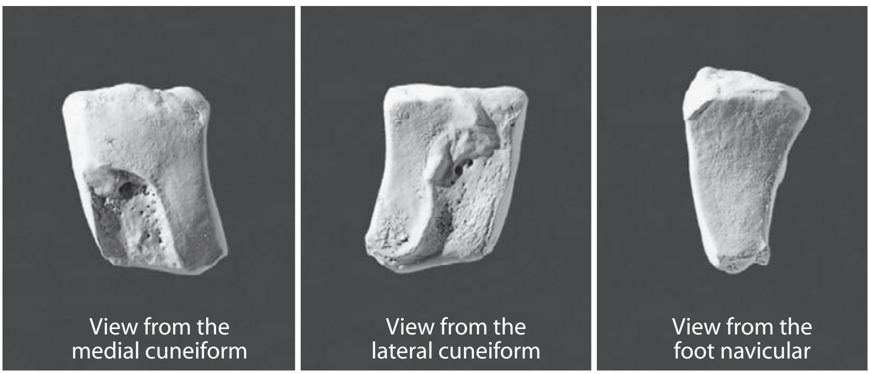


Figure 16.15 **Right intermediate (second) cuneiform.** Dorsal is up. Natural size.

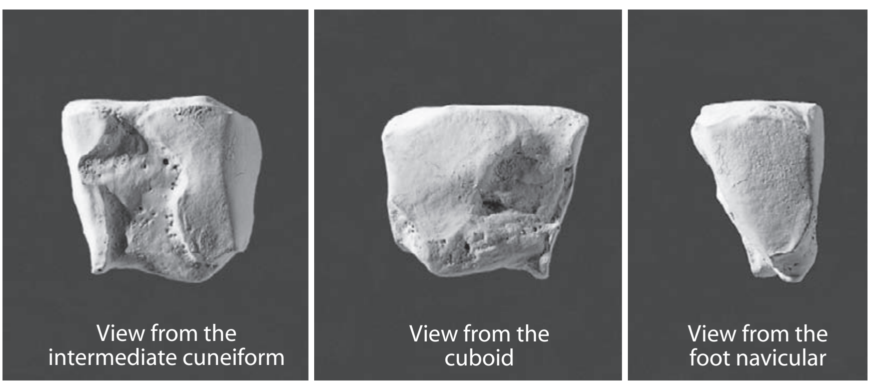


Figure 16.16 **Right lateral (third) cuneiform.** Dorsal is up. Natural size.

metatarsals. Medially it contacts the intermediate cuneiform, laterally the cuboid, and proximally the navicular.

- **Anatomical siding.** The dorsal surface is a rectangular, nonarticular platform, and the bone wedges inferiorly to this. The proximal (navicular) articulation is wider but smaller than the elongate, wedge-shaped distal MT 3 facet. The border between the navicular and the cuboid facets projects in a V-shape as the base of the third cuneiform wedges between these two bones.
- **Positional siding.** Place the flat, nonarticular surface up (wedge down), with the smaller end facet toward you. The Africa-shaped facet is away from you. The longest boundary of the upper surface is on the side from which the bone comes.

16.1.8 Growth

The tarsals each ossify from a single center, with the exception of the calcaneus, which has an epiphysis at its posterior end.

16.1.9 Possible Confusion

As with the carpals, most of the tarsals are compact and robust structures. Identification of fragmentary tarsals is therefore not usually required. The exception to this is the calcaneus, which is less dense and is often broken in its nonarticular areas. Because most of the tarsals are larger than carpals, they are more often recovered from archeological contexts. Siding of tarsals, as with carpals, is facilitated by positional techniques. Some of the techniques presented here are adopted from Bass (1995).

16.2 Metatarsals (Figures 16.17–16.21)

The metatarsals, like the metacarpals, are numbered from MT 1 (the hallux, or big toe) through MT 5, according to the five rays of the foot. They are all tubular bones with round distal articular surfaces (**heads**) and more squarish proximal ends (**bases**). As with metacarpals, metatarsals are identified and sided most effectively according to the morphology of their bases.

The plantar metatarsal **shaft** (body) surfaces are always more concave in lateral view than their dorsal shaft surfaces. The bases of nonhallucial metatarsal all articulate with each other. Each of the tarsals in the distal row articulate with at least one metatarsal base.

16.2.1 First Metatarsal

The first metatarsal is the shortest but most massive metatarsal. It articulates at its base with the medial cuneiform. The **sesamoid grooves** at the base of the head correspond to sesamoid bones (Figure 16.23) in the *tendons of flexor hallucis brevis*, a short

Figure 16.17 **Right foot, dorsal** (superior). Rays 1 – 5, showing the metatarsals and the proximal, intermediate, and distal foot phalanges. Distal is up; lateral is toward the right. Natural size.

Figure 16.18 **Right foot, plantar** (inferior). Rays 1 – 5, showing the metatarsals and the proximal, intermediate, and distal foot phalanges. Distal is up; lateral is toward the left. Natural size.

Figure 16.19 **Right foot, lateral.** Rays 1–5, showing the metatarsals and the proximal, intermediate, and distal foot phalanges. Natural size.

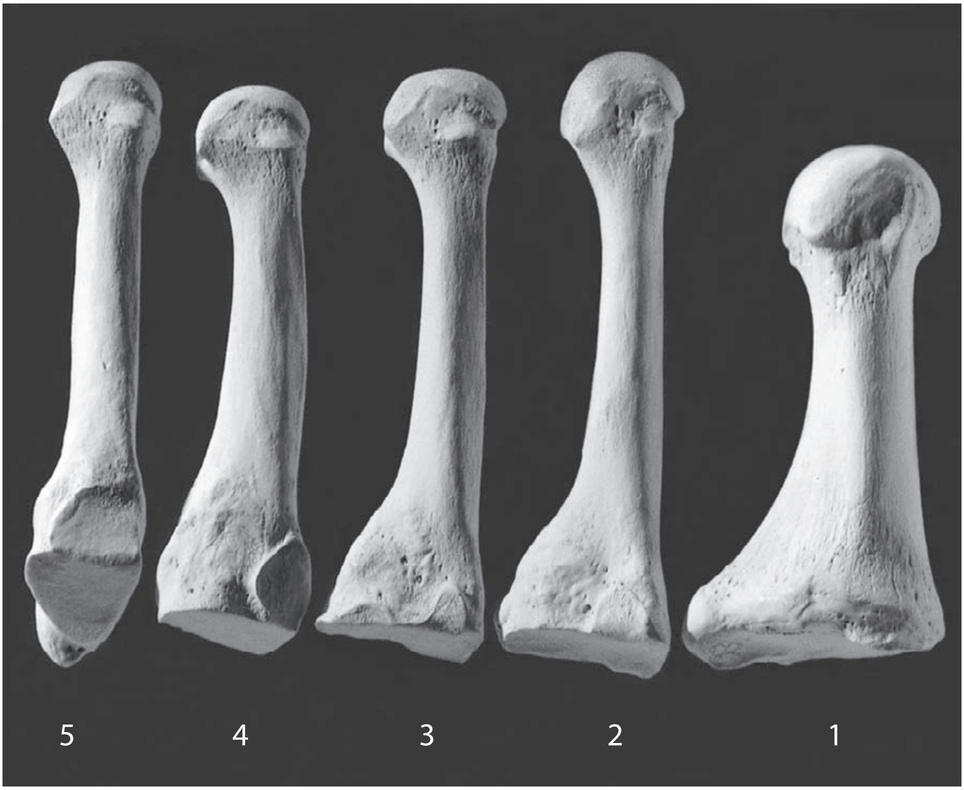


Figure 16.20 **Right metatarsals, medial.** Distal is up. Natural size.

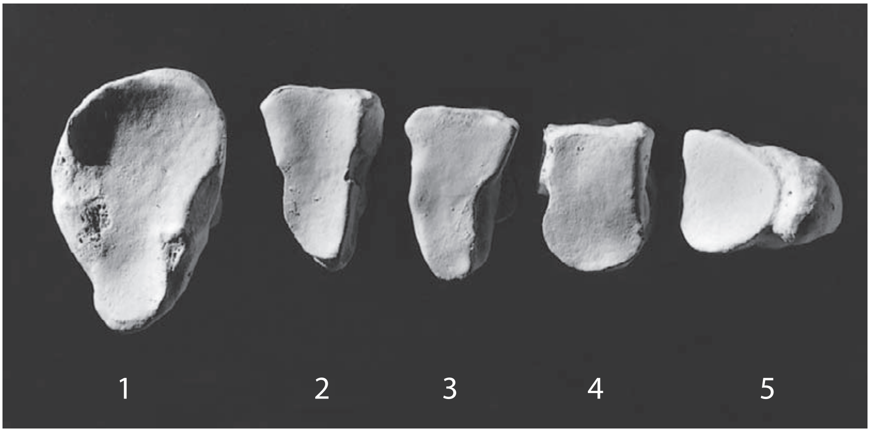


Figure 16.21 **Right metatarsal bases, proximal.** Dorsal is up. Natural size.

plantarflexor of the big toe.

- **Siding.** The basal facet has a convex medial profile and a straight lateral profile.

16.2.2 Second Metatarsal

The second metatarsal is the longest and narrowest metatarsal. It has two lateral facets at the base, each articularing with the lateral cuneiform and MT 3. It articulates proximally with the intermediate cuneiform and medially with the medial cuneiform. Its base has slightly more of a "styloid" appearance than the base of MT 3.

- **Siding.** The most proximal point on the base is lateral to the main shaft axis.

16.2.3 Third Metatarsal

The third metatarsal is very similar to MT 2, but its base has two medial basal facets that are smaller than MT 2 lateral facets. The lateral basal facet is single and large. The base is squarer than the MT 2 base, and there is a large, bulging tubercle distal to the lateral articular facet. The base articulates with MT 2 and MT 4 and with the lateral cuneiform.

- **Siding.** The most proximal point on the base is lateral to the main shaft axis.

16.2.4 Fourth Metatarsal

The fourth metatarsal is shorter than MT 2 or MT 3. It has single medial and lateral basal facets for articulation with MT 3 and MT 5. The proximal facet for the cuboid is fairly oval.

- **Siding.** The most proximal point on the base is lateral to the main shaft axis.

16.2.5 Fifth Metatarsal

The fifth metatarsal bears a **styloid process**, a distinctive, blunt, nonarticular basal projection. It is lateral, opposite the MT 4 facet, and projects proximally. It is the insertion point for the *tendon of the peroneus brevis muscle*, a calf muscle that acts to plantarflex and evert the foot at the ankle. The proximal basal articulation is for the cuboid.

- **Siding.** The styloid process is lateral. Groove on the base of the tubercle is inferior.

16.2.6 Growth (Figure 16.22)

Metatarsals each ossify from two centers. For MT 2, MT 3, MT 4, and MT 5, there is one center for both the base and shaft and a second for the distal end. For the MT 1, there is one center for the body and one for the proximal end.

16.2.7 Possible Confusion

Metatarsals and metacarpals are similar in gross size and shape but are easily distinguished from each other. Metatarsal 2, MT 3, MT 4, and MT 5 are longer than MC 2, MC 3, MC 4, and MC 5, with straighter and narrower shafts. Metatarsal heads are compressed more mediolaterally and are smaller relative to their bases than metacarpal heads.

16.2.8 Siding

Metatarsal bases are always proximal, and the most proximal part of the base is always lateral on MT 2, MT 3, MT 4, and MT 5.

16.3 Foot Phalanges (Figures 16.17–16.19)

Foot phalanges share a common basic design (heads, bases, and shafts) with hand phalanges (see Section 13.3).

16.3.1 Proximal Foot Phalanges

Each proximal foot phalanx displays a single, concave proximal facet for the metatarsal head, and a spool-shaped, or trochlear, surface distally. The hallucial proximal phalanx is larger and stouter than the others.

16.3.2 Intermediate Foot Phalanges

Each intermediate foot phalanx displays a double proximal articular facet for the head of the proximal phalanx. Each also has a trochlea-shaped distal articular facet. These phalanges are "stunted," squat versions of their analogs in the hand.

16.3.3 Distal Foot Phalanges

Each distal foot phalanx displays a double proximal articular facet for the head of the intermediate phalanx, but the terminal tip of the bone is a nonarticular pad, the **distal**

Figure 16.22 Metatarsal growth. The pairs of immature metatarsals are shown here in plantar view, with ray 1 on the left and ray 5 on the right. They are from one-year-old and six-year-old individuals. Natural size.

Figure 16.23 **Sesamoids of the right foot.** superior (dorsal) view (*left*); lateral view (*right*).

phalangeal tubercle (tuft). These phalanges are very small and stubby compared to distal hand phalanges.

16.3.4 Growth

Foot phalanges each ossify from two centers, one for the shaft and distal end and one for the base.

16.3.5 Possible Confusion

Hand and foot phalanges are easily distinguished, even when isolated. Foot phalanges are all much shorter than their analogs in the hand.

- Proximal foot phalanges are the only ones that might be mistaken for hand phalanges.
- Phalangeal shafts in the hand are compressed dorsoventrally, forming a D-shape in cross section, while those in the foot are more circular in cross section.
- Foot phalanges display more constriction at midshaft than hand phalanges.
- The hallux has only a proximal and a morphologically distal phalanx, and these squat, massive bones are very distinctive.

16.3.6 Siding

For siding hand and foot phalanges it is best to work with whole specimens and comparative materials. The head is distal, and the base is proximal. The dorsal phalangeal shaft surfaces are smooth and straight, whereas the plantar surfaces are more irregular and curved.

Chapter 17

Osteological & Dental Pathology

In Chapter 4, on bone biology, we introduced the concept of variation and its importance to work in human osteology. We described this variation as stemming from four main sources: age, sex, ancestry, and idiosyncrasy. Many facets of human osteological variation are illustrated by the descriptions of the various skeletal elements in Chapters 7–16, and by the analysis of age, sex, ancestry, and stature presented in Chapter 19. This chapter continues to consider variation, concentrating on variation due to pathology. Nonmetric, nonpathological variations (discrete traits) are essential in reconstructing various biological dimensions of former human populations. These are reviewed in Chapter 19.

This chapter introduces a variety of biological processes that can result in skeletal modifications before death (**antemortem**). Cultural practices that take place just before or after death (**perimortem**) are also examined. Here, the discussion of skeletal modifications focuses on pathological conditions. Chapter 5 examined some additional perimortem modifications, but there we concentrated on changes to the bone that occur at or after the death of the individual (**postmortem changes**). The reader should note that the most critical step in recording paleopathological conditions is the recognition of true bone abnormalities, as opposed to those within the normal range of variation in immature and adult healthy individuals.

Paleoepidemiology is the study of disease in a past community. **Paleopathology** is the study of diseases in ancient populations as revealed by skeletal remains and preserved soft tissues. Bones and teeth can be records of events in the life of an individual, including trauma and disease. Indeed, dramatic insights into the health of individuals, and of populations, may be gained from studies in osteological pathology. As Miller and colleagues (1996) note, the objectives of paleopathological research include diagnosing specific diseases in individual skeletal remains and examining the populational and evolutionary effects of these interactions between humans and the diseases that afflict them.

Pathological changes observable in osteological materials result from an imbalance in the normal equilibrium of bone resorption and formation, or growth-related disorders. This imbalance can arise as a result of many factors, including mechanical stress, changes in blood supply, inflammation of soft tissues, changes brought about by infectious diseases, hormonal, nutritional and metabolic upsets, and tumors (Mensforth *et al.*, 1978). Diagnosing the exact cause of an observed skeletal pathology is, however, not always possible. For example, an individual's growth may be interrupted by a range of factors that include infectious disease, starvation, or trauma. This growth arrest may lead to the formation of **Harris lines** in the long bones, lines of increased bone density that represent the position of the growth plate at the time of insult to the organism. The lines are visible radiographically, or in cross section, and may be used to estimate the age at which the individual was stressed.

Radiographic assessment is an essential component of describing and diagnosing disease in skeletal remains. Observations on different individuals may be combined to estimate the degree to which the population was stressed. From the Harris lines themselves, however, only general statements about the variety of possible stressors (including disease and diet) may be made (Maat, 1984; Hummert and Van Gerven, 1985). Furthermore, the lines may be removed by bone remodeling after they form. These Harris lines illustrate yet another problem common to comparative work in paleopathology. Macchiarelli and colleagues (1994) have shown that **interobserver error** may be high in radiographic interpretations, and even the scoring of the same radiographs by the same individual on different occasions (**intraobserver error**) can result in reported differences. Waldron and Rogers (1991) echo these concerns based on a study of interobserver variation in coding osteoarthritis in skeletal remains.

The osteologist is at a decided disadvantage compared to the forensic pathologist or clinician. Whereas a clinician can monitor progress of a disease in a patient, the paleopathologist is limited to the static appearance of the skeleton at the time of death. Furthermore, in the majority of paleopathology cases, diagnosis is necessarily based on gross appearance and radiology. In contrast, the clinician diagnosing disease in a living patient can assess patient history, soft tissue, chemistry, pathogens, and pain. It follows that paleopathological diagnoses based on skeletal lesions will rarely have the precision routinely encountered in clinical settings. Developments in molecular biology, however, are opening new doors for the paleopathologist.

A number of diseases are genetic in nature and could potentially be detected in past populations using DNA analysis. Disease processes characterized by long-term infection by substantial densities of viral or bacterial pathogens might also be detected through recovery of the DNA of the pathogen. As yet, very few studies of paleopathology have utilized DNA methods. An early application was amplification of the *Mycobacterium tuberculosis* DNA from a Peruvian mummy to verify a pre-Columbian occurrence of tuberculosis in the New World (Salo *et al.*, 1994).

Unfortunately, few diseases leave signatures of any kind on the human skeleton, and those that do may cause very similar skeletal reactions. The only real advantage that the osteologist has in studying pathology is the ability to study the entire skeleton at once, without soft tissue cover. For these reasons, Steinbock (1976) suggested that the most rational approach to differential diagnosis in human skeletal pathology is to state the most likely diagnosis followed by a list of possible alternatives in order of decreasing likelihood.

As Miller *et al.* (1996) note, there are two major impediments to paleopathological work. First, there is a paucity of well-documented, clinically diagnosed skeletal samples to use as controls against which unknown skeletal samples (forensic, archeological, or paleontological) may be compared. The second problem lies with the difficulty in finding skeletal abnormalities, or patterns of abnormalities, that are unique to individual disease categories. Miller and colleagues (1996) suggest that paleopathologies be diagnosed and classified in one of seven categories: (1) anomaly, (2) trauma repair, (3) inflammatory/immune, (4) circulatory (vascular), (5) metabolic, (6) neuromechanical, or (7) neoplastic (cancers). In a series of blind tests, these authors found that even trained specialists working on skeletal remains only achieved accuracies of about 43% at this broad diagnostic level, while only about 30% of more specific diagnoses were accurate. Buikstra and Ubelaker's Standards volume (1994) advocates the division of paleopathological changes into nine categories: (1) abnormalities of shape, (2) abnormalities of size, (3) bone loss, (4) abnormal bone formation, (5) fractures and dislocations, (6) porotic hyperostosis/cribra orbitalia, (7) vertebral pathology, (8) arthritis, and (9) miscellaneous conditions.

The first step in any paleopathological analysis is to establish the envelope of what is normal in size, shape, and topography for a healthy human's skeleton. When skeletal remains fall outside that envelope, pathology is one possible explanation. There are two basic steps to paleopathological work. The first is description and the second is diagnosis. Diagnosis will rarely approach what is possible in the clinical setting because bone usually responds to insults by either resorbing or depositing, and it may therefore easily respond to different diseases in very similar ways. Description is the most important step in paleopathological work because even if the following diagnosis is incorrect, other workers can come along later and amend or modify the diagnosis.

In any description, identify the nature and distribution of anomalies across the skeleton and observe the pattern of distribution of these anomalies across the population. These anomalies can take the form of lesions or of changes in size or shape. Note the distribution of all lesions, whether single, multiple, diffuse, or concentrated. Note if bone is eaten away (lytic) or deposited (blastic). Check all bones of the skeleton for further evidence. Techniques and methods for paleopathological diagnosis may include, in addition to gross anatomy, radiographs, histology, microradiographs, scanning electron micrographs, chemical analysis, serology, and DNA techniques.

Books by Roberts and Manchester (1995), Steinbock (1976), Ortner and Putschar (1981), Ortner (2003), and an encyclopedia by Aufderheide and Rodriguez-Martin (1998) provide excellent guides to osteological pathology and Lewis (2000) provides a status report on paleopathology for non-adults. Additional illustrations and techniques are found in Buikstra and Ubelaker (1994) and Lovell (2000). The reader is urged to consult these sources when working with potentially pathological human skeletal remains. This chapter is intended to supplement these texts and is organized accordingly. It is designed to provide the reader with an introduction to the kinds of dental and osteological pathology encountered most commonly in work with prehistoric skeletal remains. All illustrated examples of osteological pathology are drawn from the Berkeley Primate Skeletal Collection, most of them from archeological contexts. In summarizing work on this collection, Richards and Antón (1987) note that in the five thousand individuals examined, over one-fifth showed anomalous development or the effects of pathological processes. Their data show that degenerative joint disease, periodontal disease, fracture, and osteomyelitis are the leading changes observed in this mostly prehistoric Californian collection.

Figure 17.1 **Healed fracture.** This left clavicle shows a postmortem fracture (the light-colored bone around the crack visible in this inferior view) and a more medial antemortem fracture that has healed. The original shaft surfaces are joined by a bony callus. The radiograph shows that the medial end of this clavicle rotated counterclockwise relative to its lateral end, resulting in a dramatic misalignment of the fractured pieces during and after healing. Prehistoric, California. One-half natural size.

17.1 Trauma

The most common pathology affecting the skeleton is degenerative change. Trauma occupies second place and affects the skeleton in several ways — fracturing or dislocating the bone, disrupting its blood or nerve supply, or artificially deforming it. See Martin and Frayer (1997) for how studies of osteological trauma have been employed to investigate violence and warfare in the past.

17.1.1 Fracture

Fracture in a bone occurs as a result of abnormal forces of tension, compression, torsion, bending, or shear applied to the bone. Several possible types of gross fracture in a bone may result from this abnormal stress (Figures 17.1 and 17.2). A **complete fracture** is one in which broken ends of a bone become separated. An **incomplete**, or "**greenstick**," fracture (infraction) is one in which breakage and bending of a bone are combined. A **comminuted fracture** is one in which the bone splinters, whereas a **compound fracture** is a fracture in which the broken bone perforates the skin. Some fractures of bone are attributable to other pathological causes—**pathological fracture** occurs as a result of bones already having been weakened by other pathological or metabolic conditions such as osteoporosis.

Fractures of bones are often described by the features of the break itself: comminuted when there is shattering of bone, compressed when the bone is squeezed, or depressed when bone fragments are depressed below the adjacent surface.

Figure 17.2 **Healed fracture.** (*Above*) This left radius has a healed midshaft fracture. The radiograph shows that the fracture offset is about equal to the width of the bone. The proximal part of the bone is offset posteriorly. Prehistoric, California. One-half natural size.

Figure 17.3 **Pseudarthrosis.** (*Right*) This left humerus was broken just above the midshaft. The fracture failed to heal (a nonunion), resulting in continued movement, which formed the false joint. Prehistoric, California. One-half natural size.

Fracture healing is described in Chapter 4. Antemortem fracture may be differentiated from postmortem fracture only when a callus, the hard tissue formed at the site of a broken bone during the healing process, is present. All other fractures that occur at or around the time of death should be diagnosed as perimortem. Full fracture healing can completely remove any gross signs of fracture, even in a radiograph. The rate of fracture repair depends on fragment alignment, the amount of movement at the site of fracture, and the health, age, diet, and blood supply of the individual. Some fractures never heal because of continued movement at the broken surface. Nonunions develop most frequently in the appendicular skeleton. It is possible that a new "joint," or **pseudarthrosis**, will form at the fracture site (Figure 17.3).

Trauma such as sword cuts or arrow perforations to bones constitute special kinds of fractures. Such wounds are capable of healing through the same processes described in Chapter 4. In any kind of fracture, adjacent bone is susceptible to subsequent pathological complications such as infection, tissue death, deformity, and arthritis brought on by the initial trauma.

The analysis of fractures at the populational level can be very informative in addressing questions of prehistoric behavior. For example, Lovejoy and Heiple (1981) assessed the Libben population and found that the overall fracture rate was high. The low incidence of fractures in children suggested that traumatic child abuse was not practiced. The results of their analysis also suggested that fracture risk was highest in the 10–25 and 45+ age categories and that the care of patients was enlightened and skillful among this Native American group.

17.1.2 Dislocation

In addition to causing bone fracture, trauma to the skeleton can also involve movement of joint participants out of contact with the simultaneous disruption of the joint capsule. If the bones participating in the joint remain dislocated, the result may be diagnosed osteologically (Figure 17.4). When the joint is dislocated, the articular cartilage cannot obtain nourishment from the synovial fluid, the cartilage disintegrates, and arthritic changes occur. Osteological manifestations of dislocation are usually confined to adults. The violent trauma necessary for dislocation usually separates the epiphyses in subadults, and slipped femoral epiphyses are common in juveniles. In the elderly, the more brittle bone usually gives way, fracturing prior to dislocation. The two joints most often displaying osteological manifestations of dislocation are the shoulder and hip joints.

17.1.3 Artificial Deformation

Fracture and dislocation described earlier result from sudden trauma to the skeleton, but long-term trauma can also modify the shape of a bone. Deformities of this kind are induced most often as a result of cultural practices such as cradleboarding, massaging, or binding the crania of infants. Another example is the foot-binding practiced by Chinese women of high status. The most common manifestations of artificial deformation of the skeleton are those of the cranium. Cultures around the world have, for

Figure 17.4 **Dislocation.** This left hip joint shows that the femoral head dislocated anterosuperiorly from its original place within the acetabulum. The cross section of the femoral neck is seen in the postexcavation break, which faces the viewer. Osteoarthritis secondary to the trauma is evident. Prehistoric, California. One-half natural size.

cosmetic reasons, altered the shape of the adult head by placing abnormal pressures on the developing skull. Ortner and Putschar (1981) describe this practice by people on every continent except Australia, but Brown's (1981) work there suggests that the practice was continentally ubiquitous. Both cultural and biological information can come from the analysis of intentionally deformed crania. For example, Antón (1989) has used intentional anteroposterior and circumferential cranial vault deformation in a Peruvian sample to study the relationship between the cranial vault and the base in the development of the craniofacial complex. O'Loughlin (2004) notes the effect of cranial deformation increasing wormian bone number. Some examples of artificial cranial deformation are illustrated in Figures 17.5 and 17.6.

17.1.4 Trephination and Amputation

Ortner and Putschar (1981) describe **trephination**, or **trepanation**, as perhaps the most remarkable trauma seen by the paleopathologist (Figure 17.7). Written accounts documenting this practice extend to the ancient Greeks, but archeological work has traced it even more deeply into the past. The practice is known from Europe, the Pacific, both Americas, Africa, and Asia. Several techniques have been used to make an artificial hole in the cranial vault, including scraping a patch of bone away, cutting a bone patch out by cutting grooves through the vault, and drilling small holes around the plug of bone to be removed. The practice was probably undertaken to yield relief from intracranial pressure (especially from compressive fractures of the skull vault) and to relieve headaches, cure mental illness, or let out evil spirits. The success rate for this prehistoric surgery, as judged by subsequent healing around the hole, was often

Figure 17.5 **Artificial cranial deformation.** Circumferential deformation is produced by wrapping the rear of the cranial vault. Prehistoric, Peru. One-half natural size.

Figure 17.6 **Artificial cranial deformation.** Anteroposterior deformation is caused by the application of pressure from behind. Prehistoric, Peru. One-half natural size.

surprisingly high. Some postmortem trephination was done to fashion amulets for the adornment of survivors. Arnott *et al.* (2003) provide an overview of trephination.

Evidence of amputation may be observed on the skeleton in the form of missing appendages or parts of appendages. Diagnosing antemortem from perimortem amputation, again, depends on the presence of healing or infection of the bone tissue at the point of trauma.

17.2 Infectious Diseases and Associated Manifestations

Infectious disease has long been a major cause of death in human populations. Unfortunately, dealing with osteological evidence of infectious disease can be frustrating because few infectious diseases leave any direct evidence of their existence in the skeleton. Many of the chronic infectious diseases that *do* leave osteological signs produce morphologically overlapping responses, making differential diagnosis impossible.

Osteitis is a general term for an inflammation of bone tissue caused by infection or injury and is not specific as to cause. The terms **osteomyelitis** and **periostitis** are slightly more confusing because they serve to generally describe osteological conditions as well as to identify specific diseases; periostitis is a symptom in a disease syndrome such as syphilis, but it is also common in many other diseases (Ortner and Putschar, 1981).

Figure 17.7 **Trephination.** Three artificially produced holes are evident on this three-quarter view of a cranium. The hole closest to the parietal boss is nearly completely obliterated by healing. The other holes also show substantial bony healing, indicating that the individual survived the operations. Prehistoric, Peru. One-half natural size.

17.2.1 Osteomyelitis

Osteomyelitis is bone inflammation caused by bacteria that usually initially enter the bone via a wound. This disease mainly affects the long bones (Figure 17.8) and is defined as an infection that involves the medullary cavity. However, usage in the paleopathology literature has often been imprecise. Osteomyelitis is almost always caused by pus-producing microorganisms (90% of the time by *Staphylococcus aureus*) and is thus called **suppurative**, or **pyogenic osteomyelitis**. The microorganisms can reach the bone directly, as a result of injury at any age, or via the bloodstream (hematogenous osteomyelitis, most often found in children). Characteristic hard tissue manifestations include an **involucrum** of coarsely woven bone around the original long bone cortex and one or more openings for pus drainage called **cloacae** (**fistulae**). The latter open through the involucrum.

17.2.2 Periostitis

Periostitis is a condition of inflammation of the periosteum caused by trauma or infection. It is not a disease. See Mensforth *et al.* (1978) for a complete review of its various etiologies. These authors demonstrate an age-specific distribution of periosteal reactions that seems to coincide with — and be a response to — infectious disease in infants and children in the prehistoric Libben population. Periostitis involves only the outer (cortical) bone, without involvement of the marrow cavity (as in osteomyelitis). It can be acute or chronic and it occurs any time the inner surface of the periosteum reacts to insult by forming woven bone that sleeves the underlying cortical bone (Figure 17.9).

17.2.3 Tuberculosis

Tuberculosis is a chronic infectious disease that results from a bacterium, *Mycobacterium tuberculosis*. Infection is usually via the respiratory system, but other body parts, including bones, can also be affected. Bone and joint destruction can result from the infection. The presence of pre-Columbian tuberculosis in the New World is assessed by Buikstra (1981b) and Roberts and Buikstra (2003). Molecular work by Salo and colleagues confirmed osteological observations in 1994. A variety of bones can be affected by tuberculosis, but the vertebral column is the most common primary focus. The most common manifestation (when viewed from the side) is the collapse of one or several vertebral bodies causing a sharp angle in the spine (**kyphosis**). Differential diagnoses from osteomyelitis and septic arthritis are often possible because tuberculosis shows destruction and cavitation in cancellous bone, without extensive associated reactive bone. The pattern of element involvement, with the vertebrae and os coxae as foci, marks tuberculosis. In addition, there is no evidence of sequestration, an involucrum, or fusion of the joints. Ortner and Putschar (1981) discuss and illustrate the skeletal effects of tuberculosis.

Figure 17.8 **Osteomyelitis.** The tibia on the left shows localized reactive bone and a cloaca, whereas that on the right shows the result of a more extensive reaction to the infection. Radiographs of the two bones show clear involvement of the medullary cavity. Prehistoric, California. One-half natural size.

17.2.4 Treponemal Infections

Skeletally significant diseases caused by a microorganism known as a spirochaete (in the genus *Treponema*) are yaws and endemic and venereal syphilis. These diseases have a worldwide distribution today, but considerable controversy exists over their origins and distribution several hundred years ago. Debate centers on whether syphilis (misdiagnosed as leprosy) was present in the Old World before Columbus returned from the New World. The controversy is well-reviewed by both Steinbock (1976) and Ortner and Putschar (1981), with a more recent update by Baker and Armelagos (1988).

In syphilis, the microorganisms enter the body through the skin or mucous membrane sites. Tertiary syphilitic skeletal lesions occur progressively, usually beginning between 2 and 10 years after infection. These can be complex, but there is usually an osteological focus of the disease in the frontal and parietals, the facial skeleton, and the tibia. Individual lesions may not be distinguishable from some cancers, tuberculosis, or other infectious changes. Steinbock (1976), Ortner and Putschar (1981), and Buckley and Dias (2002) provide further details.

17.3 Circulatory Disturbances and Hematopoietic Disorders

When blood supply to bones (see Chapter 4) is upset by trauma or other diseases, a variety of bony manifestations can occur, including death of bone tissue. Anemias can also affect the gross appearance of bones. Iron deficiencies, sickle cell anemia, and thalassemia all result in the expansion of spaces occupied by hematopoietic marrow within the bones. The result is often visible in the skull, with a widening of the diploë leading to a thickening of the cranial vault. Zimmerman and Kelley (1982) attempt a differential diagnosis of different types of anemias.

Porotic hyperostosis, or **spongy hyperostosis**, is a condition exhibiting lesions, usually of the cranial vault. These represent a thinning and often complete destruction of the outer table of the cranial vault that results in a sieve-like or "coral-like" appearance of the ectocranial surface. The lesions seem to be caused by anemia-associated hypertrophy of the diploë between the inner and the outer tables. Porotic hyperostosis is most often seen in immature individuals and is recognizable as a porosity of the cranial vault. It is usually bilaterally symmetrical, focused on the parietals and the anterolateral quadrant of the orbital roofs. The orbital lesions are called **cribra orbitalia**, and a similar disturbance of the endocranial surface is called **cribra cranii** (Figure 17.10).

Causes of this bony reaction have been extensively speculated. Its high frequency in the southwest of North America was once thought to be because of a maize-based, iron-deficient diet. However, work on the phenomenon in a large sample of California skeletons (nonagricultural, fish-dependent) by Walker (1986) suggested that porotic hyperostosis is sometimes due to nutrient losses associated with diarrheal diseases rather than to diet *per se*, a position supported by Kent (1987). In a study of skeletal remains from the prehistoric southwest, Palkovich (1987) suggests that endemically inadequate maternal diet can combine with infection to produce very early onset of iron-deficient anemia with resultant porotic hyperostosis. Research by Stuart-Macadam (1987a, b) stresses the association between osteological manifestations and anemia,

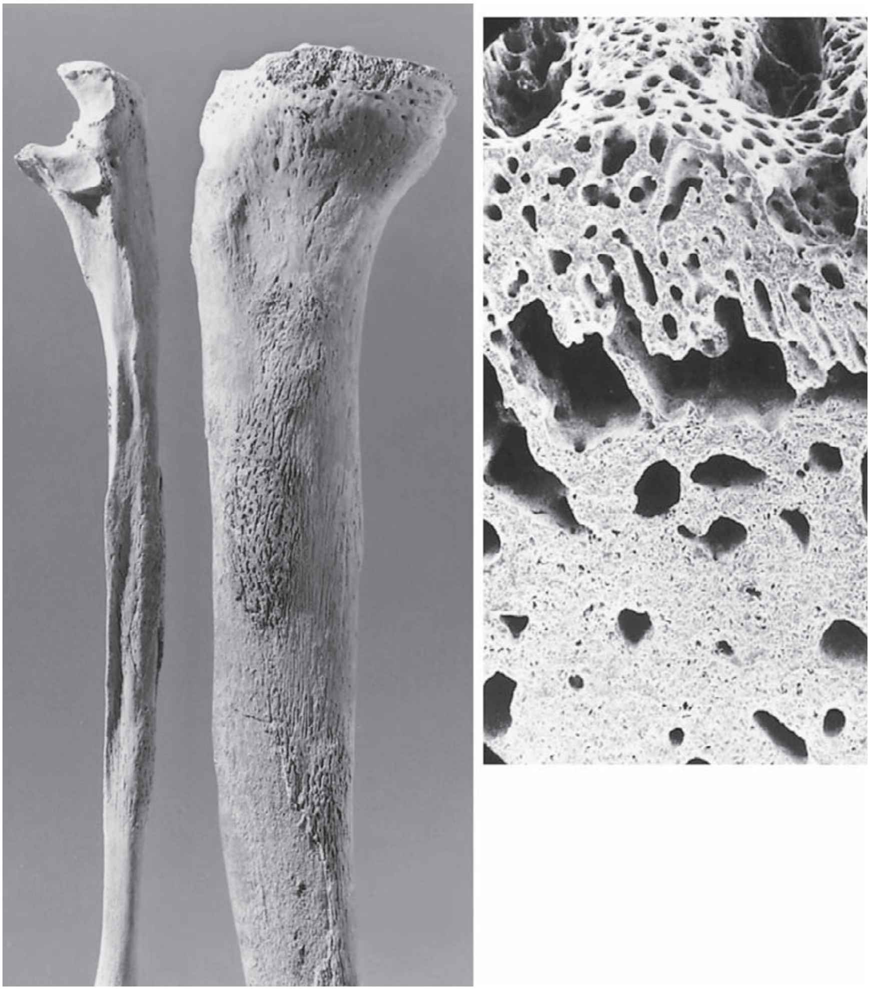


Figure 17.9 **Periostitis.** (*left*) The right tibia and left ulna of the same individual show reactive bone that overlies the cortex. In gross aspect the postmortem exfoliation of reactive bone has exposed the underlying cortex on the posterior ulnar edge. Prehistoric, California. One-half natural size. (*right*) The scanning electron micrograph shows a cross section through the surface of a similarly affected individual. Scale: approximately 20×.

a subject further reviewed by Wapler *et al.* (2004). Using the prehistoric Libben sample, Mensforth *et al.* (1978) demonstrate that porotic hyperostosis is commonly caused by the normal sequelae of infection. As noted earlier, they found a direct relationship between periostitis (infection) and porotic hyperostitis (iron deficiency) in subadults. This is consistent with clinical data that suggest that iron may be sequestered within the body as a defense against infection. Thus, much prehistoric porotic hyperostosis may be the secondary consequence of infectious disease, not of diet. Indeed, Stuart-Macadam (1991) posits that porotic hyperostosis is the result of an interaction among customs, diet, hygiene, parasites, and infectious diseases. She feels evidence for chronic disease in skeletal material should not be interpreted as an individual's inability to adapt to the environment but rather as evidence of the individual's fight for health against the pathogen.

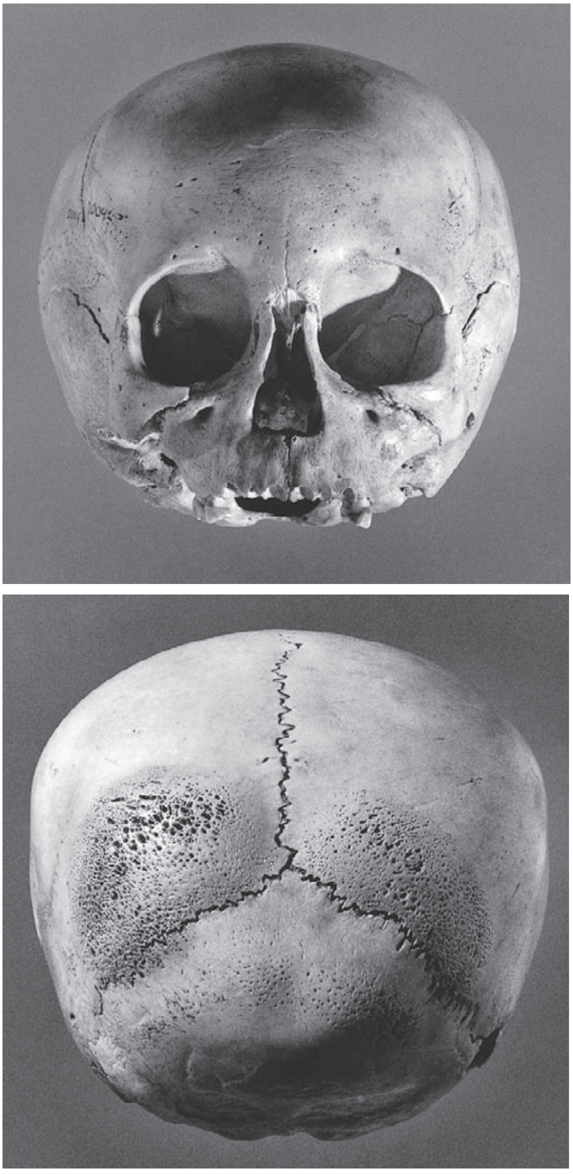


Figure 17.10 **Cribra orbitalia, porotic hyperostosis.** The skull of a 5-year-old child is shown in anteroinferior and posterior views to display the cribra orbitalia of the frontal (in the roofs of the orbits) and spongy hyperostosis of the parietals and occipital. Prehistoric, Peru. One-half natural size.

17.4 Metabolic and Hormonal Imbalance

Narrowly defined, metabolic disorders of bone are disorders in which a reduction in bone mass is the result of inadequate osteoid production, or mineralization or excessive deossification of bone. Nutritional deficiencies are usually classified under metabolic disorders. Hormonal disturbances can also lead to dramatic changes in normal skeletal anatomy.

17.4.1 Scurvy

Scurvy is a metabolic disease caused by a long-term insufficient intake of vitamin C, which is essential for the production of collagen and, therefore, osteoid. Skeletal manifestations are most apparent in infants, usually in the form of cortical thinning and pathological fractures in rapidly growing bone areas. Maat (2004) provides a useful review and case study.

17.4.2 Rickets

Rickets is most often a nutritional disease resulting from an insufficient amount of vitamin D in the diet that causes a failure of mineral deposition in the bone tissue. As a result, excessive uncalcified osteoid accumulates, and the bone tissue remains soft and flexible. The disease was described in the 1600s, but its nutritional source was not discovered until the 1920s. The osteological effects of rickets are present throughout the skeleton, but they are most pronounced in the limbs, which are usually bent and distorted. The legs are characteristically bowed outward or inward. In adults, the same dietary deficiency is called osteomalacia, a disease usually linked to general malnutrition, particularly to deficiencies in protein, fat, calcium, and phosphorus. Its greatest effect is on bones in which remodeling is highest (ribs, sternum, vertebrae, and pelvis), making them subject to pathological fracture.

17.4.3 Osteoporosis

Osteoporosis, or **osteopenia** in the nonclinical situation, refers to the increased porosity (reduced density) of bone that is most often part of the aging process. It is a consequence of the failure of the organism to maintain the balance between bone resorption and formation. Postmenopausal women are most at risk for osteoporosis because of the cessation of estrogen production. Males are endowed initially with more bone mass than females and so do not become vulnerable to osteoporosis until later in life (in their 70s and 80s). It is estimated that annual costs associated with osteoporosis in the United States alone involve $7 billion. Osteoporosis is associated with 1.2 million bone fractures in the elderly each year. Research into basic bone biology, particularly into the factors that activate and inactivate osteoclasts, has been spurred on by these statistics. Agarwal and Stout (2003) provide an anthropological perspective on osteoporosis.

17.4.4 Endocrine Disturbances and Dysplasias

The growth of the skeleton is controlled, in large part, by the secretion of hormones in the pituitary and thyroid. Pathology in these glands can lead to extreme skeletal changes. **Gigantism** results from excessive production of somatotrophic hormone and consequent overstimulation of growth cartilages and gigantic proportions of the skeleton. **Acromegaly** is similarly caused by an overly productive pituitary, but after the epiphyses are fused. The most dramatic osteological manifestation of acromegaly is growth at the mandibular condyle and a resulting elongation and distortion of the lower jaw. **Dwarfism** is caused by a variety of conditions. **Achondroplasia** is a hereditary form of dwarfism with limb shortening, almost normal trunk and vault development, and a small face (Figure 17.11). It is a hereditary disease caused by the congenital disturbance of cartilage formation at the epiphyses, a skeletal dysplasia rather than an endocrine disturbance.

Figure 17.11 **Achondroplasia.** The left humerus and left femur of an achondroplastic dwarf (*far left* and *far right*) are compared with a normal human humerus and femur from a single individual (*center*). Note the disproportions and fully adult status of the achondroplastic individual. Prehistoric, California. One-fourth natural size.

17.5 Tumors

Osteogenic **sarcoma** is more common than bony cancer resulting from metastasis. Skeletal tumors usually stem from other tissue sources, and their appearance can be very dramatic. Modern classifications of skeletal tumors name over forty different tumor types in bone and associated cartilage and fibrous connective tissue. Histological specimens and biochemical data are usually needed to sort these out. Tumors are divided somewhat arbitrarily into benign or malignant and are classified according to the tissues in which they originate. **Multiple myeloma**, for example, is a rare primary malignant tumor of hematopoietic tissue. Its effect on bone tissues is a widespread pattern of lytic lesions on various skeletal elements.

The most common tumor of bone is an **osteochondroma**. These are benign tumors, usually asymptomatic. They always arise at epiphyseal lines and protrude at right angles to the long axis of a bone. They resemble ossified tendons in many cases. An **osteoma** is a mound of compact bone, usually on the ectocranial surface; these are often called "button" osteomata (Eshed *et al.*, 2002). They are hard, dense, and ivory-like in appearance and occur in about 1% of all people. **Ear exostoses** are "osteomata" of the inner aspect of the external auditory meatus.

The most commonly formed osteogenic sarcomas occur during the growth period. These include **osteosarcomata**, **chondrosarcomata**, and **Ewing's sarcomata**. Both Steinbock (1976) and Ortner and Putschar (1981) provide good information on these rare cancers.

17.6 Arthritis

Arthritis is the inflammation of a joint—a general inflammation that includes soft tissue effects. The inflammation can come as a result of trauma as well as of bone and joint infections (see Rogers *et al.*, 1987, for a summary and classification).

17.6.1 Osteoarthritis

Osteoarthritis, the most common form of arthritis, is characterized by destruction of the articular cartilage in a joint and formation of adjacent bone, in the form of bony lipping and spur formation (**osteophytes**), around the edges of the joint. A better term for this phenomenon is **degenerative joint disease** (Figures 17.12–17.14). The causes of this disease are, for the most part, mechanical. The disease occurs mostly in load-bearing joints, particularly in the spine, the hip, and the knees. Osteoarthritis is an inherent part of the aging process. For a review of current knowledge about osteoarthritis, consult Epstein (1989), and for a review of prehistoric arthritis in the Americas, see Bridges (1992).

Osteoarthritis is usually classified as either primary, resulting from a combination of factors that include age, sex, hormones, mechanical stress, and genetic predisposition, or secondary, initiated by trauma or another cause such as the invasion of the joint by bacteria (**septic**, or **pyogenic arthritis**—often a complication of osteomyelitis). Studies of the patterning of osteoarthritic lesions of the skeleton at the individual

Figure 17.12 **Osteoarthritis**. The normal lumbar vertebra (*left*) lacks the osteophyte development seen on the anterior and lateral edges of the vertebra with degenerative arthritis (*right*). Prehistoric, California. One-half natural size.

Figure 17.13 **Osteoarthritis**. Eburnation and marginal lipping are evident on this left knee joint, seen here in posterolateral view and lit from the lower right to show detail. The eburnation is the ivory-like, shiny patch on the medial femoral and tibial condyles. Prehistoric, California. One-half natural size.

Figure 17.14
Osteoarthritis. Trauma to this left femur produced secondary osteoarthritic changes to the joint, seen here in the form of a bony extension and deformation of the femoral head and a buildup of osteophytes around the perimeter of the acetabulum. Prehistoric, California. One-third natural size.

and at the population level can shed light on prehistoric activity patterns. For example, Merbs (1983) was able to show that osteoarthritic changes seen in female Hudson Bay Inuit skeletons correlated with ethnographic accounts and archeological evidence for scraping and cutting animal hides and sewing, whereas lesions seen in males correlated with harpoon throwing and kayak paddling.

A phenomenon often found associated with osteoarthritis is **eburnation**, the result of subchondral bone being exposed when cartilage is destroyed. Bone affected this way takes on a polished, ivory-like appearance (Figure 17.13). The projecting spicules of bone associated with osteoarthritis are called osteophytes. Nearly all individuals older than 60 years exhibit these arthritic features, especially in the lower thoracic and lumbar regions. Rogers *et al.* (1987, 1989) assess classifications of osteoarthritis, and Bridges (1993) notes that the scoring procedures used to record the disease seriously affect the results of any comparative study.

17.6.2 Rheumatoid Arthritis

Middle-aged women have a predisposition for this arthritis. Its exact cause remains unknown but almost certainly varies with genetic background. In rheumatoid arthritis, the immune system of the body attacks its own cartilage. Bone changes are atrophic and are especially focused in the hands and feet. The lesions are usually bilaterally symmetrical. Rheumatoid arthritis is the least common arthropathy in archeological skeletal material. Woods and Rothschild (1988) argue that it is evidenced in New World skeletal remains, and Rothschild *et al.* (1990) propose recognition criteria for skeletal remains.

17.6.3 Ankylosing Spondylitis

An **ankylosis** is an abnormal immobility or fixation of a joint resulting from pathological changes in the joint. **Ankylosing spondylitis** is a chronic and usually progressive disease that affects the vertebral column. The associated ligaments of the spine ossify, and the intervertebral joints become immobilized.

17.7 Dental Pathology

Because the teeth interact directly with the environment, they are susceptible to damage from physical and biological influences not operating on other skeletal elements. A study of dental pathology can be useful for investigating the health and diets of individuals and populations. Even though tooth wear that is excessive by today's standards has characterized humans and their ancestors for millions of years, it should be noted that tooth wear and artificial tooth modification have been included in this chapter only for convenience. Lukacs (1989) divides dental diseases into four categories: infectious, degenerative, developmental, and genetic. All of these, of course, are interrelated in the dental health of the individual. Tooth wear should be thought of as a pathol-

Figure 17.15 **Tooth wear.** Heavy attrition on dentition of this adult male has eliminated all but the third molar crowns. The individual continued to chew on the stubs of his incisors, canines, premolars, and second molar after the tooth crowns had worn away. Such wear is a normal phenomenon in older individuals from aboriginal populations with grit in the diet. Prehistoric, California. Natural size.

ogy only when it is so extreme that the associated bone is affected negatively. Hillson (2002) provides a useful review of dental pathology, with guidelines for assessing and scoring caries and periodontal disease (following his 2001 recommendations). Chapter 19 considers how tooth wear may be used to age skeletal material and discusses how such wear can be used to assess prehistoric diets. Figure 17.15 shows how extreme tooth wear was under many prehistoric conditions.

17.7.1 Caries

Dental **caries** is a disease process characterized by the progressive decalcification of enamel or dentine. The macroscopic appearance of caries can vary from opaque spots on the crown to gaping cavities in the tooth. A prerequisite for the formation of dental caries is **dental plaque** and a diet that includes fermentable carbohydrates. Plaque is the matrix and its inhabiting community of bacteria that forms on the tooth. Carious lesions can begin anywhere that plaque accumulates, most often in the fissures of tooth crowns and in the interproximal areas. Figure 17.16 shows a large carious lesion.

Larsen (1983) observed that the prehistoric shift to agriculture on the Georgia coast led to an increase in the frequency of carious lesions, most markedly in females. This finding indicated differing subsistence roles between the sexes and is an example of how archeological and osteological data can be combined in insightful ways. Walker and Erlandson (1986) saw a similar but inverse shift on the California coast. Here, prehistoric people made a subsistence shift from a cariogenic diet, consisting mostly of plant foods, to an intensive exploitation of fish.

17.7.2 Dental Hypoplasia

Dental hypoplasia is a condition characterized by transverse lines, pits, and grooves on the surface of tooth crowns. These disturbances are defects in enamel development. Amelogenesis, or enamel formation, begins at the occlusal apex of each tooth crown and proceeds rootward, ending where the crown meets the root at the cervicoenamel line. During this process, stress to the organism may result in a temporary upset of ameloblastic activity and a consequent enamel defect marking the interruption of development. These enamel hypoplastic defects can take many forms, ranging from single pits to lines to grooves. As Danforth *et al.* (1993) note, because scoring of these features varies greatly between observers, interobserver and intraobserver bias must be considered in any comparison of results from different studies.

Several different factors can cause dental hypoplasias (see Goodman and Armelagos (1985), and Skinner and Goodman (1992), for reviews), all of them the result of metabolic insult to the organism. Like Harris lines (see earlier discussion), hypoplastic bands in individuals can indicate the age at insult. Study of these developmental defects in populations can give insights into patterns of dietary and disease stress in prehistoric groups. Goodman and Rose (1991) provide a fine discussion of enamel hypoplasias as clues about the adequacy of prehistoric diet, and Goodman and Song (1999) provide more detail on estimating ages of hypoplastic defect formation. Figure 17.17 shows heavy hypoplastic banding and pitting on a child's permanent canines.

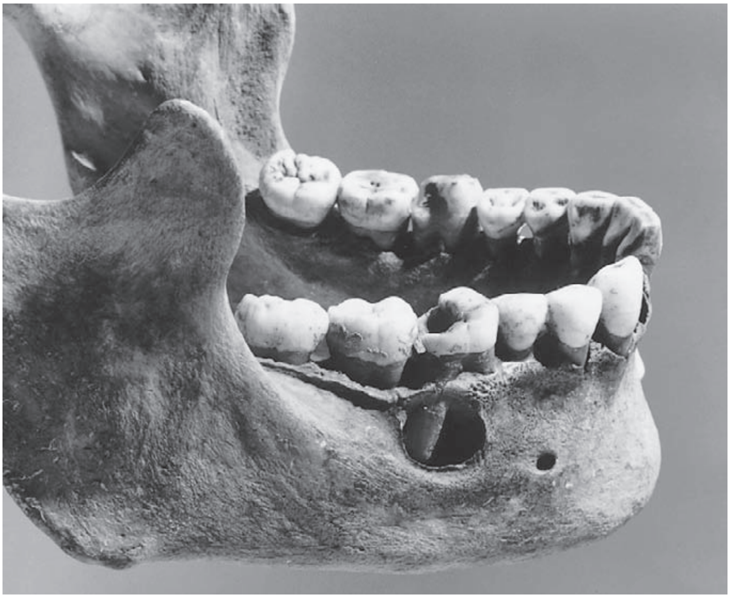


Figure 17.16 **Caries.** Bilateral carious lesions of the first molars are evident on this individual. A related abscess around the distal first molar root is seen posterosuperior to the right mental foramen. Prehistoric, California. Natural size.

17.7.3 Periodontal Disease

Periodontitis is the inflammation of tissues around a tooth. It can involve both soft tissues and the bone itself. Periodontal disease in skeletal remains is recognized as a result of infection of the alveolar bone and adjacent tissues. It causes recession of the alveolar bone, as either a horizontal lowering of the crest of the alveolar process or as an irregular lowering of the process, with pockets or wells expanding into the cancellous bone of the jaws. The agents of infection are microorganisms, and the disease is usually due to the combined effects of large, mixed communities of bacteria. An **abscess** is a localized collection of pus in a cavity formed by tissue disintegration. Abscesses are often found as cavities within alveolar bone near the tooth root apices. Figure 17.16 illustrates these features. Clarke and Hirsch (1991) provide a thorough account of factors influencing alveolar bone.

17.7.4 Dental Calculus

Dental calculus is mineralized plaque on a tooth surface. The fact that calculus can trap food debris has been used by Dobney and Brothwell (1986) as an approach for ascertaining aspects of prehistoric diet. Figure 17.17 shows remnants of calculus build-up.

Figure 17.17 **Dental hypoplasia.** This 12-year-old child suffered a metabolic upset during the formation of his canines (to see when this occurred, consult Figure 19.1). This upset recorded itself in the linear hypoplasia seen bilaterally on the labial surface of the canine crowns. Calculus is also seen on the labial surface of the incisor crowns. Prehistoric, California. Natural size.

17.7.5 Artificial Dental Modification

A variety of cultural practices (technically, forms of trauma) impacts dentition. People engrave, color, and even intentionally pull out (**evulse**) teeth for cosmetic purposes. Brothwell (1981) illustrates the variety of decorations encountered on dental remains, primarily on the anterior teeth. These artificial incisions should not be confused with hypoplasias. Milner and Larsen (1991) review filing, chipping, inlays, and other alterations, referring to these as **dental mutilations**, whereas purposeful removal of usually anterior teeth is termed **ablation**.

Frayer (1991) and many others have interpreted the interproximal grooves sometimes present between adjacent teeth as grooves left by the use of toothpicks, and such features are even known from fossil hominid teeth of more than two million years in age. Hlusko (2003) infers that these grooves were made by grass stalks used as toothpicks. Fox (1992) reviews literature on cultural striations in the human dentition, noting several studies that have shown handedness based on the directionality of oblique scratch marks on the labial surfaces of upper incisors, particularly among paleolithic hominids. These marks were presumably made because food was secured by using the front teeth as a vise while pieces were cut away with a stone implement that came into contact with the teeth.

17.8 Occupation

In both forensic and particularly in archeological contexts, it is important to determine the occupational and social status of individuals now represented by skeletons. Steele (2000) reviews the skeletal indicators of handedness, but handedness is hardly occupation. Kennedy (1989) traces the history of occupational studies in anthropology and medicine. Waldron's (1994) call for critical evaluation of claims is apt and enlightening. He notes that in their fervor to deduce as much as possible about the lives of ancient individuals, osteologists have made some extravagant claims about environmental stresses, parity, social status, and occupation. As he notes, some authors have been unable to resist the temptation to deduce an underlying cause for every bony lesion, identifying individuals as horsemen, sling throwers, weavers, and corn grinders based on the presence of bowed limb bones, spinal deformities, and osteoarthritis at various joints.

Perhaps because information regarding occupation and status is so valuable in an archeological context, not enough attention is paid to the premises that underlie such identifications. Waldron's (1994) examination of whether patterns of osteoarthritis can be used to identify occupation is a useful departure. Proceeding from known to unknown, he notes that there is a wealth of modern clinical data on osteoarthritis and occupation. He finds no convincing epidemiological evidence of a consistent, coherent relationship between a particular occupation and a particular form of osteoarthritis. Indeed, given the fact that sex, race, weight, movement, and genetic predisposition are all known factors that influence development of the disease, this is not surprising. Waldron (1994) concludes that because we know that occupation is not the sole cause of osteoarthritis, there cannot be any likelihood of being able to deduce the former from the latter. Furthermore, even in cases in which occupationally related activity does seem to be important in determining the expression of arthritis, there are no unique features about this expression—most people who develop arthritis at the finger joints are not mill workers, even though mill workers do develop arthritis at these joints. For single skeletons, therefore, the prospects seem bleak.

On a populational basis, however, the prospects are better. Here, by examining the patterns of osteoarthritis in each skeleton, and among all skeletons, it might be possible to draw conclusions about activity pattern differences on a group, or population level. This is the underlying basis of the only comprehensive skeletal study of activity-induced pathology, a small populational study of Canadian Inuits in which activity patterns such as kayaking, harpoon throwing, and sewing were related to osteoarthritic patterns on a populational basis (Merbs, 1983). A study by Stirland (1992) on sailors from King Henry VIII's A.D. 1545 flagship, *Mary Rose*, is another, smaller, and more limited sample in which an attempt to relate occupation to paleopathology is made. Even in the best of cases, however, it remains impossible to definitively conclude that any single individual had a particular occupation based on any particular arthritic joint in his or her skeleton. As Waldron (1994, p. 98) cautions, "There is a perfectly understandable drive to make the most of what little evidence survives in the skeleton and this sometimes has the effect of overwhelming the critical faculties." The osteologist should be wary of poorly supported claims about diet, disease, demography, and occupation at both the level of the individual skeleton and the level of the population sample.

Chapter 18

Laboratory Procedures & Reporting

Analysis begins in the field and extends to the laboratory. The procedures discussed in Chapter 2 are related primarily to the exposure and recovery of skeletal remains. There, we traced remains from their point of discovery into the laboratory. Now we introduce laboratory procedures commonly applied to human osteological material and consider the elements of effective reporting of analytical results. It is important to note, particularly for forensic settings, that Standard Operating Procedures (SOPs) for agencies involved in cases with evidentiary human remains must be followed very closely (see Chapter 2). The chain of custody must always be rigidly respected and documented, and security of the remains respected.

18.1 Setting

Sound procedures, an appropriate setting, and careful use of the proper equipment are essential in osteological analysis, not only to ensure accurate results but also to safeguard the skeletal remains. Of primary importance is that work be conducted over a padded surface. Care should be taken to prevent specimens from contacting hard surfaces or rolling onto the floor. Even well-preserved bones that seem sturdy may be fragile when compared to the instruments used to measure them. The osteologist must therefore be careful not to crush, pierce, scratch, or otherwise damage the specimen with the instruments. Poking or prodding the skeletal material with the fingers can also easily damage the bone, especially the more fragile parts of the cranium.

The study of bones is best done in a well-lit laboratory (Figure 18.1). Lighting is critical. Overhead fluorescent lights are poor for osteological work because they tend to fill the room with diffuse light. Observation of osteological detail depends on the control of incident light on the specimen, and for this reason a swing-arm, incandescent light source is recommended for osteological analysis. A unidirectional light source makes it possible for the researcher to highlight subtle bony features or modifications by angling the light to enhance the visibility of surface detail.

It must be noted that there may be several biological and chemical hazards involved with recovery and analysis of skeletal remains, particularly in forensic contexts (Galloway and Snodgrass, 1998).

Figure 18.1 In the laboratory, osteological specimens are fully labeled and restored. Here the osteologist checks for joins. When joins are found, the bones are glued together and temporarily supported in a sandbox while the glue sets. Comparative material should be accessible during these operations. The washing and drying of additional specimens proceeds in the background.

18.2 Preservation

The strengthening of bones can be accomplished in several ways during and after recovery. Various hardeners, or preservatives, are available. These are usually either water- or acetone-soluble; they include polyvinyl acetate (PVA, or Vinac, a plastic dissolved in acetone), Paraloid B72, Bedacryl (which can be purchased in hard chunks which are then dissolved in an organic solvent), Butvar (a powder mixed in solvent), and many others. Cyanoacrylate glues of various viscosities are irreversible but may be necessary to apply before the removal of remains, particularly heavily burned or ashed tooth crowns in forensic contexts (Mincer *et al*., 1990). Johnson (2001) reviews modern consolidants used in osteological work and Rossi *et al.* (2004) consider these in relation to fragile cremated remains and thin sectioning. Consult with the conservator of the institution that will house the osteological material about the kind of preservative preferred.

The key to using any preservative is correct dilution. The most frequent failure in preservative use is the failure to dilute the solution enough, which results in poor penetration and the formation of a hard outer skin on the specimen but a lack of internal hardening. Impregnation with a preservative having the consistency of water is recommended, usually about a 5–10% solution. It is usually best to dip whole specimens into the solution and then let them dry on a wire screen. In the case of more fragile remains that will not stand up to immersion, drip the solution onto the specimen. Use organic solvents (thinners) with extreme caution. Many of these chemicals are dangerous; avoid breathing their fumes and remember that they are often extremely dangerous because of their flammability.

18.3 Preparation

Techniques used in skeletal preparation (cleaning) vary according to the condition of the bone and the context of its discovery. Forensic osteology requires special treatment (see later). Continue to use common sense. If the bone is well preserved, it can be washed in lukewarm water (without detergents or any other additives) using brushes, wooden probes, and spray bottles. Never wash more than one skeleton at a time. Use a screen in all washing, field and laboratory, to keep small bones from being lost. As the washing water becomes muddy, small fragments may detach and become lost in the sediment at the bottom of the basin or disappear down the drain. Clean the basin and screen frequently, making sure that both are checked between processing each burial. Depending on humidity, the washed bones dry in 24 to 48 hours on wire racks in the shade. In the laboratory, you can speed this up by using a fan to blow air across racks of drying bones. Never use a heat source due to the danger of bone surface exfoliation.

For fossils, more sophisticated preparation techniques are often called for. Fossils are sometimes encased in a very hard matrix that may be even harder than the bone itself. Sometimes the matrix can be softened with acetone, paint thinner, or even water. Very important fossil specimens should be molded (see section 18.8) before cleaning to make a record of prepreparation status. When cleaning, matrix samples should be kept so that future investigators might be able to establish **provenience**, the stratigraphic and spatial position of the specimen.

Some commonly used paleontological preparation tools and techniques include the following:

- Hammer and chisel. This technique has a long history, and many fossils have the scars to prove it. Speed is an asset, but the shock imposed on the specimen and the lack of fine control are negative points.
- Dental drill. This fast but dangerous technique has been used for many years. Positive points include good cutting power, more control than a hammer and chisel, and lack of shock to the specimen. However, extreme care must be taken to keep the surface of the grinder from drilling into the surface of the object being cleaned.
- Dental pick (or needle held in vise) under binocular microscope. This is often the most effective way to clean a fossil; it gives the preparator much control and limits potential damage to tiny areas. However, this work requires an enormous

Figure 18.2 Laboratory-induced damage on the Pleistocene fossil *Homo* cranium from Petralona, Greece. Removal of matrix by a high-speed grinding wheel has produced damage on the original surfaces of the left nasal bone, and chiseling marks are seen above the left orbit. Natural size.

amount of time and patience.

- Acid treatment. Dilute acetic, formic, or hydrochloric acids can be used to dissolve matrix holding some fossils. Excellent detail may be obtained by this technique, but it calls for patient, extended monitoring to keep the acid from attacking the specimen itself, etching its surface, or weakening its structural integrity. Take all standard laboratory precautions when using acids.
- Air abrasion. This preparation technique uses a tool that shoots a stream of particles at the matrix like a miniature sandblaster. This provides speed and control without shock. However, the abrasive particles may obscure detail and frost the bone and tooth surfaces. In addition, it is difficult to control the abrasive stream as it ramifies through cracks below the surface of a specimen.

The most essential ingredients in successful fossil preparation are patience and experience, but help and advice from skilled preparators are crucial. Note that all of the techniques discussed here carry with them hazards for the fossils. It is better to be safe than sorry in preparing important fossils. Preparation trauma that is readily observable on previously cleaned fossils shows that many past workers were not careful enough (Figures 18.2–18.3).

Other specialized preparation techniques in osteology involve forensic material

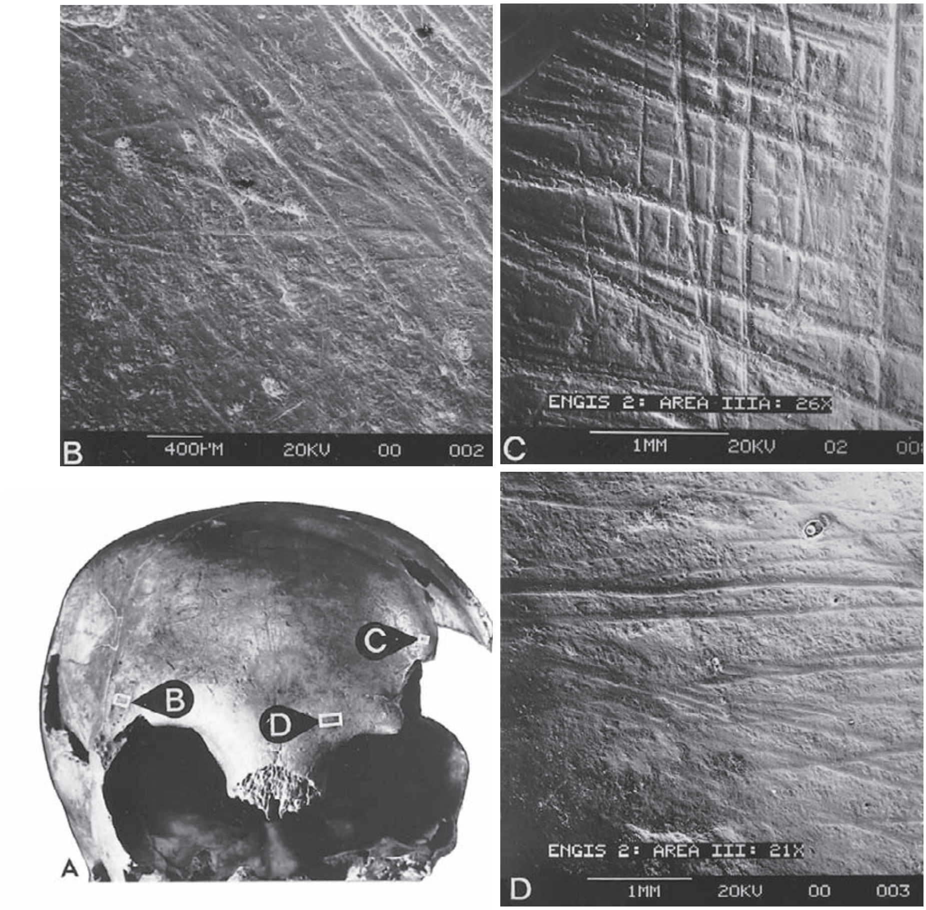


Figure 18.3 Frontal view of an immature Neanderthal cranium from Engis, Belgium (A). The superficial scratches along the midline were made by a diagraph instrument needle, and those along the broken edge of the left frontal were made by sandpaper used to smooth the previously plaster-reconstructed area behind. These marks were interpreted as evidence of Neanderthal mortuary practice (Russell and LeMort, 1986). This interpretation was shown to be mistaken by White and Toth (1989). Scanning electron micrographs (B–D) show the sandpaper striations. Note the “doubling back” at the end of each sandpaper grain’s path as the end of the sanding stroke was reached. These figures illustrate the utility of the scanning electron microscope in investigating bone modification at magnification.

with adhering flesh. Here, most of the flesh can be removed carefully with cutting tools. The specimen can then be boiled with or without chemicals such as enzyme-based detergents. For a discussion of a variety of defleshing techniques useful in building comparative mammalian skeletal collections, consult Hildebrand (1968) and Mori (1970), as well as Fenton *et al.* (2003). Be sure to consult a soft tissue pathologist before removing soft tissues—never destroy evidence of any kind. Even insect larvae contained in these tissues may provide important clues in a forensic case.

18.4 Restoration

Restoration involves putting pieces of broken bones back together. A detailed knowledge of osteology greatly simplifies this process; the ability to identify the side and position of fragments allows the quick identification of joins. The restoration of fragmentary bones is often described as more difficult than doing a jigsaw puzzle. This is an exaggeration. A broken skeleton has one more dimension and far more information than a picture puzzle of a polar bear in a snowstorm. Restoration is often quick and easy for the competent osteologist (see Figure 18.1 for an illustration of restoration in progress). The following are valuable guidelines for restoration:

- Use a glue that may be dissolved later. This ensures future workers the ability to correct any unintentional mistakes of restoration.
- Do not hurry. As in preparation, patience and experience are essential in good skeletal restoration.
- Restore the face and vault separately before joining them. Use the mandibular condyles as a guide to restoring the correct cranial breadth when this is in doubt.
- Be sure the bones to be glued together are dry, unless a water-soluble glue is being used.
- Do not glue until you are positive of a good join. Check under the microscope if necessary.
- Make sure the joining surfaces are clean of debris. Adhering grit, preservative, and flakes of bone can result in misalignment of broken pieces.
- Use color, texture, and—most importantly—anatomy to match the pieces.
- Never glue teeth into their sockets until you are absolutely positive that they belong there. Interproximal contact facets provide an invaluable guide to accurate tooth placement.
- Do not glue yourself into a corner by leaving unfilled gaps between bones. Instead, use masking tape to make temporary joins. Do not leave the masking tape on for more than a couple of months and be careful that the bone surface can release the tape without exfoliating. When satisfied that the joins are correct, progressively remove the tape and glue the broken surfaces together.
- Reconstruct only where necessary. Use soft plaster or a 50:50 mixture of paraffin wax and dry plaster heated to a liquid in a saucepan on a hotplate (not an open flame). Do not ignite the paraffin. This restoration material is easy to work with and remove. In contrast, modeling clays (plasticine) tend to be more greasy and should generally not be used except as temporary props. After the restoration is complete, be sure to demarcate the reconstructed from the real surfaces. Reconstruction (as opposed to restoration) is rarely justifiable for an original specimen because it is subjective and it obscures valuable cross-sectional information.
- Use a sandbox and gravity to position pieces while rebuilding them. Anchor one piece in the sand and balance the other piece on top of it, perhaps temporarily supporting the glue join with masking tape (Figure 18.1). Be sure to let the glue completely harden before removing the piece from the sandbox.
- Where contacts are limited and weak, brace the parts by using struts made of wooden or glass rods.
- Do not use glues, preservatives, or reconstruction material that will inhibit mold-

ing rubbers that may be used on the specimen at a later time. Check any such substances for compatibility with molding rubber before applying them to the specimen.
- For some specimens, complete restoration is extremely difficult; some distortion is the result of warping rather than fracture. Such warping is impossible to correct.

18.5 Sorting

The osteologist is often faced with the challenge of sorting a collection containing more than one skeletal individual. Of primary importance in this sorting are age, size, and sex differences as well as bilateral, nonmetric traits. Matching articular or interproximal facets often provides clues about association. Preservational factors such as bone color, weathering, or integrity are of secondary importance, but are sometimes useful in sorting individuals.

The **minimum number of individuals** (**MNI**) in any assemblage of bones is the minimum number of individuals necessary to account for all of the elements in the assemblage. A very simple example might be an assemblage consisting of two specimens, a fragment of left humeral head and a fragment of left distal humerus. These two specimens, even though the intervening shaft is missing, *could* represent the same individual (unless they are of patently different individual ages). Even though there might be two individuals involved, the MNI value would, in this case, be 1.

This basic logic is used to determine the MNI value for any assemblage of human remains by following these procedures:

- First, remove all nonhuman elements.
- Next, separate the bones according to element and side.
- Within each right-side element category, count the minimum number of individuals, not pieces, represented. Consider all possible joins between fragments and assess the age of each fragment.
- Perform the same minimum number count for left-side bones within each element category and then check for individuals represented by left-side bones that either do match, or possibly belong, to those from the right. These do not increase the count.
- Left-side bones that do not match corresponding right-side ones in age or morphology are added to the minimum number count.

After this is done for all paired and unpaired elements, the greatest minimum number of individuals has been determined.

Consider, for example, an assemblage consisting of two right maxillae with full adult dentitions, three left femora of adults, one right femur of an infant, two sacra, four adult right calcanei, and three permanent right upper central incisors. The MNI in this assemblage is six — the infant plus five adults (determined by two right central incisors in maxillae, and three isolated upper right central incisors). The maximum number of individuals is determined by counting all nonjoining, nonmatching elements — in this case, a total of fifteen. For another example, see Figure 18.4. Note that the MNI is not equal to the "most likely number of individuals" (Adams and Konigsberg, 2004).

18.6 Metric Acquisition and Analysis

Because osteological work is part of the scientific enterprise, it is necessary to communicate results to other researchers in an unambiguous and precise manner. One of the most convenient and effective ways to communicate osteological observations is to quantify them — to express them in numbers. Thus, to inform colleagues and others about a particular tooth, it is a simple matter to measure and count characteristics of that tooth.

Recent advances in computerized tomographic (CT) and laser scanning technologies have made it possible for osteologists to acquire metrics digitally, and to display them via a computer screen remote to the specimen(s) under study. At first glance,

Figure 18.4 To determine the minimum number of individuals for this sample of ten specimens (shown one-half natural size), first note that there are no nonhuman pieces. Sort the pieces by skeletal element and side. There are two right tali, three left mandibles, one maxilla, and four right ulnae. One of the ulnae is immature. The MNI is thus equal to at least four people. Because no pieces join or are antimeres (opposite sides of the same individual), it is possible that each piece represents a different individual, so the maximum number of individuals indicated for this sample is ten.

this technological capability brings with it the prospect of fast, easy, and accurate data acquisition and distribution. Rare or valuable specimens can now be digitized by laser or CT scans and "held" in computer memory (Ousley and McKoewn, 2001; Zollikofer *et al*., 1998; Mafart and Delingette, 2002). So alluring are the siren songs of these new capabilities that some have suggested that they obviate the need to curate original specimens (see also Chapter 3). This is a mistaken and extremely dangerous philosophy in osteology.

History holds lessons here. When it became possible to "capture" morphology of fossil specimens via silicon rubber and accurate plastics, replicas of the fossil originals were distributed throughout the world. These casts are immensely valuable as teaching and preliminary research tools, but experience has shown that they are no substitute for the originals. Distortion, matrix cover, and internal morphology are all lost in a cast. Workers unfamiliar with originals can be badly misled by such features, features only visible with reference to the original. Misinterpretations based on inaccurate observations and measurements on photographs and casts are an embarrassing part of the published literature of human paleontology. See Clarke and Howell (1972) for an analysis of problems inherent in observations and measurements from photographs and casts.

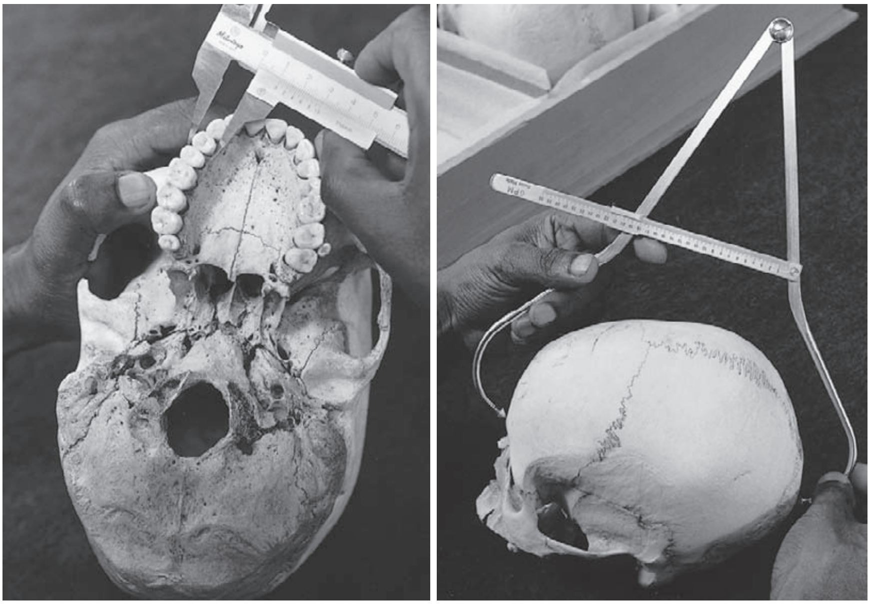
With either two- or three-dimensional digital images scanned from original osteological specimens, these problems are compounded dramatically as the investigator moves another step away from the original. Color, texture, internal anatomy, matrix cover, preservative cover, preparation damage, erosions, and distortions of all kinds may be faithfully recorded by such imaging of the original, but for the osteologist seated at a computer monitor on the other side of the planet, these features are often not digitally distinguishable from actual bony anatomy. Humans routinely make mistakes, and these technologies seem poised to increase dramatically the number and impact of these mistakes in human osteology. For obvious reasons, osteologists should always refer to the original specimen, even when acquiring metric data from digital sources.

The popular image of an osteologist at work is one of a person in a white laboratory coat, measuring instrument in hand, manipulating some bone (usually a cranium). The role of the professional osteologist is far broader than this. In the formative days of osteology, quantification of bony anatomy was the focus of most work. Elaborate sets of measuring points were defined, and vast quantities of metric data were compiled. Just because a certain measurement has been reported, however, does not mean that it is either useful or even reproducible (Stirland, 1994). Conversely, new metrics are routinely developed to quantify morphological observations. The traditional days in which measurement was done for measurement's sake are thankfully over now, but metric analysis does continue to play a primary role in osteology. Howells (1969a) provides an interesting background for the selection of skeletal metric points.

All scientific measurements, including those in osteology, should be taken in the metric system. This system expresses linear osteological measurements in millimeters, centimeters, and meters. Some observations may be quantified even though they are difficult or inappropriate to record as actual measurements. For example, traits such as the Carabelli's cusp on upper molars may be recorded as absent or present. Variables recorded in this way are called **discrete variables**, as opposed to **continuous variables** such as linear measurements.

Many measuring tools have been invented and developed for osteological analysis.

Figure 18.5 illustrates some of them. The most frequently used is the sliding caliper, which has a pair of jaws whose variable gape is measured via a dial or scale on the caliper shaft. A spreading caliper is usually used for work on cranial anatomy. Osteometric boards are useful in measuring lengths and angles of postcranial elements. Devices for orienting crania are also available, and instruments called diagraphs are used to trace certain profiles of crania held in these devices. Most of these precision



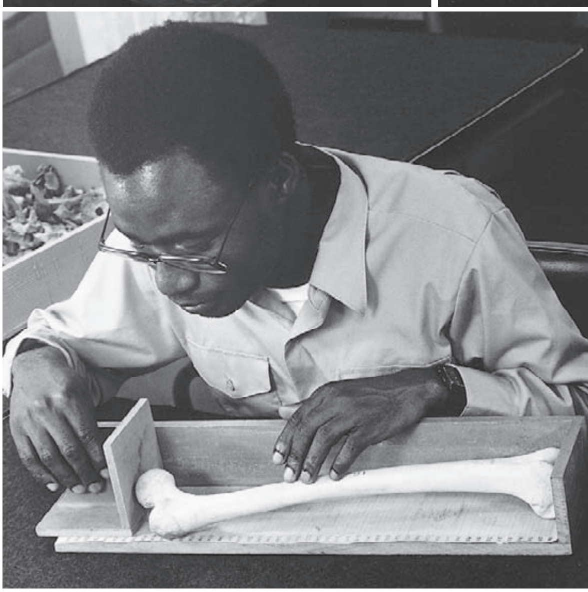


Figure 18.5 Tools for osteometric measurement. *Upper left*, the basic sliding vernier caliper is used to measure the buccolingual breadth of the right maxillary third premolar. Note the rare nonmetric anomaly seen in this dentition: bilaterally present supernumerary molars. *Upper right*, measurement of cranial length with the spreading caliper. *Left*, measurement of femoral bicondylar length with the osteometric board.

instruments are made of steel and are expensive. They are also sharp. Care should be exercised to see that the instruments are not damaged during use. More importantly, because bone is softer than steel, these instruments can scratch or perforate bone surfaces, and care should be taken to see that such damage does not occur during analysis. Many of these instruments have now been linked to microcomputers, allowing metric data accumulated on large samples of osteological material to be entered and manipulated electronically.

Metric analysis in osteology requires more than simply measuring a given element. It is critically important to provide precise definitions of each measurement. Furthermore, the degree to which measurements can be reproduced is important in metric analysis. The example in Table 18.1 shows one way of calculating and reporting the technique-based measurement error (intraobserver error). Heathcote (1981) and Buikstra and Ubelaker (1994) provide further details on measurement error in human osteology.

Metric data in osteology are usually compiled as a result of measuring arcs, chords, or volumes. Indices are made by combining these values. For example, the Cranial

Table 18.1

A Useful Procedure for Estimating Measurement Error

A. An osteologist measures a tooth for the first time and gets a reading of 10.8 mm. Measurement A = 10.8 mm
B. Time is allowed to pass (best if a few days) so that knowledge of the original measurement does not influence the remeasurement. The same investigator then remeasures the same tooth at 11.0 mm. Measurement B = 11.0 mm
C. After another hiatus, the same investigator measures the tooth at 11.5 mm. Measurement C = 11.5 mm
D. There are now three measurements. To calculate the mean (average) of these, add the three measurements (**measurements A + B + C = 33.3 mm**) and divide the total by the number of measurements (3). The result is the mean, or average, 33.3 ÷ 3 = 11.1 mm.
E. To determine the degree to which the original measures deviate from this average, figure the difference between the mean and each measurement. Add these differences (**A: 11.1 − 10.8 = 0.3 B: 11.1 − 11.0 = 0.1 C: 11.5 − 11.1 = 0.4 Σ = 0.8**) and then divide the summed differences by the number of measurements (3) taken (**0.8 ÷ 3 = 0.267**).

The result reflects the degree to which the actual measurements differ from the mean. Convert this to a percentage of the average value (**0.267/11.1 = 0.024 = 2.4%**). The average measurement error from the 11.1 mm mean is about 2% in this example. By reporting this value, the osteologist informs the audience about how repeatable any given measurement is.

Index is the product of the maximum cranial breadth (*bi-euryon*) and 100, divided by the maximum cranial length (*glabella* to *opisthocranion*). Indices are convenient because they express shape as a single variable. For example, a short or "broad" skull has a higher index than a long, narrow skull. Bass (1995) provides a concise guide to standard measurements and indices most widely used in human osteology. Cranial metrics and indices are summarized in White and Folkens (2000). Buikstra and Ubelaker (1994) recommend that 34 cranial and 44 postcranial standard measurements be taken on intact skeletons.

Expression of skeletal element shape, or morphology, can be examined by univariate (single measurement) or bivariate (two measurements, as in an index) means. The use of multiple measurements to express skeletal shape has been called multivariate morphometrics. The successes and failures of multivariate analysis in human osteology and paleontology are examined by Lovejoy (1978), Howells (1973), Frayer (1985), Reyment *et al.* (1984), and Corruccini (1978, 1987). Richtsmeier *et al.* (1992, 2002) provide a good review of anthropological morphometrics. Robb (2000) provides a good introduction to the tools that human osteologists will need to do more than *acquire* data. The thoughtful and appropriate *analysis* of those results is not a trivial endeavor.

18.7 Molecular Osteology

Howells (1995, p. 2) poses the question: "Is a given unknown skull, with a male assignment based on morphological characters (Chapter 19), indeed a male rather than a somewhat extreme female? There is no way of telling, and that is the problem." This is no longer the case.

Traditional methods for analyzing skeletal remains are based on examining the sizes and shapes of bones. Recent advances in other fields have given rise to a new set of methods that allow the osteologist to analyze the molecular constituents of bone. Under certain conditions, skeletal remains retain sufficient densities of DNA, amino acids, and various isotopes to permit their recovery and analysis. See Schmidt-Schultz and Schultz (2004) for a consideration of protein preservation in prehistoric bone. The techniques used are often complex and require specially equipped laboratory facilities. Possible contamination is always an issue (Nicholson *et al.* 2002). However, the accuracy and precision of the results obtained may be superior to those of traditional methods, depending on the nature of the question. DNA analysis, in particular, allows the bioarcheologist or forensic osteologist to address questions that are beyond the range of morphological methods.

As molecular biologists develop ways to extract more information from modern DNA, the types of questions that can be addressed with ancient DNA are expanding rapidly. For reviews, see Kaestle and Horsburgh (2002) and Pääbo *et al.* (2004). Currently, there are five major questions about a deceased individual that DNA analysis of skeletal remains can potentially address: sex, pathology, ancestry, individuation, and diet. Molecular techniques are thus becoming the method of choice for various types of osteological analysis. Even so, these techniques are best applied as part of an overall osteological analysis rather than in isolation.

18.7.1 Sampling

The use of new high-tech molecular methods does not mean that the fundamentals of proper recovery, preparation, and documentation of skeletal remains can be ignored. Indeed, mistakes made prior to, or during, the sampling of material for molecular analysis can seriously compromise results. In addition to the standard set of recommendations for recovery and documentation of skeletal remains (Chapter 2), investigators wishing to obtain good samples for molecular analysis should consider the following: If molecular analysis is to be employed on newly recovered skeletal material, recovery procedures should be modified to minimize contamination of the remains by modern compounds and modern humans. The specific procedures will depend on the nature of the site, the available time and resources, and the type of analysis planned. For DNA analysis, these would ideally include using disposable latex gloves and hair nets, and sterilizing excavation tools. If this is not practical for the entire sample, a reasonable compromise may be to employ such procedures on the specific elements destined for DNA analysis. Remember that all specimens should be treated as potentially infectious and protected against contamination and degradation. The Armed Forces DNA Identification Laboratory (AFDIL) has particular SOPs (see Chapter 2) that cover these topics and many others.

The exposure of skeletal remains substantially alters their environment. This may, in turn, lead to further decay of their molecular constituents. Currently, little is known about the effects of preservatives and changes in temperature, humidity, moisture, and air circulation on the preservation of various biomolecules. Until more information is available, the wisest course is to minimize the magnitude of such changes as much as is practical. Consulting with the specialist who will be conducting the molecular analysis is advisable.

The evaluation of the accuracy of molecular analyses depends in part upon proper documentation of the provenience of the samples. If molecular analysis is to be employed on newly recovered skeletal material, particular attention should be paid to properly documenting both the context of the remains and the excavation methods employed. Depending on the type of analysis planned, it may be advisable to obtain soil samples from the area surrounding the elements to be analyzed. Here again, consultation with the appropriate specialist is crucial.

Whether the molecular methods are to be applied to newly recovered skeletal remains or to museum collections, the choice of which specimens to sample must be made carefully. Because molecular techniques are typically destructive, specimens for sampling should be chosen to minimize the morphological information lost while maximizing the potential information gained in the molecular analysis (DeGusta and White, 1996). In order to adequately weigh these often-competing goals, it is imperative that the skeletal remains first be examined for signs of pathology, bone modification, and other morphological variations. Only then can an accurate assessment be made of the "morphological value" of the skeletal specimens and of the various portions of individual specimens. It is often useful for molecular analysis to be first attempted on nonhuman remains or on human specimens of dubious provenience to establish the feasibility of the method prior to the destructive sampling of more valuable specimens.

Removal of skeletal tissue for molecular analysis destroys information about the morphology of the bone, but this loss can be reduced greatly by proper documentation prior to sampling. The exact methods employed to record the morphology will depend on the anticipated degree of destruction and the importance of the specimen. Minimally, high-quality photographs (with a scale bar) and radiographs should be taken and developed prior to sampling. Molding and casting of specimens provide a three-dimensional record of the morphology. This, in combination with photographs, minimizes the loss of information. Documentation only preserves morphological information if it remains permanently accessible, so casts and photographs of the relevant specimens (along with copies of the results of the molecular analysis) should be deposited properly and promptly in the appropriate archives.

18.7.2 DNA and PCR

Deoxyribonucleic acid (DNA) is the molecule of heredity. The genetic code in DNA is based on four chemical building blocks called nucleotides: adenine, cytosine, thymine, and guanine. These nucleotides can be thought of as forming a four-letter alphabet that spells out the assembly instructions for all the proteins that make up an organism. Almost every cell in a person's body has a complete copy of their DNA, and all these copies are essentially identical. There is a tremendous amount of research aimed at extracting various types of information from DNA, in part because many diseases are thought to have a genetic component. In a biomedical context, specific diseases, such as Huntington's disease and sickle cell anemia, can be diagnosed based from DNA alone. The sex and general ancestry of an unknown individual can be determined from DNA. Comparisons of DNA samples can be used to establish identity and paternity. Brown (2000) provides an overview of the application of ancient DNA studies to human osteology.

The ability to determine sex, ancestry, disease status, and identity from DNA has obvious applications in osteology, forensics, archeology, and even paleontology. These applications, though, all depend on the ability to obtain DNA from organic remains of unknown antiquity. After an organism dies, the highly organized molecules of DNA degrade rapidly. The key conceptual breakthrough that led to the field of "ancient DNA" was the recognition that despite this decay, fragments of DNA are sometimes present in remains of great antiquity. With only a few modifications, existing techniques for isolating modern DNA can also be used to retrieve this DNA (Higuchi *et al.*, 1984; Pääbo, 1985). These techniques originally required a large amount of preserved DNA, a criteria met only in cases of exceptional preservation (e.g., mummies or ice-embedded animals).

Development of the **polymerase chain reaction** (PCR) made it possible to retrieve exponentially smaller amounts of DNA (Mullis and Faloona, 1987). In order to analyze DNA, it is necessary to have a sufficient quantity of it. Using conventional techniques, even a dozen molecules of DNA are effectively invisible—they are too small to detect. The PCR acts as a "molecular photocopy machine" by making literally millions of copies of a section of DNA. This is referred to as amplification, and PCR can amplify a section of DNA starting from only a few original molecules. The large amount of DNA yielded by the method can then be analyzed quite easily using a variety of standard techniques. Using PCR, researchers were able to retrieve DNA from ancient skeletal remains (Hagelberg *et al.*, 1989). This advance made ancient DNA methodology applicable to a broad range of questions in osteology.

The general methodology for obtaining and analyzing DNA from a bone or tooth involves three general stages. First, the DNA must be extracted and isolated. This involves reducing about a gram of bone or tooth to powder. The powder is then treated chemically to remove proteins and other compounds and to concentrate the DNA. Second, a predetermined section of the DNA is amplified using PCR. Finally, the resulting DNA sample is analyzed, typically by determining its nucleotide sequence. Steadman (2003) provides a review of mitochondrial DNA analysis and histomorphology. As she notes for the forensic context, DNA can build a genetic profile and result in individuation, but it cannot construct a biological profile of the individual.

18.7.3 Contamination

Despite the exciting potential of ancient DNA, the applications are still limited by methodological difficulties (Handt *et al.*, 1994; Kelman and Kelman, 1999). The major problem is contamination by exogenous DNA (DNA not from the targeted individual). Living organisms are constantly shedding DNA-bearing tissues in the form of skin cells, hair, saliva, and other secretions. Archeological skeletal remains, for example, risk being contaminated by the DNA from organisms in the soil, microorganisms growing within the bones, excavators, curators, or even the DNA analysts themselves. The problem of contamination is worsened by the nature of PCR. The polymerase chain reaction preferentially amplifies well-preserved DNA molecules, which are more likely to be modern contaminants than truly ancient DNA. Because PCR produces large amounts of highly concentrated DNA, laboratories often encounter problems with the products of previous PCR reactions contaminating current work. Contamination is of extreme concern when attempting to retrieve DNA from ancient human remains, as humans are also the main source of exogenous DNA, making contamination more difficult to detect. Several published DNA sequences from very ancient remains are now widely held to be inauthentic (Lindahl, 1997). Because the materials used for the extraction of DNA are often unique, and the analysis is time consuming, independent replication of results is not always carried out. A number of techniques have been developed to reduce the chances of contamination occurring, and to increase the likelihood of the contamination being recognized. The independent verification of ancient DNA results is also becoming more common. So, whereas contamination will likely continue to be of concern, the body of reliable ancient DNA work will also continue to expand.

18.7.4 Taphonomy of DNA

The specifics of death, burial, and **diagenesis** (a change in the chemical, physical, or biological composition of bone subsequent to death) that can result in the preservation of DNA in some cases, but not in others, are unknown. The preservation of DNA does seem to be influenced primarily by environmental conditions rather than by time, at least for remains younger than about 10,000 years (Parsons and Weedn, 1997). Bones and teeth that are well-preserved macroscopically and microscopically seem more likely to yield DNA. Empirical evidence also suggests that remains from colder regions may preserve DNA better than remains from warmer areas (Poinar *et al.*, 1996). It is also clear that mitochondrial DNA (mtDNA)—a small, non-nuclear genome that is inherited only from the mother—is easier to retrieve than nuclear DNA (Parsons and Weedn, 1997). This is likely due to the greater number of copies of mtDNA and perhaps its smaller, circular structure.

Amino acids are the chemical building blocks of proteins in all living organisms. Each type of amino acid comes in two mirror-image forms known as antiomers: the D-form and the L-form. All amino acids that are incorporated into a protein are in the L-form, but over time they gradually convert into the D-form, a process known as racemization. Attempts to use the ratio of D- to L-forms as an absolute dating method have generally failed, as this ratio is significantly affected by diagenesis, but the technique has found two applications in modern osteology.

Poinar *et al.* (1996) have shown that the degree of racemization of aspartic acid in skeletal remains is correlated with the preservation of DNA. Beyond a certain degree of racemization, no DNA was able to be amplified. This technique takes advantage of the sensitivity of the racemization process to environmental factors, the same factors that speed the decay of DNA. The main uses of amino acid racemization in ancient DNA work are to assess the prospects of retrieving DNA and to help confirm the authenticity of the DNA obtained.

18.8 Molding and Casting

Casts of skeletal material are used in osteology and paleontology for several purposes. They provide a good three-dimensional archival record of the object under study (Mann and Monge, 1987; Smith and Latimer, 1989). In addition, they are useful in communicating findings with colleagues and for slicing into cross sections for comparative purposes. Specialized techniques and materials used in molding and casting teeth are outlined in Hillson (1992, 1996). Several molding methods may be used for bones, depending on the needs of the investigator; details are provided by White and Folkens (2000). Computerized tomographic (CT) and laser scanning methods combined with stereolithographic output are relatively new technologies that allow osteologists to perform "digital molding" of hard tissue specimens, with the added benefit of revealing internal structure (Mafart and Delingette, 2002).

18.9 Photography

Osteologists use photography to archive (record) bony material and its context as well as to communicate information in publications and presentations. Maximizing the utility of photography in osteology assumes an understanding of the medium that goes beyond the abilities of the casual photographer.

The advent of digital photography has changed the face of scientific imaging. It is rapidly replacing film, but its brings a number of important considerations along with the benefits. Understanding the technology and the differences between digital and film photography is important. However, an adequate discussion of this is beyond the scope of this manual. For a concise technical review of digital imaging fundamentals see Andrew Mutz's article online at: **http://www.codesta.com/knowledge/technical/digital_photography**. Offered here are only a few general considerations regarding photography in osteology.

18.9.1 Equipment

Routine situations in osteology require using a single-lens reflex camera (SLR). This is true for both film and digitial photography. Another format with distinct advantages in fieldwork is "instant" or Polaroid® photography. However, digital photography has met many of the advantages of instant photography (immediate feedback, convenience) and has mitigated its disadvantages (cost, availability, single print, and waste).

The utility of SLR cameras and the physics of optics remain unchanged from film to digital. The ideal lenses for photographing specimens are "flat-field" lenses—those with focal lengths about twice that of "normal" (70–120 mm in 35 mm format). The optical qualities of these lenses produce a flat field of focus without the characteristic linear distortions of wide-angle lenses or the depth compression of telephoto lenses. Small sensors (as in all-in-one consumer digital cameras) can match the optical effect of 35 mm film using shorter focal length lenses. Many digital SLRs have sensors compatible with lenses from film SLRs, but the effective focal lengths may differ. Some manufacturers use "full-size" sensors (similar to the 24×36 mm active area of 35 mm film) that do not require focal length conversion. Other equally high-quality cameras have a sensor measuring 23.7×15.7 mm, giving an 85 mm lens an effective focal length of 130 mm. The latter gets more focal length out of a lens, yet produces the same quality image.

Lenses with macro-focusing capabilities (also called "close-up" lenses) are useful in documenting small specimens. These lenses allow the focal point of a lens to extend farther from the film plane, effectively enlarging the subject. For example, macro lenses with a 1:1 capability can record a tooth life-size on the film, thus maximizing detail. A 105 mm macro lens is ideal for general-purpose osteological photography.

Digital video is increasingly common in the field as camcorders get smaller and better. The Mini-DV format is popular. Compact High-Definition is gaining attention. Both of these formats create footage suitable for broadcast. Some camcorders have the option of shooting interlaced or progressive (non-interlaced) video. Interlaced (old technology video) combines two fields of alternating scan lines to create each frame of video. Progressive video scans an image in one pass of sequential scan lines for each frame of video. This results in a smoother and sharper picture with higher resolution and no motion artifacts. Camcorders with progressive scan capability also have a single-shot mode that can serve as an emergency back-up for stills. Capturing a single video frame for use in print or still-image presentation from progressive scan is easier and at a higher quality than is possible from interlaced video. Single frame captures from interlaced video benefit from the application of a special filter in Adobe®Photoshop®.

Equipment maintenance is extremely important in the field. Environmental considerations are often neglected until it is too late. Heat, sand, cold, and moisture all wreak havoc on camera equipment. Fungal growth on internal lens elements is common in very humid environments. Dry and windy conditions require diligent protection from blowing sand and the harsh effects of heat on equipment and media. Extreme cold can defeat batteries quickly in electronic cameras. Lithium batteries may be difficult to find away from cities. All of these concerns are exacerbated in digital photography. There is no mechanical backup solution in digital photography. For workers involved primarily in exotic field work, a mechanical film camera is still necessary, at least for backup.

18.9.2 Exposure and Film (or other Recording Media)

The sensitivity of film and digital sensors to light is rated by an ISO number—a higher number means more light-sensitive. In film photography you choose a film with a particular ISO according to anticipated conditions and you are constrained by the limits of that film until the entire roll is exposed. In digital photography you can dial in the desired ISO for the conditions and can adjust the ISO at any time.

The interrelationship of ISO, lens aperture, and shutter speed matters in a correct exposure. Good photographers are aware of this three-item juggling act at all times, even with the sophisticated metering schemes in many cameras. The "sunny 16" rule serves as a practical starting point. It means that on a clear sunny day with a lens aperture of f/16, the shutter speed will equal the ISO rating of the film.

- **Lens aperture** controls how much of the subject closer to or farther from the camera is in focus (depth of field), as well as the *amount* of light that reaches the film. Small apertures create a greater depth of field, but less light gets through. Large apertures cause more of the foreground and background to be out of focus. Because the aperture (or f-stop) is expressed as a ratio of the diameter of the hole to the focal length of the lens, f/22 is smaller (less light) than f/4.
- **Shutter speed** controls how the motion of the subject is recorded and the *duration* of the exposure. A bone in the sand affords a slow shutter speed in order to achieve a small aperture for greater depth of field. However, hand-holding the camera at a slow shutter speed can cause camera shake and a blurred image. The rule is: hand-hold only with a shutter speed number larger than the focal length of the lens. This means 1/125 sec. with a 105 mm lens. Slower shutter speeds require the use of a tripod to insure a sharp image.
- **ISO** is all about the *sensitivity* of the media. Cloudy days and shooting in shadows require more sensitivity. Low-ISO films contain finer grains of light-sensitive crystals that produce sharper photos and higher contrast, but require longer shutter times or wider apertures or both. High-ISO films are faster, but can be grainy, flat in contrast, and preserve less detail. In digital photography, lower-ISOs are optimal. High-ISO settings only amplify the signal from the sensor. This can produce digital "noise"—undesired random pixels scattered about an image.
- The marked full steps of aperture, shutter speed, and ISO on most cameras and lenses double or halve the exposure with each step. From f/16 to f/11 doubles the light through the lens; from 1/125 sec. to 1/250 sec. the duration of the exposure is cut in half; and a film rated at ISO400 is twice as sensitive to light as ISO200.

- Use of a **gray card** (18% reflectance) is the best way to set a proper exposure in most conditions. Light meters are calibrated to this standard. You can meter from the camera filling the viewfinder with the gray card or you can point a hand-held light meter at an evenly-illuminated card (devoid of shadows or glare). Gray cards are available at any camera store catering to the professional and can be cut down to a convenient pocket size.

While traveling, film—of any ISO, exposed or unexposed—should never be x-rayed. Exposure to airport x-rays are cumulative and affect faster ISO films the most. Do not leave film in checked luggage. Always have it hand-checked at security. X-rays do not affect digital images or storage media, though strong magnetic fields may.

Lower-end digital cameras record images only in JPEG format, usually with an option of high-, medium-, or low-quality compression ratios. JPEG is a "lossy" algorithm that discards information as it compresses files. It can introduce artifacts into an image which are compounded with each compression/decompression. Though not meaningful in snapshots, these can have ramifications in critical science photography. The universal workhorse TIFF format is available on many cameras, but produces larger files. Professional cameras can record in 12-bit "camera RAW" format that produces huge files. This uncompressed format contains all the information captured by the camera without in-camera image processing. It includes time, date, frame number, lens, and exposure information. It can be customized to include other information such as distance to the subject and GPS latitude/longitude data. The pristine image data in RAW files provide the most flexibility. However, RAW files require processing down the line, including sharpening and adjusting levels. It takes some practice to get the technique correct. Nikon®, Canon®, and other professional lines offer proprietary software designed to simplify processing RAW images. Similar results are obtainable using Adobe Photoshop. Good cameras have the option of recording a RAW image and a processed JPEG image at the same time. This is the best of both worlds. It captures the maximum amount of image data while providing an immediately usable image.

A variety of capture media exist including Memory Sticks™, Microdrives®, and wireless connections to computer hard drives. CompactFlash® cards (a.k.a. CF™ cards) are proving to be robust storage devices. Some ultra-high-capacity CF cards have been reported to have stability problems. Four 1 GB CF cards may be better than one 4 GB card. Images on memory devices in a camera are easily downloaded to a computer hard drive. It is important to archive digital images on CDs or DVDs at their maximum quality.

Slides and negatives should be stored in polypropylene sleeves. Metal boxes for slides and glassine envelopes for negatives are acceptable. Avoid using vinyl slide sheets as the off-gassing of the vinyl will destroy dyes on film. Rare and valuable images, both prints and slides, should be duplicated with internegatives and/or scanned and then locked away under archival museum conditions. Repeated projections of slides and exposure of all film and prints to the elements degrades their quality over time.

18.9.3 Lighting and Setup

Proper orientation and lighting separate the professional-looking photograph from snapshots. Tripods and speedlights (electronic flashes) are fundamental for good photographs. Field photography primarily relies on available natural light, but the quality of light changes with weather and time of day. Photographs taken very early or late in the day often involve shadows that can be mitigated with an electronic flash. Fill flashes can reveal detail in deep mid-day shadows and reduce harsh image contrast. White cards, T-shirts, and crumpled aluminum foil can be used to bounce softer light into dark shadows. Manipulating light to come from the side of a subject will emphasize detail and texture. An off-camera flash sync cord is convenient for this purpose. A straight-on flash will "flatten" an image by eliminating most shadows. Ring flashes are used in forensic and medical photography for flat, even illumination.

A little thought about setting up shots will improve their value. Backgrounds should contrast with the subject. Spraying water lightly on the matrix around fossil bones *in situ* helps create contrast. In the lab, black or gray velvet or felt backgrounds improve color accuracy. Specimens can be stabilized and presented in a proper plane of reference with things as simple as a set of rubber washers. Avoid oil-based clays that contaminate specimens. A reference scale should appear with all specimens. Rock hammers, coins, and lens caps are poor substitutes for an easy-to-read metric scale. A scale is most useful when raised to the focal plane of the important part of the subject. The target scales on the cover flaps of this manual were designed to fold out and provide an ideal reference scale for most situations. A china marker or fine grease pencil can be used to make notes in the spaces provided and will wipe off easily. Sharpie® permanent markers also work and can be removed using a white plastic eraser.

18.9.4 Legal Considerations

Photography can be a powerful tool when an osteologist is called upon to serve as an expert witness (see Chapter 3.1). All photographic evidence presented in court is subject to cross-examination, including the manner in which it was acquired, archived, and reproduced. "Admissibility" of evidence is different from "weight" of the evidence. Some jurisdictions question the admissibility of digital photography due to the ease of manipulating the image, preferring film-based images instead. Others simply consider that all photography goes to the "weight" of the evidence.

If it is expected that your photography will be used to support opinions in a legal context, the best practice is to shoot film to establish a basic record and then take advantage of the flexibility and convenience of digital photography. A "throw-away camera" is often sufficient in this regard, constituting inexpensive insurance. As attorneys and courts become more aware that forensic image analysis can identify manipulated digital images, they are less likely to challenge digital pictures when they are initially captured in RAW format and backed up with conventional film.

Concerns are being raised in academia about digital photography and image manipulation and how this relates to data integrity. Sharpening of a RAW image and making tonal adjustments are important parts of basic image processing. However, the ease of applying cloning stamps and cutting and pasting parts in Adobe Photoshop has led journal editors to say this is questionable and science ethicists to declare the practice simply wrong. Some journals are developing image manipulation guidelines and others encourage researchers to submit originals along with edited images. Archiving native RAW digital files and taking a few film shots are valuable should you need to defend the integrity of images used to tell an important story. Suffice it to say, immense caution is warranted when one chooses to modify an image to enhance a scientific point. See Gilbert and Richards (2000) for a discussion of digital imaging of bone modification and the ethical question of digital alteration.

18.10 Radiography

Analysis of bones in the living individual is usually accomplished by exposing a film to x-rays passed through the body part. The bone tissue blocks some x-rays, resulting in a negative image on the film called a **radiograph**. Because bones, including internal parts of bones, block some of the rays, the radiograph can be a valuable aid in diagnosing bone condition in medicine.

Radiography is also a valuable tool for the osteologist. Because there is no risk to a dry bone specimen, various exposures and orientations may be made to show the internal architecture of a bone or the developmental status of an unerupted dentition. Osteologists often use fully enclosed x-ray devices within shielded, benchtop cases with external controls (Faxitron or other). The specimen should be oriented so that the x-ray beam passes through the center of the area of interest and so that this area is perpendicular to the beam and parallel with the film plane. The specimen and film should be as far as practical from the x-ray source and as close to one another as possible. Computer-assisted enhancement of radiographs may be useful after processing (Odwak and Schulting, 1996). The development of computed tomography scanning adds a potent, nondestructive bone-sectioning tool to the osteologist's kit. CT scanners are usually only found in hospital radiography departments, and their use requires collaboration with personnel therein. Spoor *et al.* (1993) discuss applications and problems involved in the derivation of osteometric data from CT scans. With the advent of industrial CT scanning, accuracies of less than one tenth of a millimeter are routine. When possible, however, it is always better to take measurements directly from the specimen. This is because measuring a laser or CT scan greatly increases the chance that matrix, clothing, distortion, or erosion will be overlooked and inaccurate measurements generated. To use any of these techniques in investigating human skeletal material, consult a specialist in radiography. See Ortner and Putschar (1981), Hillson (1996), and Bruwelheide (2001) for discussions of radiography in osteological and dental analyses, and Mafart and Delingette (2002) for applications of three-dimensional imaging in paleoanthropology and prehistoric archeology.

18.11 Microscopy

Fine details on the surface of a bone or tooth may be best investigated with a binocular dissecting microscope. Intense, unidirectional light sources can be used to emphasize microscopic detail. For discriminating between various kinds of surface alteration on bones (root marks, cut marks, pathology), the binocular microscope is a most valuable aid. To photograph microscopic structure or trauma on the surface of a bone, the scanning electron microscope (SEM) can provide excellent images with great depth

Figure 18.6 A three-dimensional laser-scanning unit at the University of California, Berkeley. The machine accurately measures three-dimensional surface topography and transfers these data to a computer where measurements, restorations, and other manipulations are possible.

of field. For large specimens that do not fit in the vacuum chamber of the microscope, or for specimens housed in institutions without SEM facilities, it may be necessary to replicate the surface of the object by molding it with dental impression rubbers and pouring an epoxy positive for use in the analysis. For work on bone surfaces at high magnification, the SEM has been the traditional tool of choice (and, unfortunately, expense), but new digital imaging technologies are changing this (Gilbert and Richards, 2000). Standard histological microscopic techniques are used to study the microscopic structure of bone below the surface or the internal structure of teeth (Hillson, 1996). Schultz (1997) provides two reviews of how microscopy can be applied in human osteological studies.

18.12 Computing

The computer revolution continues to impact all areas of science, including human osteology. Satellites communicate with hand-held GPS (Global Positioning System) computers to determine latitude and longitude. Ruggedized laptop computers connected to electronic distance-measuring devices allow laser-precision in plotting specimens in the field. Desktop computers receive, process, and output our thoughts, our data, and our images. Laser scanners connected to computers allow the external form of objects to be imaged in three dimensions, imported to the computer, and manipulated digitally in many ways (Figure 18.6). Medical computers allow us to peer deep within osseous structures to see formerly hidden evidence of ancient pathology. The exploding global communications network makes it possible to exchange ideas and data rapidly across international frontiers and between field and laboratory. As a result of all of these developments, it is impossible to think of working in human osteology without the aid and working knowledge of computer technologies.

In addition to the basic word-processing skills and programs necessary for scholarly communication, all osteologists should learn the basics of database and spreadsheet programs that allow for the rapid and easy manipulation of large osteological data sets. Computers are tools that help the imagination, but they do not substitute for it. Unfortunately, human osteologists have not been immune to the false hope that computers and technology can replace real specimens and real expertise. The current high-tech craze has created some interesting exercises. For example, bones have been imaged by CT and laser scans, input to desktop and mainframe systems, manipulated therein (with attendant beautiful colors and bones floating and rotating in space), and then copied by sculpting the digitized bony form into plastic. Some such exercises are useful to surgeons customizing prosthetic devices and to investigators assessing fragile remains in matrix (Lynnerup *et al*., 1997). However, some of this high-tech wizardry applied to archeological and paleontological specimens leaves the observer to conclude, "That was really awesome, but so what?" Computers can do incredible things, but they are tools that help us investigate, organize, and document. They do not substitute for our own imagination or critical judgement when assessing osteological remains.

18.13 Reporting

After the usually unpublished initial field reports to granting agencies and various governmental regulatory agencies, published reporting of hominid osteological remains from paleontological contexts often occurs in three stages: first, announcement in a prominent international journal such as *Science* or *Nature*, followed by anatomical description in a more specialized journal such as the *American Journal of Physical Anthropology*, and finally, usually years later, full monographic treatment. Basic metric, preservational, and contextual data are reported, along with interpretations, in all three publication venues.

In forensic human osteology, the reporting of skeletal remains usually follows a different series of steps. Here, because of the rigorous procedures adopted by law enforcement agencies and medical examiners (DiMaio and DiMaio, 1989), the osteologist's most important report becomes part of the legal record instead of moving straight toward publication. The format for forensic reporting in the United States and beyond is set by the National Forensic Anthropology Data Bank at the University of Tennessee, Knoxville (Moore-Jansen and Jantz, 1989). The inventory encompasses the entire skeleton, and bones are scored for presence/absence and condition, with notes on things like pathology. Sundick (1984) provides a good review of the osteologist's participation in forensic cases.

In a forensic setting, the pressure for accurate and immediate reporting is sometimes very intense. Osteologists may be forced to conduct their examinations in suboptimal conditions—at morgues, in criminal laboratories, and even in refrigerated trucks or warehouses at the disaster scene. Pressure may come from the sensitivity of the case, from relatives wishing to conduct funerary rites, or from law enforcement agents requiring quick answers to pursue their investigations or hold their suspects. Under these conditions of inadequate facilities (including inadequate comparative materials) and intense pressure, osteologists are more prone to make mistakes. Suffice it to say that there is no tolerance for such mistakes in a forensic context, whatever the conditions. The forensic osteologist should always state what is defensible in a court of law, keep speculation to a minimum, and work closely with others on the multidisciplinary investigation team.

In archeological osteology, the collaborating archeologist and osteologist usually work out a reporting procedure in advance of the excavations and determine what information should be made available in reports or publications. The recent publication of the volume *Standards for Data Collection from Human Skeletal Remains* is a milestone in the standardization of data collection for osteological remains from archeological contexts. This 1994 volume, realized only under the pressure of federal legislation forcing imminent destruction of osteological collections (see Chapter 3), contains a series of chapters and appendices (inventory forms for adult and immature remains) that provide a framework for the observation and recording of osteological attributes. It is an invaluable resource for the osteologist practicing in an archeological context.

The following points are offered as a general guide to reporting on human osteological material. Most osteological reports, particularly in forensic settings, cover the points outlined here.

- **Introduction**. The osteologist should note when and how first contact was made regarding the case. The nature of the materials received or observed should be noted here. Any steps taken by the osteologist to preserve or otherwise alter the material should be outlined.
- **Bones present.** This is simply a listing of what bony remains were analyzed, sometimes with MNI determinations and their explanations included.
- **Context and condition of the remains.** This is particularly important in forensic and archeological work. Note should be made of the context in which the bones were found. Remember that all of the remains received for analysis constitute evidence, often crucial and always irreplaceable. In particular, any cultural or biological remains associated with the bones should be noted. Soft tissue adhering to the bones should be described. Before removal of any soft tissue remains, check with a forensic pathologist about sampling of this material. Any soft tissue present should be radiographed extensively before removal to check for objects within (bullets, clothing, etc.). Never dispose of any associated material without consulting the officials involved in the investigation.
- **Pathology.** Assessment should be limited to the hard tissue. Note any evidence of bony pathology and leave the soft tissue to other experts. Note healed fractures and

other osteological manifestations of disease.

- **Anomalies.** Report anything unusual about the skeletal remains, such as supernumerary digits or other nonmetric traits. These facts may help in individuation. In assessing radiographs, note any features that might be compared to antemortem films and thereby establish identity.
- **Trauma.** Report any signs of osteological trauma, ranging from healed fractures to excavation-related fractures. Try to determine how recent the fractures are by noting evidence of healing, color differences, or root-mark etching on broken surfaces. Express an opinion on whether the bone was fresh when broken (perimortem fracture) or dry (nonvital). Distinguish between pre- and post-depositional trauma when possible (Maples, 1986).
- **Age, sex, race, stature, and weight.** For these, be as specific as possible, but do not give estimates whose precision is not warranted. Give the appropriate limits of confidence in all determinations. Tell what methods were used to make the estimates and why these methods were used.
- **Time and cause of death.** Osteologists are almost never able to make these estimates with certainty. Whereas experienced investigators may speculate on time of death by using odor, grease, tissue, or bone weathering, these attributes all vary according to temperature, humidity, and cover. And how can the osteologist examining a gunshot through the head know that the victim was poisoned before being shot? For these reasons, the osteologist must work closely with a professional forensic pathologist and strictly avoid speculations about death based on bony evidence in isolation. By studying healed lesions the osteologist can sometimes say whether a person survived a skeletal trauma, but unhealed lesions often do not, by themselves, indicate the cause of death. The osteologist's legal contribution is usually limited to identification, sometimes including individuation. The skeleton itself gives little evidence relevant to questions about the time and cause of death.
- **Individuation** is sometimes referred to as "personal identification" (Rogers, 1986). This is the determination of the personal identity of the remains. The best hope for individuation, without soft tissue indicators such as fingerprints, is in dental records. For skeletal material lacking dental evidence for individuation, it is often possible to match pathological lesions or antemortem photographs or radiographs with postmortem images of the bone. Positive identifications may be based on old fractures or discrete trabecular or sinus patterns (Webster *et al*., 1986). See Caldwell (1986) for a discussion of techniques used in facial reproduction from a dry skull. Individuation is often important in legal and insurance matters.
- **Metrics and nonmetrics.** Report standard dental, cranial, and postcranial measurements, as well as observations on nonmetric traits.
- **Summary.** Simply summarize the most significant conclusions reached for the sections given here.

Osteological findings of general interest are usually reported in a scientific publication that makes data available to the scientific community as a permanent record. In describing the results of osteological analysis, communication must be unambiguous. The osteologist should specify exactly what materials were analyzed, what procedures were used in the analysis, and what results were achieved. Most scientific publications have basic sections of "Introduction," "Materials and Methods," "Results," "Conclusions," and "Bibliography." Scientific papers on human osteology are found frequently in book or monograph form as well as in journals such as the *American Journal of Physical Anthropology* and *Journal of Forensic Sciences*.

18.14 Curation

During the initial processing of skeletal material, it is advisable to label all bones individually with a prefix designating the site and a number representing the skeletal individual. For example, BOD-VP-1/1 is a specimen number for the first vertebrate paleontological specimen from the first locality collected in the Bodo area of Ethiopia in 1981. It is crucial that this labeling be legible, with numerals that anyone can read. Be very careful not to confuse 9s with 2s or 1s with 7s. Specimen numbers should be written in permanent, waterproof ink and protected under nail polish. For softer bones, it may be necessary to let a drop of preservative dry and harden on the bone surface before putting the label on the bone. This treatment prevents the ink from diffusing into an illegible blob. Specimen numbers are essential; they represent the critical links between bones and information on their original context. Mixing of labeled material is very bad practice in the laboratory, but mixing of unlabeled material is often irreversible, and therefore unforgivable. Labels should be put on bones early in the curatorial process.

There are two main objectives of curation. The first, as in other steps outlined earlier, is to prevent loss of information. Information loss can come in the form of actual physical destruction of the bones and teeth, in the mixing of unlabeled elements in the collection, or in the loss or destruction of the records (including computer records) for the skeletal material. Almost all simple breakage of bones can be repaired with glue. The objective of curation, however, is to prevent breakage in the first place by handling and storing bony material properly. Untrained or unqualified persons should not handle osteological material without supervision. Metric or photographic analysis of material should not be allowed to damage the specimens. Bones are fairly tolerant of a range of storage conditions, but their containers (boxes, trays, bags, padding) should be composed of a nondeteriorating, acid-free material. Bones should be stored in areas in which humidity, incident light, and extreme temperatures are kept to a minimum. Steps should be taken to see that insects and rodents are kept away from stored skeletal material and records. To prevent accidental loss of records from flooding, fire, or theft, it is advisable to make a copy of all skeletal records (whether digitally to a computer disk or as a hard copy) and to store this copy in a separate location.

The second major role of curation is the provision of research access to the collection. To provide this access, it is necessary to impose and maintain a high degree of organization in the skeletal collection. A researcher should be able to move quickly and efficiently between the bony remains and their records. Computer databases are important, not only for collection organization, but also as a means of enhancing research access. Caffell *et al.* (2001) provide an overview of curatorial procedures and problems in human osteology.

Chapter 19

The Skeletal Biology of Individuals & Populations

When osteological remains are recovered in forensic and archeological situations, the osteologist is often called on to make more than taxonomic identifications. Human skeletal remains often reach the osteologist without any documentation about their individual age, sex, stature, or racial affinity. The bulk of the literature on human osteology is composed of thousands of books and articles describing the development of methods to allow accurate and precise identification of individual traits in skeletal remains. This research continues today, even after a century of intensive study. All of this research and publication have been driven by the need for basic biological information about skeletal material from forensic and archeological contexts. In archeology, individual attributes of a skeletal individual become the fundamental components of work in the investigation of mortuary practices, paleopathology, and paleodemography. In forensic osteology, these individual biological attributes are important in narrowing the field of investigation to certain subsets of people and in establishing the individual identity of the remains. This chapter is an introduction to the progress that has been made in assessing the age, sex, stature, ancestry ("racial," or geographic, affinity), and individuation of human skeletal remains.

Our focus on the human skeletal elements in Chapters 7–16 was aimed at recognition, providing a guide to diagnostic aspects of human bones. Size and shape characteristics usually allow for the unambiguous sorting of human from nonhuman bone, even in very fragmentary material. Although the determination of sex from skeletal remains appears to be an analogous either/or decision, only a few skeletal characters allow the osteologist to make this choice. Furthermore, the other characteristics discussed in this chapter—individual age, stature, and ancestry—do not lend themselves to such easy and simple divisions as human/nonhuman or male/female. Rather, they grade continuously from prenatal to elderly, from short to tall, and from one geographic group to another. For this reason, it is often best to consider assessments of these characteristics as estimations rather than determinations.

Sorting human from nonhuman skeletal remains and identifying the remains by element, side, age, and sex are generally the most important contributions the osteologist can make to archeological research. Such identifications, far from being trivial, are often critical in answering archeological questions. Additional information, however, can often be obtained from skeletal populations. This information can be crucial in reaching a fuller understanding of the past. The reconstruction of population biology from skeletal remains is an activity that involves potential pitfalls as well as potential benefits for the osteologist.

The aims of paleoepidemiology (the study of disease in ancient communities) and paleodemography (the study of vital statistics in ancient communities) are to make statements about past populations based on the characteristics of subsets of those populations, including those for whom skeletal remains were recovered. As Waldron (1994) notes, four extrinsic factors act on dead populations, all reducing the size of the subset available for study. These four factors are extrinsic in the sense that they are independent of the biological features of the population under study. First, only a portion of those that die are buried at the site being studied. Second, only a portion of the buried evade destruction. Third, only a portion of the undestroyed are discovered. Fourth, only a portion of the discovered are recovered for the osteologist to analyze. With any of these fractionations, the skeletal subset can be biased relative to the sample of people in the original population who actually died. Careful evaluation of such potential bias is critical to accurately reconstructing populational attributes of ancient humans.

In the preceding chapters, emphasis was placed on the identification of skeletal parts at the level of the individual. The identifications of individuals and their sex, age, stature, pathology, and idiosyncratic skeletal characteristics can be critically important in forensic, archeological, or paleontological contexts. In the archeological context, however, skeletal remains allow us to take further steps in anthropological analysis. Such analysis aims to elucidate biological parameters of past human populations, including relatedness, diet, disease, and demography. These are areas of human osteology in which research continues at a rapid pace. The reader can keep current in techniques, protocols, and findings through reference to primary research published in journals such as *The American Journal of Physical Anthropology*, *The Journal of Forensic Sciences*, *Forensic Science International*, and *The International Journal of Osteoarchaeology*.

19.1 Accuracy and Precision of Estimation

Accuracy is the degree to which an estimate conforms to reality. Precision is the degree of refinement with which an estimate is made. Aging a mandible as subadult might be accurate, for example, but would still be imprecise. How accurately and precisely can the osteologist estimate the age, sex, stature, and affinity of human skeletal remains? There is no simple answer to the question. Any identification of a biological parameter such as age, sex, stature, or ancestry is, in effect, a probability statement. The likelihood that a given identification is accurate depends on a number of different factors that are worth general consideration before we turn to the analytical methods themselves.

- Accuracy and precision of identification depend on age categories. Because the growing human undergoes a progressive development of the bones and teeth, younger individuals can, in general, be aged more precisely than older individuals. For example, the ends of the limb bones form and fuse at known ages. Tooth formation and eruption are well-documented, although somewhat variable. After these growth processes end at maturity, there is little continuing skeletal change to monitor. Subsequent changes in the adult skeleton are often degenerative and task- or health-specific, and therefore not so well-correlated with elapsed time. Although precise skeletal aging becomes more difficult with adults, establishing the sex of an individual becomes easier. This is because sexual characteristics of the skeleton often develop only when sexual maturity is attained. Most of the criteria established for deducing ancestry are only useful in comparisons between adults. Krogman and İşcan (1986) provide a more detailed overview of these concerns in their text on forensic osteology.

- Accuracy and precision of identification depend on available skeletal elements. Different elements have different developmental stages. Some, such as tooth eruption, correspond more closely to chronological age than others, such as cranial suture closure. Some skeletal elements, such as the pubis of the os coxae, display sexually diagnostic characters, whereas others do not. Some elements, such as the femur, show high correlations with stature, whereas others do not. Some bones of the cranium are useful in discriminating between modern human groups, and others are not.
- Accuracy and precision of identification depend on sample composition. Accuracy of identification diminishes when the osteologist is forced to identify isolated individuals by means of age and sex standards derived from other populations. The most accurate and precise sexing and aging are obtained when it is possible to arrange many skeletal specimens in a series (to **seriate**) and to compare within a single biological population. For estimating sex, age, or racial affinity, it is always a great advantage to work with populations of skeletons rather than with isolated finds. This is sometimes the case in archeological settings, but forensic settings rarely provide the opportunity to work with large unknown samples.
- Accuracy and precision of identification depend on analytical methods. Different methods yield determinations of sex and age that have different reliability. For example, sexing a pubis with the Phenice technique (see Section 19.4.2) is highly reliable, whereas use of the sciatic notch is far less reliable.
- Accuracy and precision of identification depend on the applicability of the analytical methods to the unknown individual or sample. Most standards used for sexing and aging skeletal remains have been established on the basis of European and American skeletal series. These standards have not been shown to apply equally to human populations in other parts of the world or from prehistoric contexts (see Mensforth and Lovejoy, 1985; Ubelaker, 1987; King *et al.*, 1998), and some studies have suggested that interpopulational differences limit their utility (Schmitt, 2004). Not only is there variation within single populations in the rate of skeletal maturation, but there is also significant variation between populations (Lampl and Johnson, 1996). This factor is significant due to the limited number of populations on which the currently used methods have been based (see Section 19.2).
- Accuracy and precision of identification depend on research context. The degree of accuracy needed in a particular analysis depends on the questions being asked and the problems being investigated. If the problem involves merely sorting subadult mandibles from adult mandibles, accuracy should be 100%. However, if the investigation necessitates separation of 35-year-old from 36-year-old mandibles, no known method will be accurate.

19.2 From Known to Unknown

The very issue of aging and sexing skeletal remains and of determining their stature and affinity implies that these biological qualities are unknown for the specimens under analysis. To solve for such unknowns, the osteologist must proceed by comparing the unknown skeletal elements to a standard series of skeletal individuals whose age and sex are known. Where do such series exist? Not in many places — certainly not in archeological cemeteries lacking written records. Age, sex, stature, and affinity of skeletons from such contexts must therefore be treated as unknown qualities. For living individuals, variables are more often known. For this reason, radiographic study of modern human development has proven important in establishing aging standards for use by osteologists. Unfortunately, many surface features of bones in the living human are not visible by radiography.

In attempting to solve for unknown biological qualities of skeletal material, osteologists have made intensive use of five major skeletal collections in which there are more-or-less adequate records of age, sex, stature, and affinity. The Hamann-Todd collection was accumulated between 1912 and 1938 at Case Western Reserve University's Department of Anatomy. Here, 3592 human individuals from low socio-economic status were collected from area hospitals. According to a study of the Todd material and its records, only about 16% of the individuals in this collection have sufficiently reliable ages at death to be used in skeletal aging studies (Lovejoy *et al*, 1985). A second sample that has seen wide use in estimating age for bony remains is a set of skeletons of American military personnel killed in the Korean War (McKern and Stewart, 1957). Unfortunately, this set consisted primarily of male individuals with a limited age distribution. A third source is the Terry collection, some 1600 U.S. white and black adult skeletons from Washington University's Anatomy Department (1920–1965), now housed at the National Museum of Natural History, Smithsonian Institution, Washington, DC. The fourth collection that has begun to produce data helpful in the analysis of skeletal remains is composed of skeletal parts gathered from autopsied individuals in Los Angeles County (Suchey *et al*., 1986). The use of coroner-based samples to test and develop aging methods is increasing (Pfau and Sciulli, 1994). The fifth collection is the Cobb collection at Howard University, composed of about 600 skeletons of blacks from the Washington, DC, area.

Standards and methods developed from these collections all suffer some limitations. Except for some infants, most of the skeletons are from adults over 25 years of age. Racial categories are, for the most part, "black" and "white," which are legal and social terms based on local custom rather than biological ancestry. Admixture is unaccounted for. These mostly dissection-room samples are often of below-average socioeconomic status. Many times the ages of death recorded in the collection records are only estimates made by the coroner.

To summarize, the accuracy and precision of an osteologist's attributions of an age, sex, or stature to a skeleton for which these variables are unknown always depend on standards derived from a series of skeletons originally accompanied by independent records of these biological attributes. There are significant problems involved with controlling biological attributes of archeologically derived skeletal material with these and other collections of modern human bones. Most important among them is that none of the series contain people who lived under aboriginal, non-Western subsistence conditions. The effects of different lifestyles on individuals that make up skeletal series can be dramatic. For example, the rate and degree of tooth wear are higher in aboriginal populations, as is the amount of muscular stress and osteological reaction to that stress.

19.3 Estimation of Age

Individual age determination in skeletal remains involves estimating the individual's age at the time of death rather than the amount of time that has elapsed since death. Ubelaker (1989, p. 63) succinctly encapsulates the procedures and problems inherent in aging skeletal remains:

> *Estimation of age-at-death involves observing morphological features in the skeletal remains, comparing the information with changes recorded for recent populations of known age, and then estimating any sources of variability likely to exist between the prehistoric and the recent population furnishing the documented data. This third step is seldom recognized or discussed in osteological studies, but it represents a significant element.*

However, many of the attributes that are used to determine age do not seem to be environmentally plastic. The degree to which age standards derived from modern osteological collections may be applied to prehistoric populations is a matter of continuing debate (Hoppa, 2000), but available studies indicate that individual variation often swamps populational differences.

Over the course of a lifetime, elements of the skeleton undergo sequential chronological change. In infancy these changes primarily involve the appearance of various skeletal elements. During childhood and adolescence, bones and teeth continue to appear, and epiphyses form and fuse. Even after age 20, bones continue to fuse, metamorphose, and degenerate. This progression forms the foundation for studies of skeletal aging. However, it is important to note that even normal development of the infant is discontinuous and saltatory (Lampl *et al.*, 1992), and that there is substantial variation among different individuals in the rate and timing of developmental changes. Pathology can also play a role (Sherwood *et al.*, 2000).

Sex identification in skeletal remains is dichotomous, but determination of an individual's age-at-death is more complex because it involves arbitrarily dividing the continuum of growth. Individuals of the same chronological age can show different degrees of development. This is true for skeletal anatomy as well as for behavior. Thus, even when osteological standards based on known samples are perfect, there is always a degree of imprecision in aging skeletal remains. What is the magnitude of this imprecision?

As noted earlier, whether dealing with cranial bones, teeth, or post cranial elements, an already-established "system" is used for osteological aging; criteria for aging are identified based on a population whose individuals have known ages. It is possible, for example, to use radiographs of people in living populations to establish that human permanent molars erupt at about 6, 12, and 18 years of age. This control series can then be used to age each individual in an unknown skeletal series, under the assumption that dental eruption followed the same periodicity in both groups.

One drawback in such an approach to the unknown skeletal series is that age assignments are made on an individual basis, without reference to other individuals in the unknown series. Such assignments place individuals into an **age class**, for instance, of 12–18 years. This aging is not as precise as assigning an absolute age, for example, of 15 years. In other words, dividing a continuum leads to imprecision. As Lovejoy and colleagues (1997) note, there are two major sources of error in any estimate of age-at-death. These are the inherent variation within the biological process of aging itself and the investigator's skill in estimating the biological age of the unknown specimen.

An approach that should always be taken with a large sample of unknown individuals to help overcome these imprecisions is **seriation**. Prior to estimating each unknown individual's age, all of the individuals represented by the skeletal element under analysis in the unknown series are arranged in a sequence of increasing age. This approach has many benefits (Lovejoy *et al*, 1985): seriation may be done quickly, with little fatigue; there is no observer error due to time-shift effects (e.g., having to stop in the middle of the analysis because the work day ends); there is constant monitoring of results, with ability to correct observer errors; and there is no loss of accuracy as a result of pooling individuals into age categories. Once the sample under analysis is seriated, at least the individuals have been aged *relative to each other*.

Seven age classes commonly used to segregate human osteological remains are as follows: **fetus** (before birth), **infant** (0–3 years), **child** (3–12 years), **adolescent** (12–20 years), **young adult** (20–35 years), **middle adult** (35–50 years), and **old adult** (50+ years) (Buikstra and Ubelaker, 1994). Scheuer and Black's volumes (2000, 2004) represent excellent resources for work involving the aging of immature human skeletal remains.

19.3.1 Estimating Subadult Age from Dentition

Eruption and wear of the teeth have been used extensively in aging the human skeleton. Tooth development is more closely associated with chronological age than is the development of most other skeletal parts, and it seems to be under tighter genetic control. Because of the regular formation and eruption times for teeth and because these elements are the remains found most commonly in forensic, archeological, and paleontological contexts, dental development is the most widely used technique for aging subadult remains. Smith (1991) provides a review of the various techniques available. It is important to note that "regular" does not mean "constant." For example, some infants erupt their teeth earlier in their lives, and different individuals erupt their teeth in different orders (Smith and Garn, 1987). It has been shown that some American blacks and whites differ in both rate and sexual dimorphism of tooth mineralization (Harris and McKee, 1990).

Tooth formation begins in the embryo a mere 14–16 weeks after conception (Hillson, 1996). There are four distinct periods of emergence of the human dentition. First, most deciduous teeth emerge during the second year of life. The two permanent incisors and the first permanent molar usually emerge between 6 and 8 years. Most permanent canines, premolars, and second molars emerge between 10 and 12 years. Finally, the third molar emerges around 18 years. Of course, there is interindividual variation in all tooth development and eruption.

Age may be determined from developing teeth in several ways. One means is by comparing the unknown individual with a chart or atlas showing the mean stage of development of the entire dentition (Figures 19.1 and 19.2). Another is through comparison of the stages of formation with each individual tooth (Table 19.1). Liversidge (1994) discusses the pros and cons of these methods and recommends the atlas approach for both accuracy and ease of use. Hillson (1996) provides an excellent review of all methods of aging the skeleton through use of dental development. The third molar is the most variable tooth in formation and eruption. Mincer *et al.* (1993) provide data on the formation of this tooth and its use in age estimation.

Ubelaker (1989) provides a graphic summary of data on dental development in Native Americans, which we reproduce in Figure 19.1. Note the possible ranges associated with each stage in the diagram. Figure 19.2 shows the source of these errors. Sex-based variation in development and eruption of teeth is most apparent at the canine position, and this tooth should be afforded less attention when aging erupting dentitions. When assessing the age of a subadult individual based on dentition, note all aspects of development, including the completeness of all crowns and roots (**formation**) and the place of each tooth relative to the alveolar margin (**eruption**). When using published standards, be sure to discriminate between emergence through the alveolar margin (bone) or through the gum (soft tissue). Also note that dental development is sensitive to sex and population differences (İşcan, 1988). For more details on dental development and eruption, see Trodden (1982) and Smith (1991).

19.3.2 Estimating Adult Age from Dentition

Once a permanent tooth erupts, it begins to wear. Rate and patterns of wear are governed by tooth developmental sequences, tooth morphology, tooth size, internal crown structure, tooth angulation, nondietary tooth use, the biomechanics of chewing, and diet (McKee and Molnar, 1988; Walker *et al.*, 1991). If the rate of wear within a population is fairly homogeneous, it follows that the extent of wear is a function of age. This fact can be used in assigning dental ages to adult specimens. Where this has been tested on modern populations, correlations between known age and tooth wear have been shown to be good (Lovejoy *et al.*, 1985; Richards and Miller, 1991). However, the osteologist should always be on the lookout for cases of accelerated wear due to pathology or use of the teeth as tools (Milner and Larsen, 1991).

The first step in assessing age by dentition is application of a seriation of all dentitions based on development and wear. Miles (1963) was the first to establish a scale of attrition based on development. The basics of the technique are as utilized in the following example: A first molar accumulates about 6 years of wear before the second molar of the same individual erupts (assuming eruption at 6 and 12 years, respectively). When a similar amount of wear (6 years' worth) is found on a third molar of another individual (a molar assumed to have erupted at age 18), the age of that individual can be estimated as $18+6=24$ years. Miles uses 6.0, 6.5, and 7.0 years between successive molar eruption. The technique underestimates individuals over 50 years of age (Miles, 2001). A variety of techniques have been applied to the quantification of tooth wear

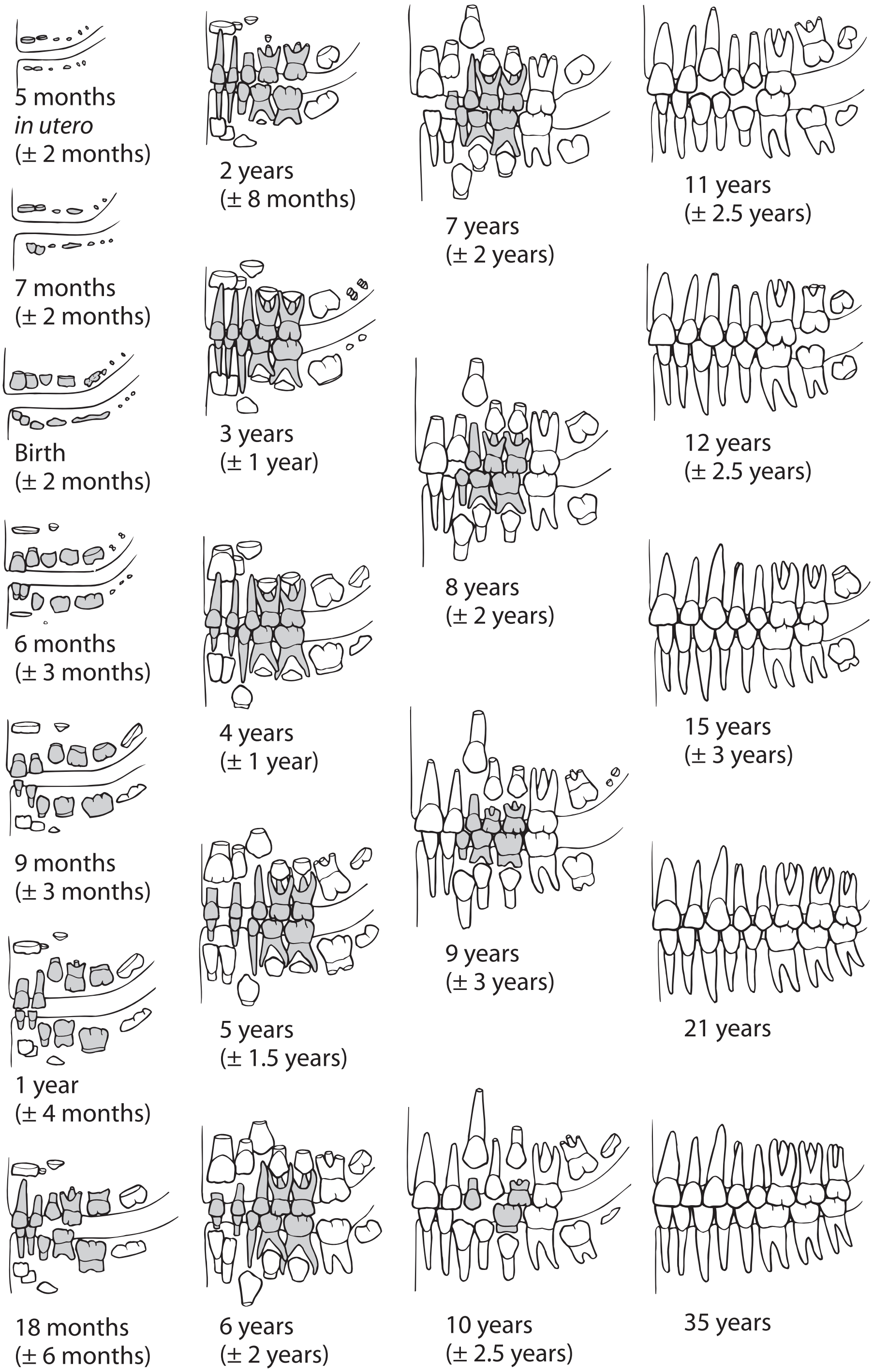


Figure 19.1 Dental development in Native Americans [adapted from Ubelaker (1989); note that data on the deciduous teeth come from non-Native Americans].

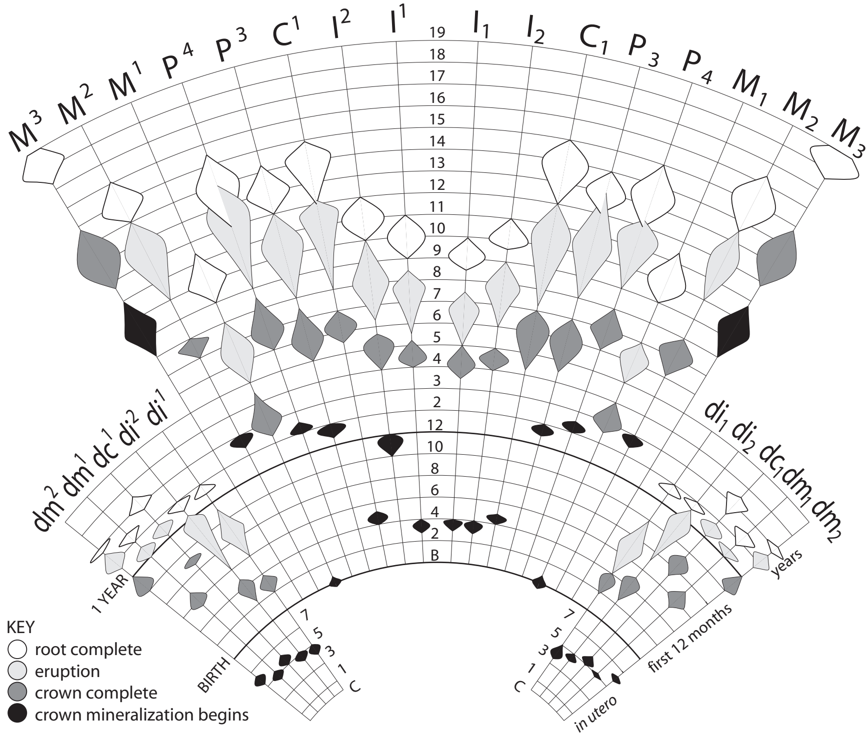


Figure 19.2 Variation in the timing of dental development based on Gustafson and Koch (1974), with third molar data from Anderson *et al.* (1976). Range values are plus or minus one standard deviation for the third molars. Patterns: black, crown mineralization begins; dark gray, crown completion; light gray, eruption; white, root completion.

(Molnar, 1971; Scott, 1979; Brothwell, 1989; Walker *et al.*, 1991; Dreier, 1994; Mayhall and Kageyamu, 1997).

Lovejoy (1985) has concluded, for the prehistoric Libben skeletal population, a large human osteological series from the midwestern United States, that dental wear assessed by seriation procedures is an important and reliable indicator of adult age-at-death. He found, on the populational level, that dental wear was very regular in form and rate. As Lovejoy notes, the assessment of a single individual in a forensic setting based on dental wear allows only a gross approximation of age, but if an entire biological population is seriated, tooth wear can yield precise results. In fact, Lovejoy and colleagues (1985a) concluded that dental wear is the best single indicator for determining the age of death in skeletal populations. They found dental wear as an age indicator to be accurate and consistently without bias. Figure 19.3 illustrates the wear standards used by these workers. Mays (2002) has also found dental wear to be a reliable indicator in a very different historical Dutch skeletal collection.

Hillson (1986) and Whittaker (2000) discuss methods useful in assessing individual age based on microscopic analysis of the permanent teeth. As teeth age, formation

Table 19.1

Average Age (in years) of a Skeletal Individual Based on Assessment of Dental Development at Each Crown Position[a]

		di1	di2	dc	dm1	dm2	I1	I2	C	P3	P4	M1	M2	M3
A. MALES														
Ci	Cusp initiation	—	—	—	—	—	—	—	0.6	2.1	3.2	0.1	3.8	9.5
Cco	Cusp coalescence	—	—	—	—	—	—	—	1.0	2.6	3.9	0.4	4.3	10.0
Coc	Crown outline complete	—	—	—	—	—	—	—	1.7	3.3	4.5	0.8	4.9	10.6
Cr ½	Crown one half	—	—	—	—	—	—	—	2.5	4.1	5.0	1.3	5.4	11.3
Cr ¾	Crown three-quarters	—	—	—	—	—	—	—	3.4	4.9	5.8	1.9	6.1	11.8
Crc	Crown complete	0.15	0.2	0.7	0.4	0.7	—	—	4.4	5.6	6.6	2.5	6.8	12.4
Ri	Root initiated	—	—	—	—	—	—	—	5.2	6.4	7.3	3.2	7.6	13.2
Rcl	Root cleft present	—	—	—	—	—	—	—	—	—	—	4.1	8.7	14.1
R ¼	Root one-quarter	—	—	—	—	—	—	5.8	6.9	7.8	8.6	4.9	9.8	14.8
R ½	Root one-half	—	—	—	—	—	5.6	6.6	8.8	9.3	10.1	5.5	10.6	15.6
R ⅔	Root two-thirds	—	—	—	—	—	6.2	7.2	—	—	—	—	—	—
R ¾	Root three-quarters	—	—	—	—	—	6.7	7.7	9.9	10.2	11.2	6.1	11.4	16.4
Rc	Root complete	1.5	1.75	3.1	2.0	3.1	7.3	8.3	11.0	11.2	12.2	7.0	12.3	17.5
A ½	Root apex half closed	—	—	—	—	—	7.9	8.9	12.4	12.7	13.5	8.5	13.9	19.1

		di1	di2	dc	dm1	dm2	I1	I2	C	P3	P4	M1	M2	M3
B. FEMALES														
Ci	Cusp initiation	—	—	—	—	—	—	—	0.6	2.0	3.3	0.2	3.6	9.9
Cco	Cusp coalescence	—	—	—	—	—	—	—	1.0	2.5	3.9	0.5	4.0	10.4
Coc	Crown outline complete	—	—	—	—	—	—	—	1.6	3.2	4.5	0.9	4.5	11.0
Cr ½	Crown one half	—	—	—	—	—	—	—	2.5	4.0	5.1	1.3	5.1	11.5
Cr ¾	Crown three-quarters	—	—	—	—	—	—	—	3.5	4.7	5.8	1.8	5.8	12.0
Crc	Crown complete	0.15	0.2	0.7	0.3	0.7	—	—	4.3	5.4	6.5	2.4	6.6	12.6
Ri	Root initiated	—	—	—	—	—	—	—	5.0	6.1	7.2	3.1	7.3	13.2
Rcl	Root cleft present	—	—	—	—	—	—	—	—	—	—	4.0	8.4	14.1
R ¼	Root one-quarter	—	—	—	—	—	4.8	5.0	6.2	7.4	8.2	4.8	9.5	15.2
R ½	Root one-half	—	—	—	—	—	5.4	5.6	7.7	8.7	9.4	5.4	10.3	16.2
R ⅔	Root two-thirds	—	—	—	—	—	5.9	6.2	—	—	—	—	—	—
R ¾	Root three-quarters	—	—	—	—	—	6.4	7.0	8.6	9.6	10.3	5.8	11.0	16.9
Rc	Root complete	1.5	1.75	3.0	1.8	2.8	7.0	7.9	9.4	10.5	11.3	6.5	11.8	17.7
A ½	Root apex half closed	—	—	—	—	—	7.5	8.3	10.6	11.6	12.8	7.9	13.5	19.5

[a] The data are from Smith's (1991) compilation of published studies.

of secondary dentine reduces the coronal height of the pulp cavity. Drusini *et al.* (1997) used this to age radiographs of adult individuals to ±5 years on 78% of teeth assessed. Other studies have shown that apical translucency of tooth roots correlates with adult age, but applications of the technique have shown it to be less useful than other methods (Kvaal *et al.*, 1994). In some forensic cases, a combination of gingival regression and root transparency may allow aging of adults over 40 and under 80 years of age with a mean error of estimation of ± 10 years (Lamendin *et al.*, 1992). Soomer *et al.* (2003) provide a comparative overview of various methods applied in forensic work.

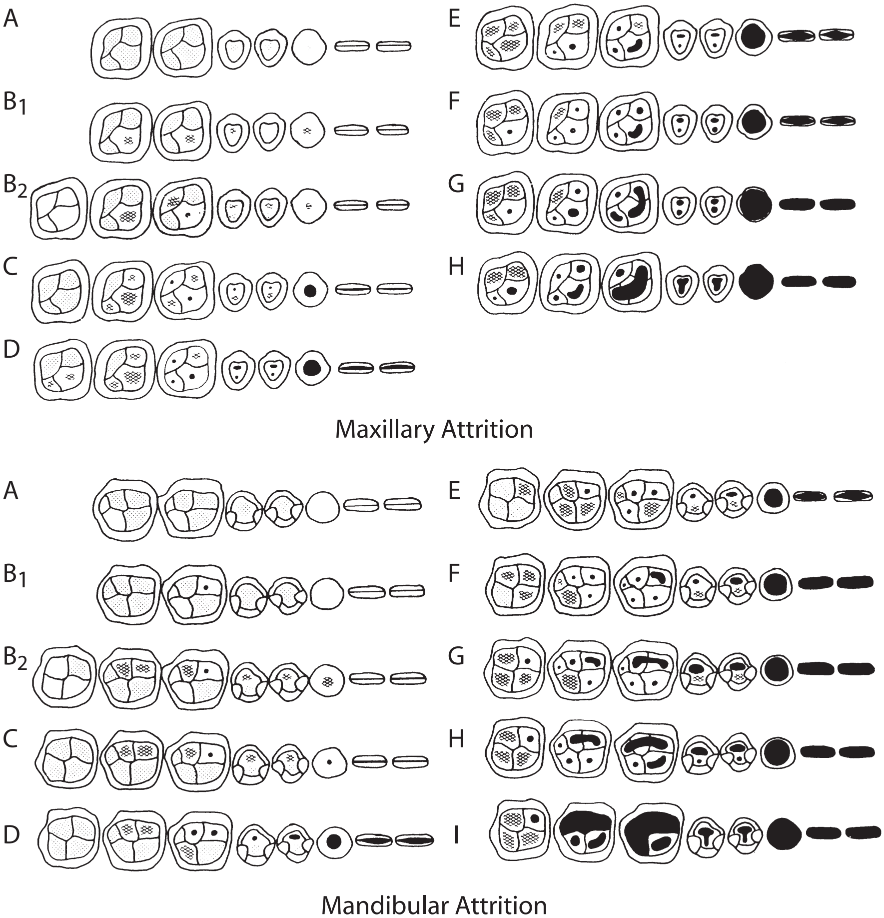


Figure 19.3 Modal tooth-wear patterns of a prehistoric Native American population from Libben, Ohio. Wear is divided into phases for right maxillary (top) and left mandibular (bottom) dentitions. Exposed dentine is shown in black. Age in years for the various phases are as follows: A, 12–18; B_1, 16–20; B_2, 16–20; C, 18–22; D, 20–24; E, 24–30; F, 30–35; G, 35–40; H (maxillary), 40–50; H (mandibular), 40–45; I, 45–55. See Lovejoy (1985) for a full description.

19.3.3 Estimating Adult Age from Cranial Suture Closure

It has been appreciated since the 1500s that sutures between various cranial bones fuse progressively as the individual ages. In the early 1900s suture closure enjoyed widespread use in skeletal aging, but the false promise of one or two accurate indicators of adult skeletal age during the 1950s (such as metamorphosis of the pubic symphysis) led to disuse of the technique. Meindl and Lovejoy (1985), however, reinvigorated the study of cranial suture closure. They chose a series of 1-cm segments of ten sutures or

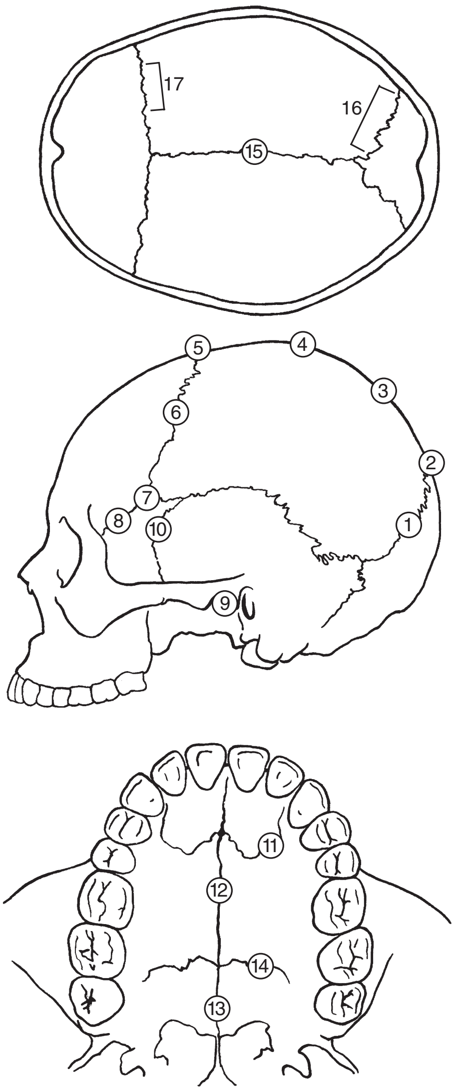


Figure 19.4 Cranial suture fusion sites, after P. Walker, in Buikstra and Ubelaker, (1994) (sites *left*, descriptions *opposite*, scores *below*). A score of from 0 (unfused) to 3 (completely obliterated) is assigned to each site. Sites are 1-centimeter ectocranial segments of the sutures as shown. Endocranial segments are slightly larger. In the Meindl and Lovejoy (1985) system, scores are independently summed for vault (Nos 1 – 7) and lateral-anterior (Nos 5 – 10) sites. Other suture sites, such as the maxillary suture (Mann *et al*., 1991), have been used to segregate individuals into even broader age categories, but their use in forensic cases has been questioned (e.g. Gruspier and Mullen, 1991).

Meindl and Lovejoy (1985) "vault" sutural ages (add scores for sites 1–7).

Composite Score	*Mean Age*	*Standard Deviation*
0	—	—
1–2	30.5	9.6
3–6	34.7	7.8
7–11	39.4	9.1
12–15	45.2	12.6
16–18	48.8	10.5
19–20	51.5	12.6
21	—	—

Meindl and Lovejoy (1985) "lateral-anterior" sutural ages (add scores for sites 6–10).

Composite Score	*Mean Age*	*Standard Deviation*
0	—	—
1	32.0	8.3
2	36.2	6.2
3–5	41.1	10.0
6	43.4	10.7
7–8	45.5	8.9
9–10	51.9	12.5
11–14	56.2	8.5
15	—	—

	Site	*Description*
1	Midlambdoid	Midpoint of left lambdoid suture
2	Lambda	Intersection of sagittal and lambdoidal sutures
3	Obelion	At obelion
4	Anterior sagittal	One-third the distance from bregma to lambda
5	Bregma	At bregma
6	Midcoronal	Midpoint of left coronal suture
7	Pterion	Usually where the parietosphenoid suture meets the frontal
8	Sphenofrontal	Midpoint of left sphenofrontal suture
9	Inferior sphenotemporal	Intersection between left sphenotemporal suture and line between articular tubercles of the temporomandibular joint
10	Superior sphenotemporal	On left sphenotemporal suture 2 cm below junction with parietal
11	Incisive suture	Incisive suture separating maxilla and premaxilla
12	Anterior median palatine	Score entire length on paired maxillae between incisive foramen and palatine bone
13	Posterior median palatine	Score entire length
14	Transverse palatine	Score entire length
15	Sagittal (endocr.)	Entire sagittal suture endocranially
16	Left lambdoidal (endocr.)	Score indicated portion
17	Left coronal (endocr.)	Score indicated portion

Meindl and Lovejoy (1985) "vault" sutural ages (add scores for sites 1–7).

Figure 19.4 (continued)

suture sites and scored these on a scale of 0 (open) to 3 (complete obliteration). The results erased some of the prejudice against suture closure assessment as a means of skeletal aging in the adult and stimulated more research in this area. Galera *et al.* (1998) provide a comparative analysis of different cranial suture aging methods. One cranial feature, the sphenooccipital synchondrosis, is particularly useful in aging isolated crania because at least 95% of all individuals have fusion here between 20 and 25 years of age, with a central tendency at 23 years of age (Krogman and İşcan, 1986).

Other cranial sutures show more variation in age of closure. The Ley *et al.* (1994) work on the Spitalfields population from Britain indicates that there may be sexual and interpopulational differences in the rates of suture closure. This study developed yet another technique of scoring suture closure. The Buikstra and Ubelaker Standards volume (1994) recommends that seventeen cranial suture segments each be given a numerical score. The score of 0, or **open**, is given when there is no evidence of any ectocranial closure. A score of 1 is given to suture sites with **minimal closure**. A score of 2 is given to sites with **significant closure**, and a score of 3 is given to a **completely obliterated** suture (complete fusion). Figure 19.4 shows the location of the 1-cm sutural sites.

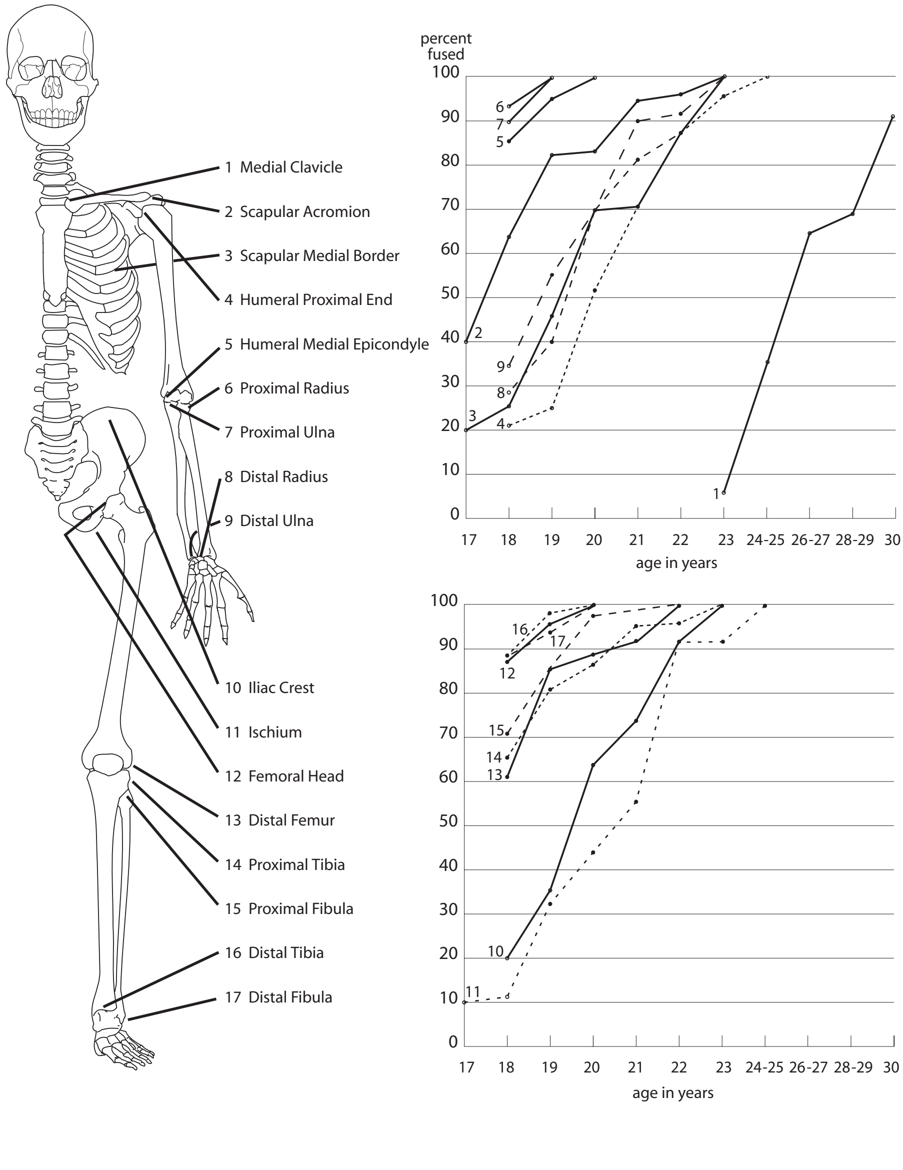


Figure 19.5 Ages of fusion for various male skeletal elements. Data on fusion from McKern and Stewart (1957). These standards, derived from U.S. military personnel who died in the Korean War, show considerable variation in fusion for any given element. For example, in the medial clavicle, McKern and Stewart (1957) found that of 10 individuals aged 17 years, none had fused epiphyses. For the clavicle, the epiphyseal cap begins to unite to the medial end of the clavicle as early as 18 years but can begin to unite at any time between 18 and 25 years. The earliest complete fusion came among some soldiers who died at 23 years, but the study showed that others lived to age 31 before fusion was complete. To use this table, choose a numbered epiphysis from above or below the waist and find its graph to the right of the skeleton. The graph shows what percentage of adult male individuals showed full fusion of each epiphysis at any given age.

19.3.4 Estimating Subadult Age from Long-Bone Length

In the absence of teeth and various epiphyses, subadult individual age may be estimated from long-bone length. This procedure of subadult skeletal aging is not as exact as others and should always be done with reference to the same or a closely related skeletal collection. Seriate the growth series and compare the isolated long-bone lengths to the series in order to derive ages. If series are not available, data presented in Ubelaker (1989) are useful in age assessment. For age and sex determination of fetal and neonatal material, consult Weaver (1986) and Fazekas and Kosa (1978).

19.3.5 Estimating Subadult Age from Epiphyseal Closure

Fusion of a postcranial epiphysis is orderly, and an epiphysis fuses at a known age. However, these ages vary by individual, sex, and population. As Stevenson (1924) points out, the intensity of epiphyseal activity is greatest between ages 15 and 23. Fusion of the epiphysis is progressive and is usually scored as unfused (nonunion), united, or fully fused (complete union). The beginning of epiphyseal union for several elements overlaps the conclusion of tooth eruption, making these aging techniques complementary.

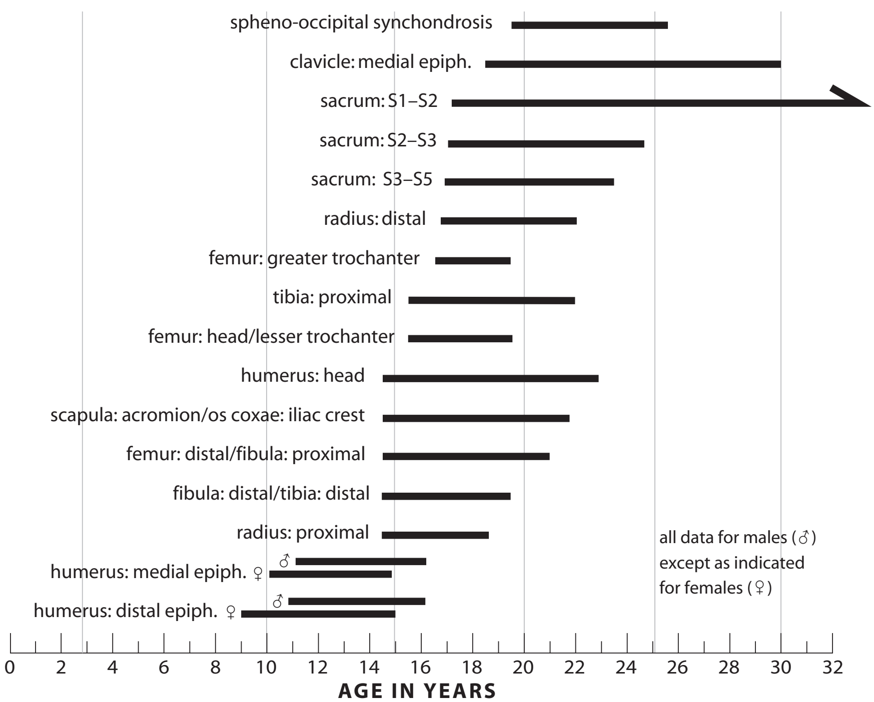


Figure 19.6 Timing of the fusion of epiphyses for various human osteological elements. Horizontal bars indicate the period during which union/fusion is occurring. Male and female data are taken from Buikstra and Ubelaker's Standards volume (1994).

Figures 19.5 and 19.6 illustrate the considerable interindividual variation in the chronology of epiphyseal union for several human skeletal elements using data taken from male Korean War dead (McKern and Stewart, 1957). Much of the work on epiphyseal union has been done on long bones, but recent work on vertebrae show the utility of these elements, particularly in aging teenagers and young adults (Albert and Maples, 1995).

It should be noted that union begins earlier in females than in males and that different individuals of the same sex can show very different times of union. The last epiphysis to fuse is usually the medial clavicle, at about 21 years. Late-fusing bones such as the clavicle, however, show wide variation in age at fusion. For example, some medial clavicle epiphyses fuse before 21 years, whereas other individuals show persistent nonfusion at age 30 [for more references, consult Stevenson (1924); Mensforth and Lovejoy (1985); Webb and Suchey (1985); and Krogman and İşcan (1986)]. Growth ends once fusion of all epiphyses occurs, under 28 years of age for the great majority of cases. As a result, fewer age indicators remain for the postcranial skeleton of the adult individual.

19.3.6 Estimating Adult Age from the Pubic Symphyseal Surface

One of the most widely used indicators of age-at-death has been metamorphosis of the symphyseal surface of the pubis of the os coxae. Age-related changes on this surface continue after full adult stature has been achieved and other epiphyses of the limbs have fused. Pubic symphyses of other primates metamorphose more quickly than human ones and usually synostose with advancing age. In humans, however, changes of the symphyseal surfaces allow them to be used in generating osteologically determined age-at-death estimates. The young adult human pubic symphysis has a rugged surface traversed by horizontal ridges and intervening grooves. This surface loses relief with age and is bounded by a rim by age 35. Subsequent erosion and general deterioration of the surface are progressive changes after this age. Figure 19.7 illustrates these changes.

Age-related changes at the pubic symphysis have been recognized for many years, and the first formal system for using these changes to determine age was developed by Todd (1920), based on a series of 306 males of known age-at-death. Todd identified four basic parts to the pubic symphysis, a surface with an irregular oval shape: (a) the ventral border (rampart), (b) the dorsal border (rampart), (c) the superior extremity, and (d) the inferior extremity. Todd noted evidence of billowing, ridging, ossific nodules, and texture on each part of the symphyseal surface. Using these observations on his sample of known ages, Todd recognized ten phases of pubic symphysis age, ranging from 18/19 years to 50+ years, and noted that these phases were more reliable age indicators between 20 and 40 years than after 40 years. He perceived three major stages in symphysis metamorphosis. His phases I–III comprised the "postadolescent" stage, phases IV–VI were the buildup stage, and phases VII–X represented the degenerative stage. Figure 19.7 illustrates Todd's original standards; subsequent work on age-based changes in this anatomical region is based on this foundation.

Few tests of this method were made, although the method gained wide acceptance. Brooks (1955) found a tendency of the Todd system to overage, especially in the third and fourth decades. In 1957, McKern and Stewart used skeletal remains of 349 male

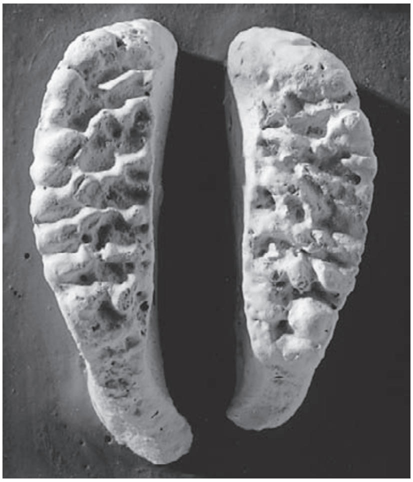
Korean War dead in an effort to refine the Todd method. Their approach was to divide the symphyseal surface longitudinally into two halves, or "components"—the "dorsal demi-face" and the "ventral demi-face." The third component of the symphysis was the "symphyseal rim." Five developmental stages were recognized for each of the three components. In using this system, the osteologist calculates a developmental stage for each component, adds these together, and derives an age of death for the specimen. This system, like that of Todd, was derived from an all-male sample of limited age range.

Gilbert and McKern (1973) used a sample of 103 females of known age to generate a component system for aging female specimens by the pubis. Because female pubic symphyses are subject to trauma during childbearing, there is a potential for premature changes in the bone surface, which could lead to overaging. In 1979, Suchey tested the Gilbert and McKern method for aging the female pubic symphysis by asking 23 professional osteologists to age pubic faces of unrevealed age. Results showed the system to be highly unreliable and prone to inaccurate estimates.

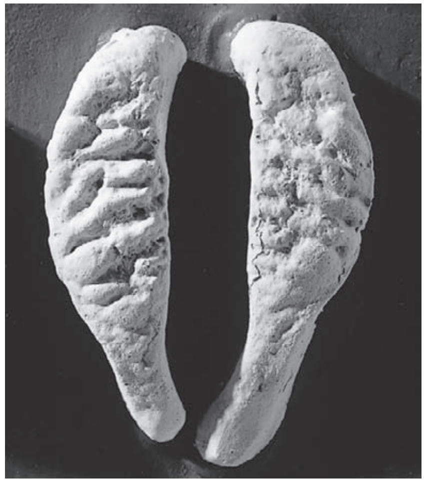
Meindl and colleagues (1985a) tested the accuracy of all these methods in a study of the Hamann-Todd collection. They found that the original Todd method was more reliable than the more recent component techniques and that all systems tended to underage. They recognize five major biological phases for the pubic symphysis and provide careful illustrative documentation of their results. They also provide a much-needed biological perspective on the metamorphosis of the pubic symphysis and assess this part of the anatomy from a comparative evolutionary background (see also Lovejoy *et al.*, 1995, 1997).

Suchey *et al.* (1986) and Katz and Suchey (1986), working on the large Los Angeles County Coroner multiracial sample, examined 739 male individuals between the ages of 14 and 92. These investigators contend that age-at-death data for their skeletal individuals are more accurate and precise than those used to build the Todd, McKern-Stewart, and Meindl *et al.* standards. The Todd and McKern-Stewart methods were tested on the Los Angeles sample and interobserver error was assessed. As a result, modifications of the earlier techniques of pubic symphysis age estimation were suggested. Katz and Suchey (1986) suggest that Todd's methodology is excellent, but that the collection he used was inadequate. They recommend the use of a modified Todd approach with six phases defined on the entire symphyseal face. Their data clearly show a large amount of variation in ages for any one phase, particularly for older individuals. For example, their Phase V shows a mean age of 51 years, but only 95% of the sample of 241 male pubic symphyses that matched this phase was within the wide age limits of 28 to 78 years.

An assessment of "race" differences among 704 of the male pubic bones was undertaken by Katz and Suchey (1989). Following implementation of the six-phase Suchey-Brooks system for male individuals, 273 female pubic bones were studied, and a system analogous to the male system was devised. Refined descriptions of the Suchey-Brooks method are found in Brooks and Suchey (1990) and in Figure 19.8. In a test of this and other pubic symphysis aging methods, Klepinger *et al.* (1992) concluded ". . . all the aging methods based on the os pubis proved disappointing in regard to both accuracy and precision." They recommend that the "racial" refinement of the Suchey-Brooks system be used, that any independent evidence of trauma or debilitation be considered, and that all estimated ages be reported within a standard deviation interval of plus or minus two years.

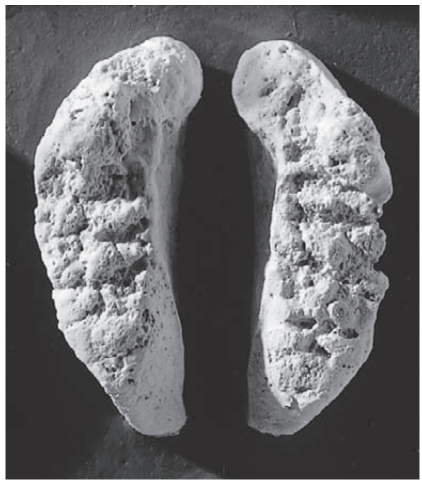


I 18–19 years



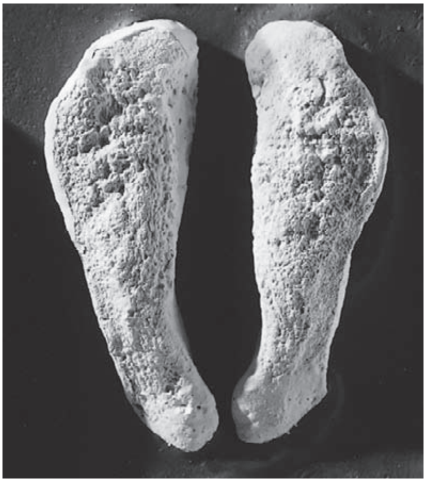
II 20–21 years

III 22–24 years

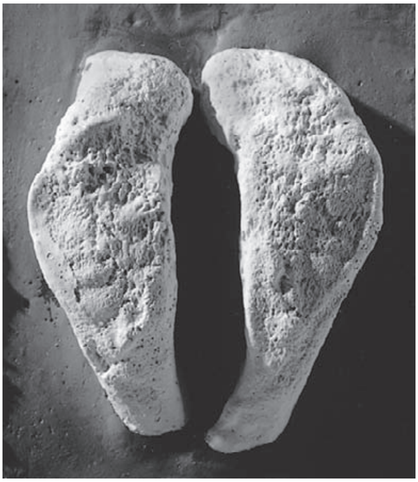


IV 25–26 years

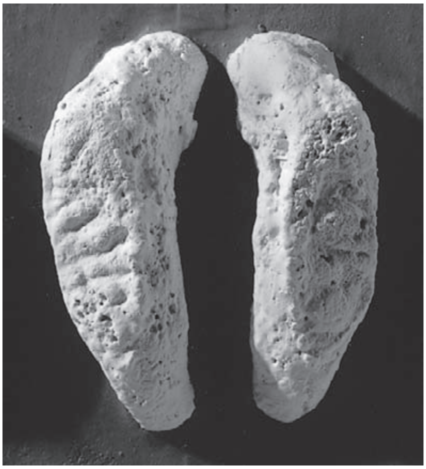
Figure 19.7 Todd's (1920) ten age phases of pubic symphysis modification in adult white males. Todd's standard specimens are shown here, natural size. The anterosuperior ends of the pubic symphyses are toward the top of the page, and the ventral margins of each symphysis pair are opposed. In the original Todd study, phases were defined according to topography on the symphyseal surface and the nature of the margins of this surface. Note the wider age ranges for the higher stages. For more details on application of the Todd technique, consult the original 1920 publication. Many newer standards have been published since this first attempt to use changes in the topography of the pubic symphysis to age the skeleton, all relying on the bony changes that correlate with age.



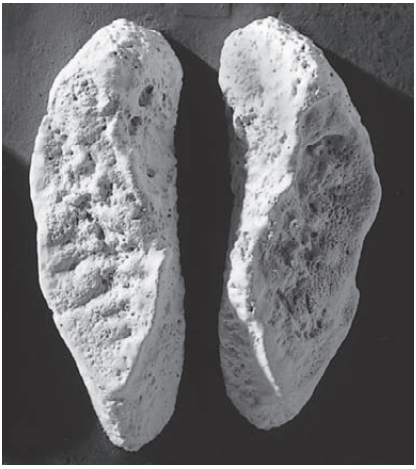
V 27–30 years



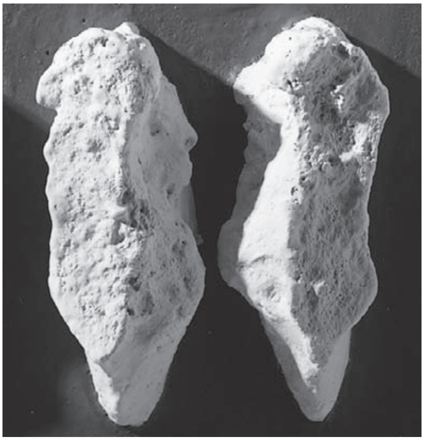
VI 30–35 years



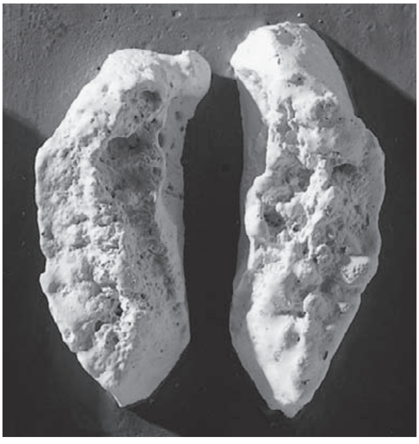
VII 35–39 years



VIII 39–44 years



IX 44–50 years



X 50+ years

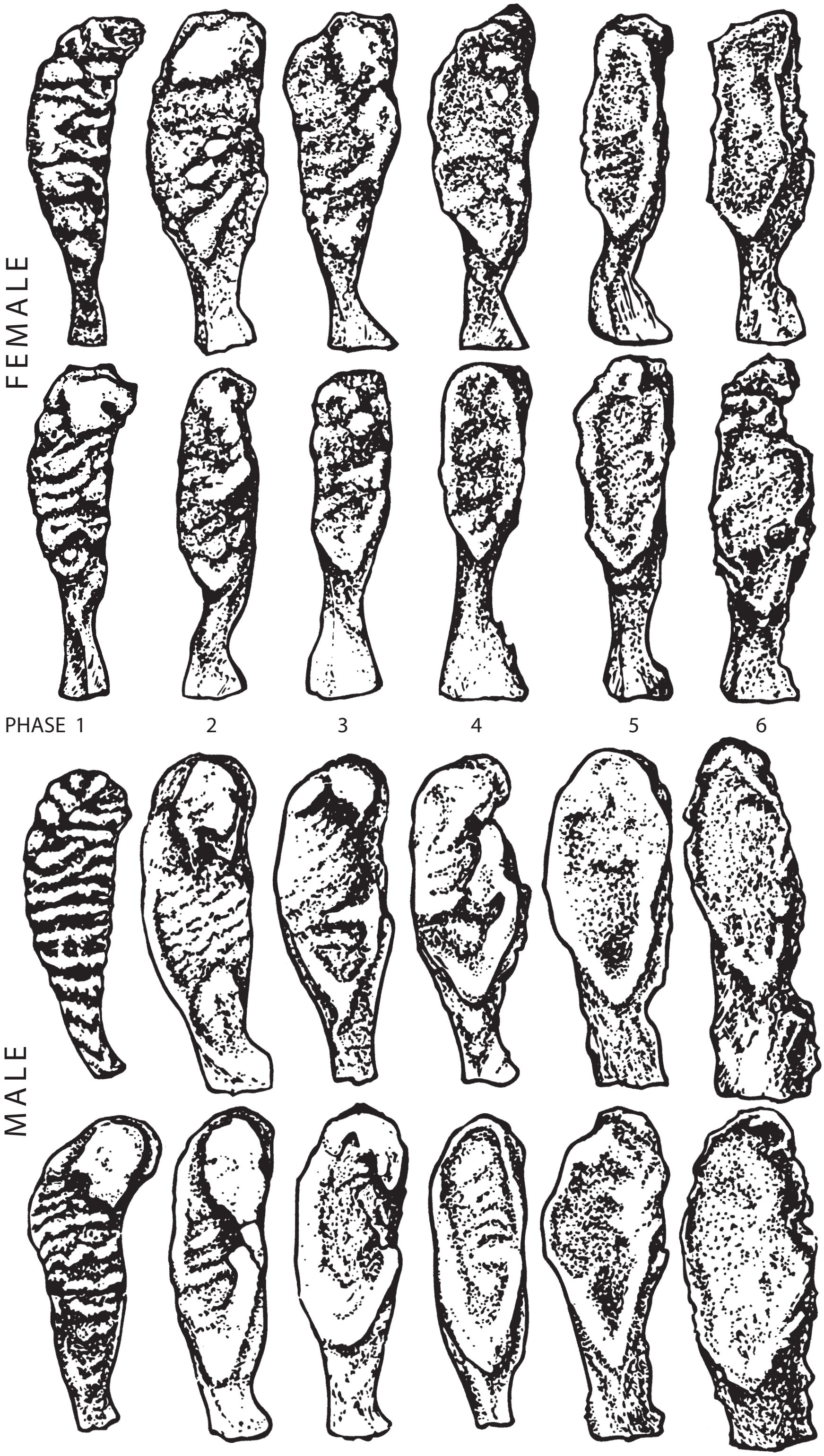

FEMALE
PHASE 1
2
3
4
5
6
MALE

Figure 19.8 The Suchey-Brooks pubic symphysis scoring system. The phase descriptions given here may be applied to either male or female symphysis faces, but matches of females should only be made in reference to the female phase types in the upper two rows. Phase descriptions are from Brooks and Suchey (1990, italics therein), and statistics for the Suchey-Brooks phases in females and males follow the descriptions; drawings by P. Walker in Buikstra and Ubelaker's Standards volume (1994). It is recommended that these illustrations be supplemented by casts before actual aging is attempted.

Phase 1: Symphyseal face has a billowing surface (ridges and furrows), which usually extends to include the pubic tubercle. The horizontal ridges are well-marked, and ventral beveling may be commencing. Although ossific nodules may occur on the upper extremity, *a key to the recognition of this phase is the lack of delimitation of either extremity (upper or lower).*

Phase 2: The symphyseal face may still show ridge development. *The face has commencing delimitation of lower and/or upper extremities occurring with or without ossific nodules.* The ventral rampart may be in beginning phases as an extension of the bony activity at either or both extremities.

Phase 3: Symphyseal face shows lower extremity and *ventral rampart in process of completion.* There can be a continuation of fusing ossific nodules forming the upper extremity and along the ventral border. Symphyseal face is smooth or can continue to show distinct ridges. Dorsal plateau is complete. Absence of lipping of symphyseal dorsal margin; no bony ligamentous outgrowths.

Phase 4: Symphyseal face is generally fine grained although remnants of the old ridge and furrow system may still remain. *Usually the oval outline is complete at this stage, but a hiatus can occur in upper ventral rim.* Pubic tubercle is fully separated from the symphyseal face by definition of upper extremity. The symphyseal face may have a distinct rim. Ventrally, bony ligamentous outgrowths may occur on inferior portion of pubic bone adjacent to symphyseal face. If any lipping occurs, it will be slight and located on the dorsal border.

Phase 5: *Symphyseal face is completely rimmed with some slight depression of the face itself, relative to the rim.* Moderate lipping is usually found on the dorsal border with more prominent ligamentous outgrowths on the ventral border. There is little or no rim erosion. Breakdown may occur on superior ventral border.

Phase 6: *Symphyseal face may show ongoing depression as rim erodes.* Ventral ligamentous attachments are marked. In many individuals the pubic tubercle appears as a separate bony knob. The face may be pitted or porous, giving an appearance of disfigurement with the ongoing process of erratic ossification. Crenulations may occur. The shape of the face is often irregular at this stage.

Descriptive Statistics:

	Female (n = 273)			*Male (n = 739)*		
Phase	Mean	Standard Dev.	95% range	Mean	Standard Dev.	95% range
1	19.4	2.6	15–24	18.5	2.1	15–23
2	25.0	4.9	19–40	23.4	3.6	19–34
3	30.7	8.1	21–53	28.7	6.5	21–46
4	38.2	10.9	26–70	35.2	9.4	23–57
5	48.1	14.6	25–83	45.6	10.4	27–66
6	60.0	12.4	42–87	61.2	12.2	34–86

19.3.7 Parturition Changes at the Pubic Symphysis

Childbirth, or parturition, may result in changes on the pubic symphysis (particularly pitting adjacent to the symphysis on the dorsal edge of the pubis), auricular surface, and preauricular area of the female os coxae. To what extent can the osteologist use these changes to assess whether, or how often, an individual has given birth? Studies designed to answer these questions include Kelley (1979) and Suchey *et al.* (1979). These studies show that up to 20% of nulliparous women display these or related features. Pitting acquired during pregnancy and childbirth may become obliterated with age. Medium-to-large pitting can occur without parturition (17 of 148 cases, Suchey *et al.*, 1979), and parturition can occur without pitting. Four of over 700 male individuals displayed medium-to-large pitting. In short, there is a correlation between pitting of the os coxae and pregnancy or parturition, but this correlation is far from perfect. The number of pregnancies cannot be predicted by the morphology of the dorsal aspect of the pubis. In a study combining humans and nonhuman mammals, Tague (1988) concludes that the severity of the resorption at the pubis is not significantly related to that of the preauricular area. Furthermore, age-at-death was shown to be significantly associated with resorption of the pubis. Cox and Scott (1992) note that pubic tubercle extension is also associated with childbirth, whereas preauricular sulci and dorsal pitting were not. Tague (1988) calls for further study of the link between estrogen and osteoclastic activity in these areas of the os coxae. Cox (2000b) provides an overview of skeletal studies of parturition, and Snodgrass and Galloway (2003) provide further critical assessment regarding forensic use of parturition pitting.

19.3.8 Estimating Adult Age from the Auricular Surface of the Ilium

Lovejoy and colleagues (1985b) examined the auricular surface of the os coxae as a possible site of regular change corresponding to age in the Hamann-Todd collection. The use of this surface for aging individual specimens has some advantages, namely that this part of the os coxae is more likely to be preserved in forensic and archeological cases and that the changes on the auricular surface, unlike those on the pubic symphysis, extend well beyond the age of 50 years. Lovejoy and colleagues describe age-related changes in surface granulation, microporosity, macroporosity, transverse organization, billowing, and striations that are somewhat similar to those described for the surface of the pubic symphysis. These investigators note that auricular surface aging is more difficult to master than the Todd method for the pubic symphysis, but they state that the potential rewards are worth the extra effort, since the method is independent of symphyseal aging but equally accurate.

The changes described by Lovejoy *et al.* (1985b) for the auricular surface are as follows. The young auricular surface (Figure 19.9), beginning in the first few years after postcranial epiphyseal fusion, shows a fine-grained surface texture and a pattern of regular, usually transverse surface undulations called billowing. The topography of the surface is very much like the subchondral bone of an unfused epiphysis, although the billowing is not so pronounced. Beginning in adulthood, these features of the sacroiliac joint are modified progressively and regularly as age increases. Granularity of the surface becomes coarser, billowing and striae are reduced dramatically, the original transverse organization of youth is lost, and the surface begins to display perforations of its subchondral bone, a condition known as "microporosity." In the later stages of life, the surface becomes increasingly dense and disorganized. Larger subchondral defects termed macroporosity progressively increase with age after the fifth decade. By the sixth and seventh decades, the surface has become dense, both microporotic and macroporotic, and has lost all evidence of transverse organization. Lovejoy and colleagues have formalized a system of eight phases with which to classify this metamorphosis (Figure 19.9 and Buikstra and Ubelaker, 1994, Figure 10). Addition of the sacroiliac joint to the osteologist's arsenal of age indicators is an important one. However, both original research and subsequent tests (Murray and Murray, 1991) on the method suggest that the method, like the pubic symphysis methods, has large estimation errors associated with it and should not be used alone in the assessment of an unknown's age-at-death. Ongoing work on this region (Osborne *et al.*, 2004; Mulhern and Jones, 2004) as well as the acetabular area (Rougé-Maillart, 2004) is active.

19.3.9 Estimating Adult Age from the Sternal Rib End

İşcan and Loth (1986) have studied metamorphosis of the sternal end of the fourth rib and found that it corresponds to age, but varies by sex. They examined "form, shape, texture and overall quality" of the sternal end and defined a series of phases that begins with a flat or billowy end with regular and rounded edges. With age, this rim thins and becomes irregular. The surface porosity increases, and the bone becomes "ragged." As with all of the newer techniques described earlier, this one has not been widely tested. Additionally, identification of the fourth rib is not always possible in incomplete skeletons. However, Dudar (1993) reports that rib four standards can "cautiously" be applied to other sternal rib ends. Russell *et al.* (1993) verify the utility of this technique on a sample of 100 males. Kunos *et al.* (1999) assess aging through first rib metamorphosis, and Yoder *et al.* (2001) examine other ribs.

19.3.10 Estimating Adult Age by Radiographic Analysis

Changes in cancellous and cortical bone structure at macroscopic and microscopic levels take place throughout life. Walker and Lovejoy (1985) have studied this phenomenon by assessing radiographs from the Hamann–Todd collection and the prehistoric Libben collection. Using seriation, these authors describe progressive, site-specific loss of bone with age in both the clavicle and the femur. Visual seriation of radiographs showed a moderately high and significant correlation between increased age of death and decreased bone density. Macchiarelli and Bondioli (1994) show significant variation in density of the proximal femur, much of it unrelated to age. Jackes (1992) discusses problems with applications to archeological remains.

19.3.11 Estimating Adult Age from Bone Microstructure

The normal remodeling of bone during adult life has been proposed as a condition

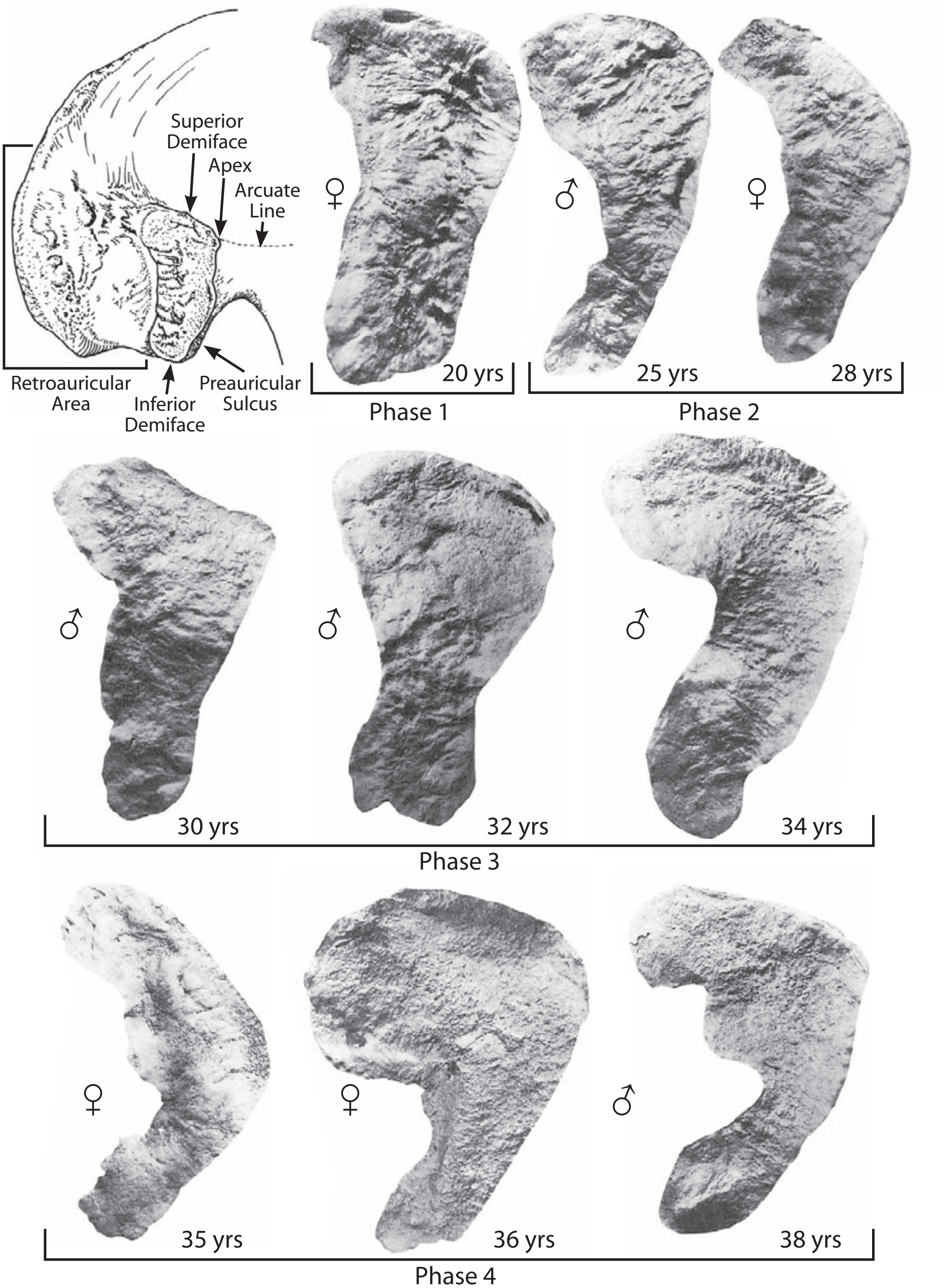
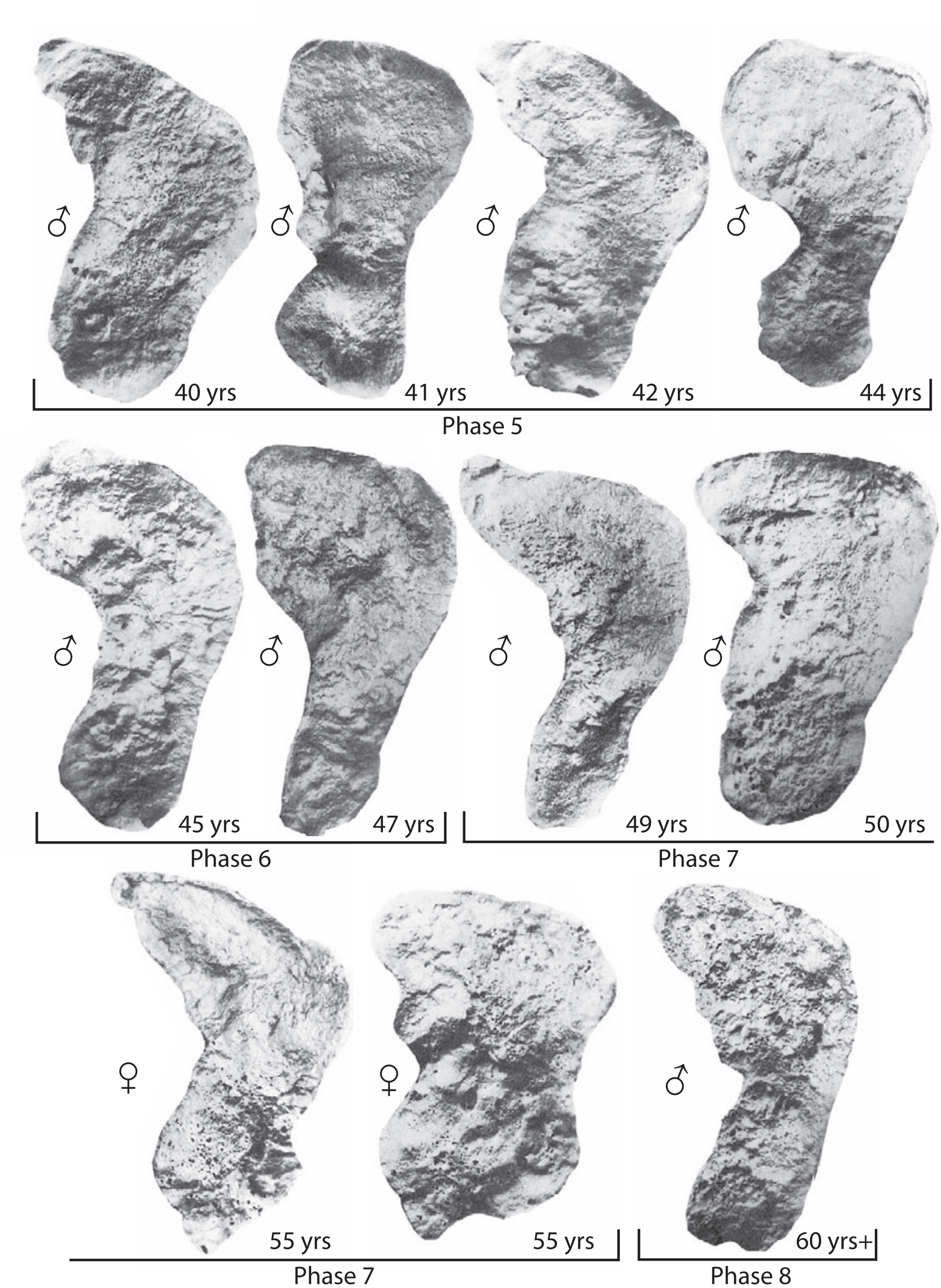


Figure 19.9 Modal changes to the auricular surface with age. Phases described by Lovejoy *et al.* (1985b) as follows:
Phase 1: Age 20–24; billowing and very fine granularity
Phase 2: Age 25–29; reduction of billowing but retention of youthful appearance
Phase 3: Age 30–34; general loss of billowing, replacement by striae, coarsening of granularity
Phase 4: Age 35–39; uniform coarse granularity



Phase 5: Age 40–44; transition from coarse granularity to dense surface; this may take place over islands on the surface of one or both faces
Phase 6: Age 45–49; completion of densification with complete loss of granularity
Phase 7: Age 50–59; dense irregular surface of rugged topography and moderate to marked activity in periauricular areas
Phase 8: Age 60+; breakdown with marginal lipping, microporosity, increased irregularity, and marked activity in periauricular areas

useful for aging skeletal material. Microscopic analysis has allowed the relationships between the number of osteons and osteon fragments and the percentages of lamellar bone and non-haversian canals to be examined. Simmons (1985), Frost (1987), and Robling and Stout (2000) provide excellent summaries of these procedures. It should be noted that these procedures are destructive to the bones under study. Many studies of histomorphometry have been undertaken on the long bones of the postcranial skeleton (for a review, see Stout, 1992). Cool *et al.* (1995) have shown that histomorphological variables of the human occipital were less reliable than those of the long bones for estimating age.

All of these methods are quantitative and depend on osteonal remodeling of bone and accumulated osteon populations. Many factors can influence this process and its products, including sex, hormones, mechanical strain, and nutrition. Remodeling is the sequential removal and replacement of older lamellar bone with newer lamellar bone and it takes place throughout the life span. Histological analysis of tissue from selected sites on the skeleton (including the ribs and clavicle: Stout and Paine, 1992; Stout *et al.*, 1994, 1996) has shown an association between age-at-death and the number of observable osteons per unit area in a cross section. The number of intact and fragmentary osteons per unit area is calculated for each bone (normally for at least two slices of each bone), and the result is put into regression equations that calculate the age. Stout (1992) identifies a variety of problems with the technique as applied by different investigators, and calls for more research in the forensic setting. Pfeiffer *et al.* (1995) and others have found that histological profiles vary by sample location, something that must be controlled for in application of these techniques. As Ericksen (1991) notes, it is critical that osteologists using bone microstructure to age archeological specimens be very cautious about pre-analysis exfoliation of unremodeled peripheral lamellae on bones. Jackes (1992) notes other complicating factors for the use of these techniques on archeological remains. Aiello and Molleson (1993) compared pubic symphyseal aging to microscopic aging techniques and found neither to be more accurate. Wallin and colleagues (1994, p. 353) have found that their determination of age-at-death through microscopic bone morphometry resulted in standard deviations of over 12 years and was "considerably less precise than generally stated in the literature."

19.3.12 Multifactorial Age Estimation

Given the variety of techniques available for assessing skeletal age-at-death (for another review, see Cox, 2000), what techniques should be used by the osteologist? In Todd's original 1920 work on the changes he had classified in the pubic symphysis, he took great pains to point out that the most accurate estimate of age can only be made after examination of the entire skeleton. However, due to the sometimes fragmentary nature of skeletal remains and the history of development of aging techniques, his advice has often been forgotten by human osteologists who followed. All osteologists use dental development, eruption, epiphyseal appearance, and fusion when aging immature skeletal material. For aging adult skeletal remains, however, osteologists are sharply divided on the question of technique. This controversy provides an important arena for the continued testing and refinement of the techniques outlined earlier.

Some osteologists, particularly those working in forensic contexts, favor the use of the pubic symphysis and assign other anatomical regions a lesser role in age analysis. Lovejoy *et al.* (1985a) note that this traditional forensic orientation to aging has led to problems when skeletons from large populations are aged by different observers using established methods. Furthermore, the value of skeletal age indicators has been judged on the basis of accuracy (differences between predicted and actual ages) without due regard to bias (the tendency of a given technique to over- or underage).

If more than one criterion is available for assessing skeletal age-at-death, all criteria should be employed (Baccino *et al*., 1999). One immediate objection to this recommendation arises because of the marked differences in the reliability between different age indicators. For example, many investigators are hesitant to alter a determination of age-at-death based on the pubic symphysis face by additional data from cranial suture closure because of the latter's supposed unreliability (see Meindl and Lovejoy, 1985). In forensic aging of single individuals, such caution may be advisable (depending on the assessed age). However, cranial suture closure is correlated with increasing age, and in the analysis of populations the addition of data on age-at-death from the sequential addition of other age indicators should improve the accuracy of determination.

19.4 Determination of Sex

The terms "sex" and "gender" have increasingly become conflated in the anthropological and medical literature. They do not refer to the same thing, they are not synonyms, and they should not be used interchangeably. Gender is an aspect of a person's social identity, whereas sex refers to a person's biological identity. This distinction is important for biological anthropologists to preserve in general, and particularly important to retain in human osteology (Walker and Cook, 1998). In the archeological context, it is often possible to determine sex through analysis of skeletal remains, and gender roles through studies of material culture (artifacts) and context.

With a sample of fifty lowland gorilla males and fifty lowland gorilla females, even the untrained observer could sort skeletal elements by sex using size and shape. For this primate, 100% accuracy in sorting is obtained easily. The same applies to orangutans. With chimpanzees, the differences are not as marked, but when the canine teeth rather than the overall size of the cranium are examined, perfect accuracy can still be approached. Moving to a sample of fifty male and fifty female modern humans, there is far less sexual dimorphism in body and canine size, and sorting accuracy is therefore reduced. Human sexual dimorphism is complex, with behavioral, physiological, and anatomical dimensions. Anatomical differences are extreme in some soft tissue areas and more limited in the skeleton. Nevertheless, skeletal differences between male and female humans do exist and can be useful to the osteologist. Buikstra and Mielke (1985) summarize in helpful tabular form the accuracy of a variety of skeletal sexing techniques, and Mays and Cox (2000) provide a more recent review.

In determining the sex of any skeletal element, the osteologist starts with 50% accuracy—random guessing will be correct half of the time. For some elements, such as the cranium, training and experience can often allow correct sorting about 80–90% of the time. It is extremely important to remember that sexual identification of human skeletal material is most accurate after the individual reaches maturity. Only then do the bones of different sexes become differentiated sufficiently to be useful in sexing.

In general, for all parts of the human skeleton, female elements are characterized by smaller size and lighter construction. For this reason, in a large, seriated, mixed-sex collection of elements, the largest, most robust elements with the heaviest rugosity are male. Males can average up to 20% larger in some skeletal dimensions, whereas in others there may be no dimorphism. The smallest, most gracile elements are female. Normal individual variation, however, always produces some small, gracile males and some large, robust females who fall toward the center of the distribution where sorting sex is difficult. In other words, the sexes overlap near the center of the distribution. For this reason, osteologists have traditionally concentrated on elements of the skull and pelvis in which sex differences in humans are the most extreme.

In addition to the complications of individual variation within the population, incorrect sex identifications are sometimes made because of variation between populations. Some populations are, on average, composed of larger, heavier, more robust individuals of both sexes, whereas other populations are characterized by the opposite tendency. Because of such interpopulational differences in size and robusticity, males from one population are sometimes mistaken for females in other populations and vice versa. The osteologist should always attempt to become familiar with the skeletal sexual dimorphism of the population from which unsexed material has been drawn. As it is with aging, seriation can be a helpful approach in determining the sex of skeletal remains from a population.

All of the morphological techniques used in sexing skeletal remains depend on the preservation of sexually dimorphic elements. All of them share a nontrivial error rate, even for adult remains. However, if DNA can be recovered from osseous remains, the sex of any individual (regardless of individual age) can be determined with high precision. This is true even for highly fragmentary remains. Sexing of osteological specimens in a forensic context, therefore, has been changed fundamentally by the introduction of molecular techniques to human osteology (Stone *et al.*, 1996; Stone, 2000).

19.4.1 Sexing the Skull and Dentition

Determination of sex based on parts of the skull follows the observation that males tend to be larger and more robust than females. In addition to size, tendencies such as those outlined here provide useful indications for determining the sex of isolated skulls. These characteristics are the traditional ones used by osteologists. Figure 19.10 illustrates them.

Relative to female crania, male crania are characterized by greater robusticity. Male crania typically display more prominent supraorbital ridges, a more prominent glabellar region, and heavier temporal and nuchal lines. Male frontals and parietals tend to be less bossed than female ones. Males tend to have relatively large, broad palates, squarer orbits, larger mastoid processes, larger sinuses, and larger occipital condyles than females. When compared to female mandibles, male mandibles are characterized by squarer chins, more gonial eversion, deeper mandibular rami, and more rugose muscle attachments (e.g., see Gülekon and Turgut, 2003).

The relative strength of these cranial tendencies can be summarized by the following: Where associated postcranial material is available, always use the pelvis for sex determination of the cranium. When sexing skulls, always use the entire population under study. Seriate this population according to the criteria you use and then sort. If you are sexing only one or a few individuals, try to use comparative populations that are genetically and temporally close to the ones from which your sample derives.

Walker, in the Buikstra and Ubelaker Standards volume (1994), provides five aspects of skull morphology that are useful in determining sex. These are shown in Figure 19.11. In all cases, a five-point scale is used, with the more gracile, feminine features at the lower end of the range. Graw *et al.* (1999) present another scoring system focused only on the supraorbital margin and Walrath *et al.* (2004) offer insights into the reliability of such methods.

Studies of the posterior border of the mandibular ramus suggested to Loth and Henneberg (1996, 1998) that this region could be used to sex unknowns with an average of about 92% accuracy. These authors claimed that adult males have a distinct angulation of the posterior border of the mandibular ramus at the level of the occlusal surface of the molars. They argued that the lack of such flexure in females allows sex to be identified. The technique was used by Donnelly *et al.* (1998) in a blind test that demonstrated a much lower accuracy (62–68%), a finding further substantiated by Haun (2000) and Hill (2000).

In an attempt to go beyond the traditional methods outlined earlier, Giles and Elliot (1963) used nine standard cranial metrics to diminish the subjectivity involved in sexing the skull. However, a study by Meindl *et al.* (1985b) has shown that subjective assessment of the skull compared favorably to the discriminant functions of Giles and Elliot. In tests on Hamann–Todd crania, Meindl *et al.* (1985b) found that older individuals show increasingly "masculine" morphology. Whereas 10.2% of the males in their sample of 100 were sexed incorrectly, only 4.9% of the females were misidentified. Given these facts, Meindl *et al.* (1985b) suggest that overall sex ratios and age class sex ratios in prehistoric cemeteries should only be estimated from adult burials with fully preserved pelves.

Because teeth are often better preserved than other skeletal elements, there have been efforts to sex the skeleton using the teeth. The degree of sexual dimorphism in human crown sizes varies between populations. Human dental dimorphism centers on the canines, but it is not nearly so pronounced as it is in the great apes. Human lower canines show the greatest dimorphism, up to 7.3% (Hillson, 1996), followed by the upper canines. Deciduous teeth are also dimorphic, with molars and canines up to 7%. Accuracy of sexing unknowns based on dental metrics, either univariate or multivariate, varies from 60% to a claimed 90% and usually lies between 75 and 80%. When it is noted that the actual size differences between sexes in individual teeth are very small, about half a millimeter on average, it can be seen that intra- and interobserver error might play a role in sex estimation. De Vito and Saunders (1990), Bermúdez de Castro *et al.* (1993), Beyer-Olsen and Alexandersen (1995), and Hillson (1996) provide reviews of the use of dental dimensions to sex human teeth.

19.4.2 Sexing the Postcranial Skeleton

As for the cranium, sexually diagnostic traits in the postcranial skeleton are difficult to identify and assess before puberty. Numerous metric studies of the postcranial skeleton have examined sexual dimorphism in the size of various adult elements. Bass (1995)

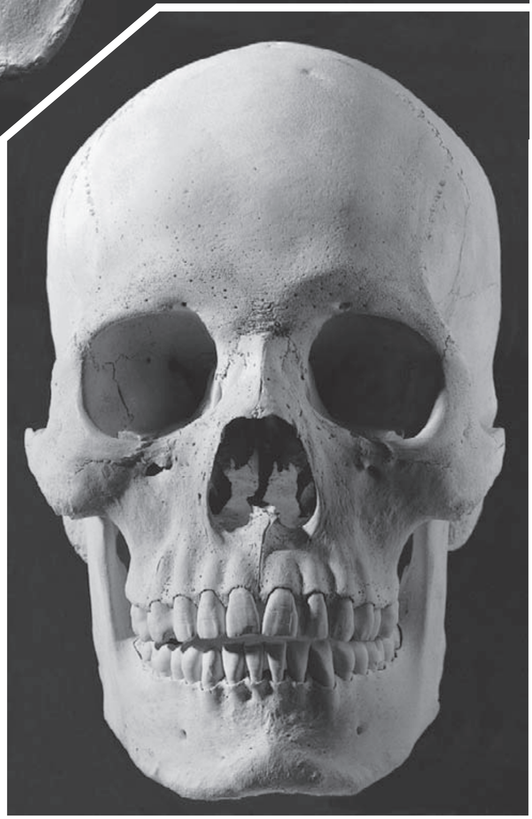
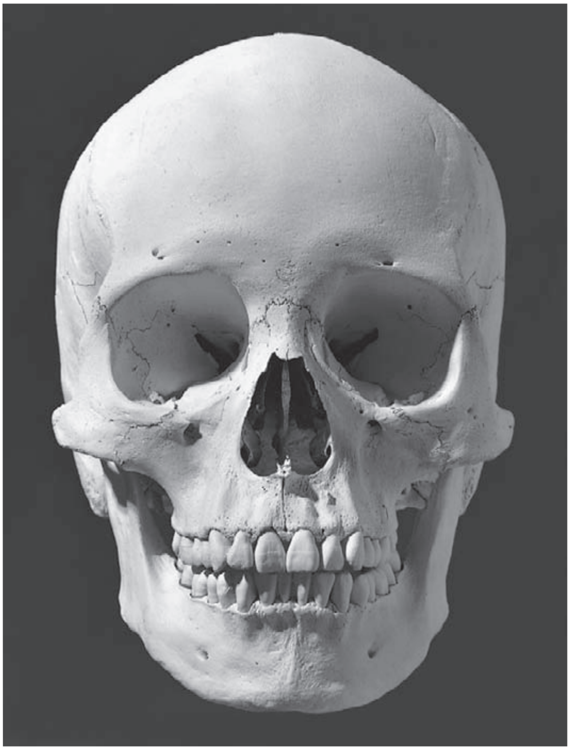


Figure 19.10 Male (*above*) and female (*opposite*) adult skulls in frontal and lateral views. The female skull chosen for this illustration was taken from the "female" end of the female range. The male is the same individual used to illustrate the cranium in Chapter 4. This comparison illustrates the differences between male and female skulls discussed in the text. It should *not* be taken as a representation of the difference between *average* male and female skulls, but rather as an indication of how much sexual variation is seen in the human skull. One-half natural size.



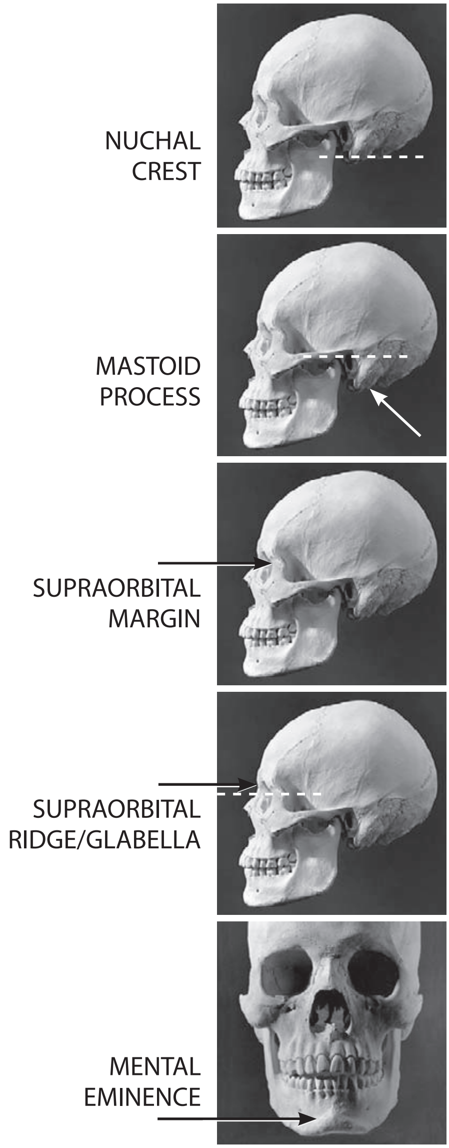


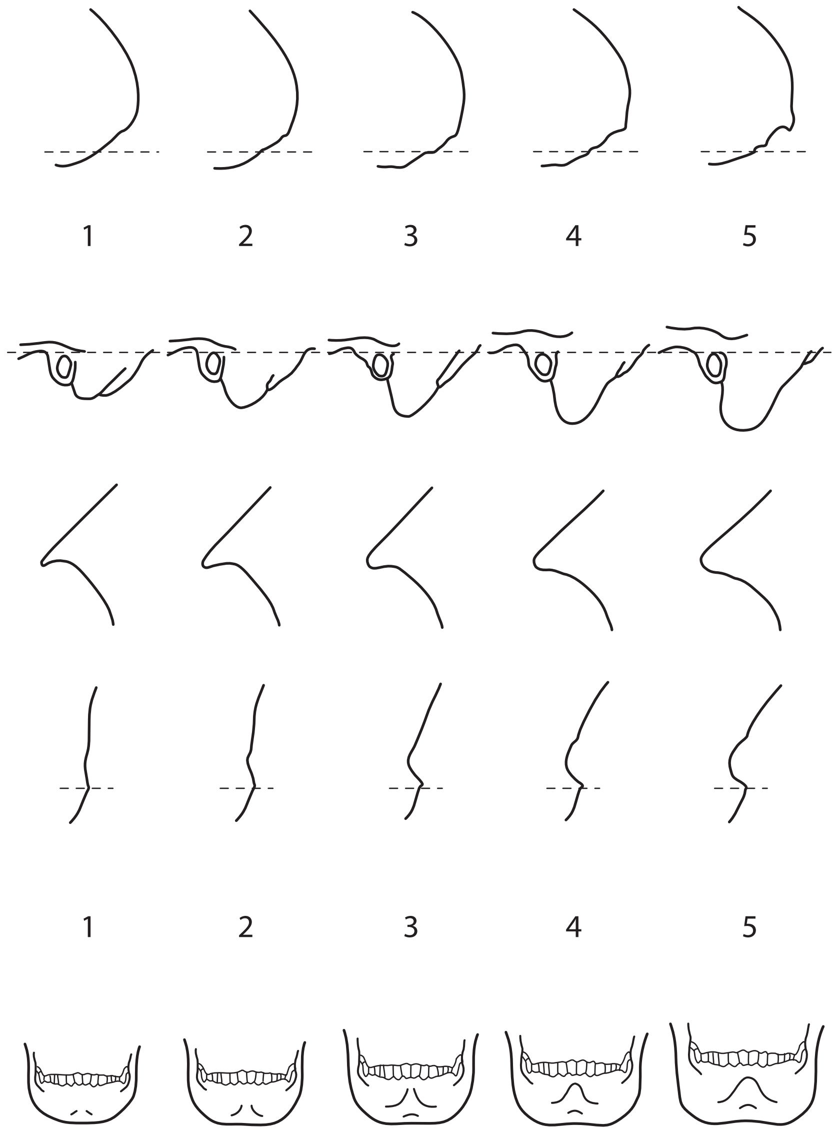
Figure 19.11 (*right* and *opposite*) A scoring system for sexually dimorphic cranial features from Walker in Buikstra and Ubelaker (1994). In recording the features, optimal results are obtained by holding the cranium or mandible at arm's length, a few inches above the appropriate portion of this figure, oriented so that the features can be directly compared with those illustrated. Move the bone from diagram to diagram until the closest match is obtained. Score each trait independently, ignoring other features. A specific procedure for each trait is described below, with the extremes described and the intermediates illustrated in the figure.

Nuchal Crest: View the lateral profile of the occipital and compare it with the diagrams. Feel the surface of the occipital with your hand and note any surface rugosity, ignoring the contour of the underlying bone. Focus on the rugosity attendant to attachment of nuchal musculature. In the case of minimal expression (score = 1), the external surface of the occipital is smooth with no bony projections visible when the lateral profile is viewed. Maximal expression (score = 5) defines a massive nuchal crest that projects a considerable distance from the bone and forms a well-defined bony ledge or "hook."

Mastoid Process: Score this feature by comparing its size with that of surrounding structures such as the external auditory meatus and the zygomatic process of the temporal bone. Mastoid processes vary considerably in their proportions. The most important variable to consider in scoring this trait is the volume of the mastoid process, not its length. Minimal expression (score = 1) is a very small mastoid process that projects only a small distance below the inferior margins of the external auditory meatus and the digastric groove. A massive mastoid process with lengths and widths several times that of the external auditory meatus should be scored as 5.

Supraorbital Margin: Begin by holding your finger against the margin of the orbit at the lateral aspect of the supraorbital foramen. Then hold the edge of the orbit between your fingers to determine its thickness. Look at each of the diagrams to determine which it seems to match most closely. In an example of minimal expression (score = 1), the border should feel extremely sharp, like the edge of a slightly dulled knife. A thick, rounded margin with a curvature approximating a pencil should be scored as 5.

Prominence of Glabella: Viewing the cranium from the side, compare the profile of the



supraorbital region with the diagrams. In a minimal prominence of glabella/supraorbital ridges (score = 1), the contour of the frontal is smooth, with little or no projection at midline. Maximal expression involves a massive glabellar prominence, forming a rounded, loaf-shaped projection that is frequently associated with well-developed supraorbital ridges.

Mental Eminence: Hold the mandible between the thumbs and index fingers with thumbs on either side of the mental eminence. Move the thumbs medially until they delimit the borders of the mental eminence. In examples of minimal expression (score = 1), there is little or no projection of the mental eminence above the surrounding bone. In contrast, a massive mental eminence that occupies most of the anterior portion of the mandible is scored as 5.

Figure 19.12 Variation in tibial size and shape among ten females (*above*) and ten males (*opposite*) selected at random from a single-site, sex-balanced sample of 100 prehistoric Californian skeletons. This sample, 20% of the total population, gives an indication of the normal sexual dimorphism encountered in modern human skeletal remains. One-sixth natural size.

provides an excellent review of these. Results on the most dimorphic limb bones can be summarized by noting that single measurements, or combinations of measurements, have usually been found to correctly identify the sex of between 80 and 90% of all individuals. Incorrect identification within any population is a consequence of size overlap between males and females in the center of the overall range (Figure 19.12). Many studies have been conducted on known-sex samples to derive functions capable of classifying sex accurately more than 85% of the time for a variety of elements ranging from the metacarpals (Falsetti, 1995; Stojanowski, 1999; but see Burrows, 2003) to the metatarsals (Robling and Ubelaker, 1997), humerus (Rogers, 1999), ulna (Purkait, 2001), and calcaneus (Introna *et al.*, 1997). Because these functions are often not tested beyond (or independent of) the skeletal population on which they were based, claims of accuracy are sometimes questionable. Rogers (1999) has claimed 92% accuracy based on four characters of the distal humerus, but testing on a wider sample will be required.

The skull has been a traditional focus of sexing studies, but a number of methods of sexing have also been applied to the pelvis. There are dramatic functional differences between male and female pelvic anatomy. These extend to the bony skeleton and represent differences found in all modern human groups. The pelvis is of vital importance in locomotion and parturition. During human evolution, selective pressures associated with these and other roles led to the sexual dimorphism seen in the modern human pelvis.

Traditional methods used to determine sex on the pelvis or its parts are based on

Figure 19.12 (*continued*)

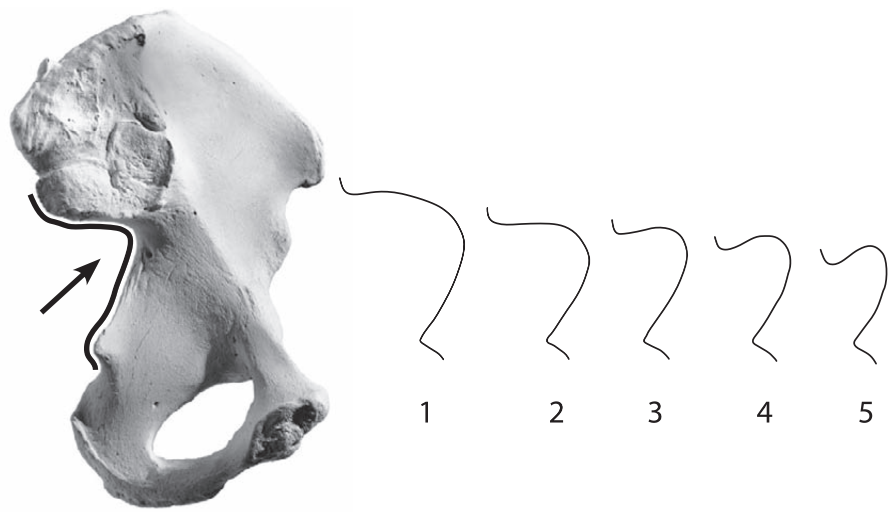


Figure 19.13 Sex differences in the greater sciatic notch, from Walker in Buikstra and Ubelaker's Standards book (1994). The greater sciatic notch tends to be broad in females and narrow in males. These shape differences are not as reliable as those in the subpubic region and should be thought of as secondary indicators. The best results for scoring are obtained by holding the os coxae above this figure so that the greater sciatic notch has the same orientation as the outlines, aligning the straight anterior portion of the notch that terminates at the ischial spine with the right side of the diagram. While holding the bone in this manner, move it to determine the closest match. Ignore any exostoses near the preauricular sulcus and the inferior posterior iliac spine. Configurations more extreme than 1 or 5 should be scored as 1 and 5, respectively. The illustration numbered 1 shows typical female morphology, whereas the higher numbers are male conformations.

the following tendencies: The sacra and ossa coxa of females are smaller and less robust than those of males. Female pelvic inlets are relatively wider than male ones. The greater sciatic notches on female ossa coxa are relatively wider than those on male bones (Figure 19.13). Females have relatively longer pubic portions of the os coxae, including the superior pubic ramus, than males. The subpubic angle, formed between the lower edges of the two inferior pubic rami, is larger in females than in males. The preauricular sulcus is present more often in females than in males. A corollary is that the auricular surface is more elevated from the female ilium than from the male ilium, even though sexual dimorphism in the auricular surface itself is insufficient for accurate sexing (Ali and MacLaughlin, 1991). The acetabulum tends to be relatively larger in males (Figure 19.14).

A variety of metric techniques have been developed to express these relationships. Washburn's attempt to quantify the relative proportion of the pubic part of the os coxae is the most famous and effective of these. Washburn (1948) measured the length of the pubis relative to the length of the ischium via an index that discriminated between

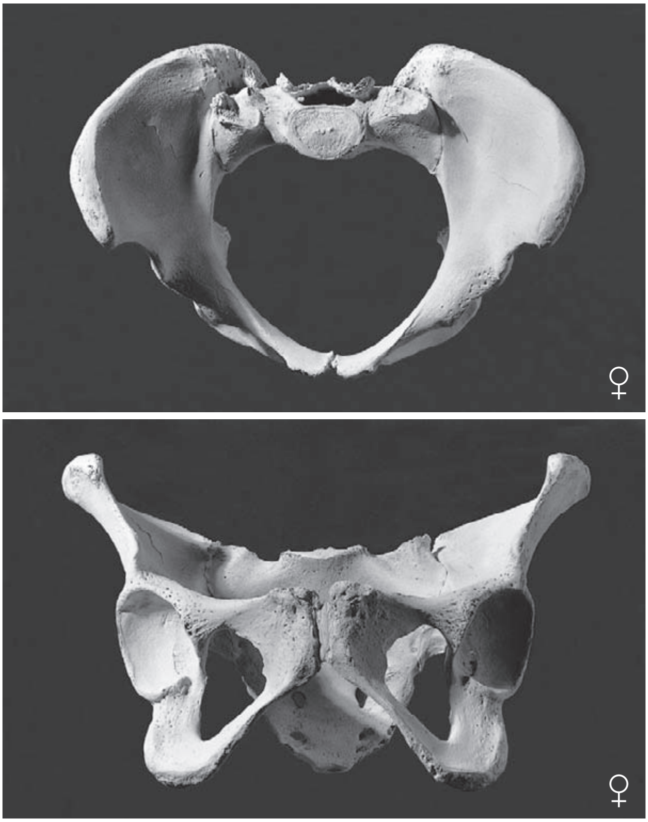


Figure 19.14 Sexual dimorphism in the bony pelvis showing differences in size and shape. Female (*above*); male (*opposite*). One-fourth natural size.

male and female ossa coxa. Rogers and Saunders (1994) provide a review of metric and morphological traits used to sex the pelvis, and Brůžek (2002) provides a more current assessment. Walker's (2005) analysis of age and population variation in sciatic notch form is a valuable review.

In 1969, T. W. Phenice published an important new method for sexing the pelvis. This paper, "A Newly Developed Visual Method of Sexing the Os Pubis," describes the most accurate method yet known for determining sex of an individual from the skeleton. Until the publication of the Phenice paper, the osteologist's success at using traditional visual methods of sexing the pelvis depended, in large part, on experience—decisions were more-or-less subjective. The application of metric criteria was difficult because much of the material was too fragmentary for reliable measurement, and even the simplest techniques were time-consuming. Phenice's method (illustrated in Figure 19.15) changed the situation, allowing more accurate, quicker sexing on any pelvis with an intact pubic region.

In employing the Phenice method to sex an os coxae, note that not every speci-

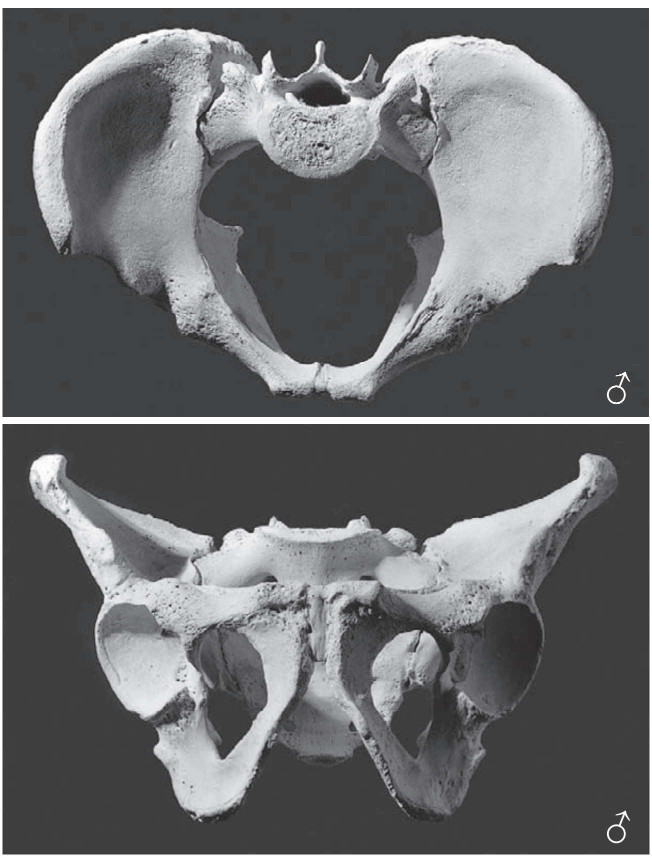


Figure 19.14 (continued)

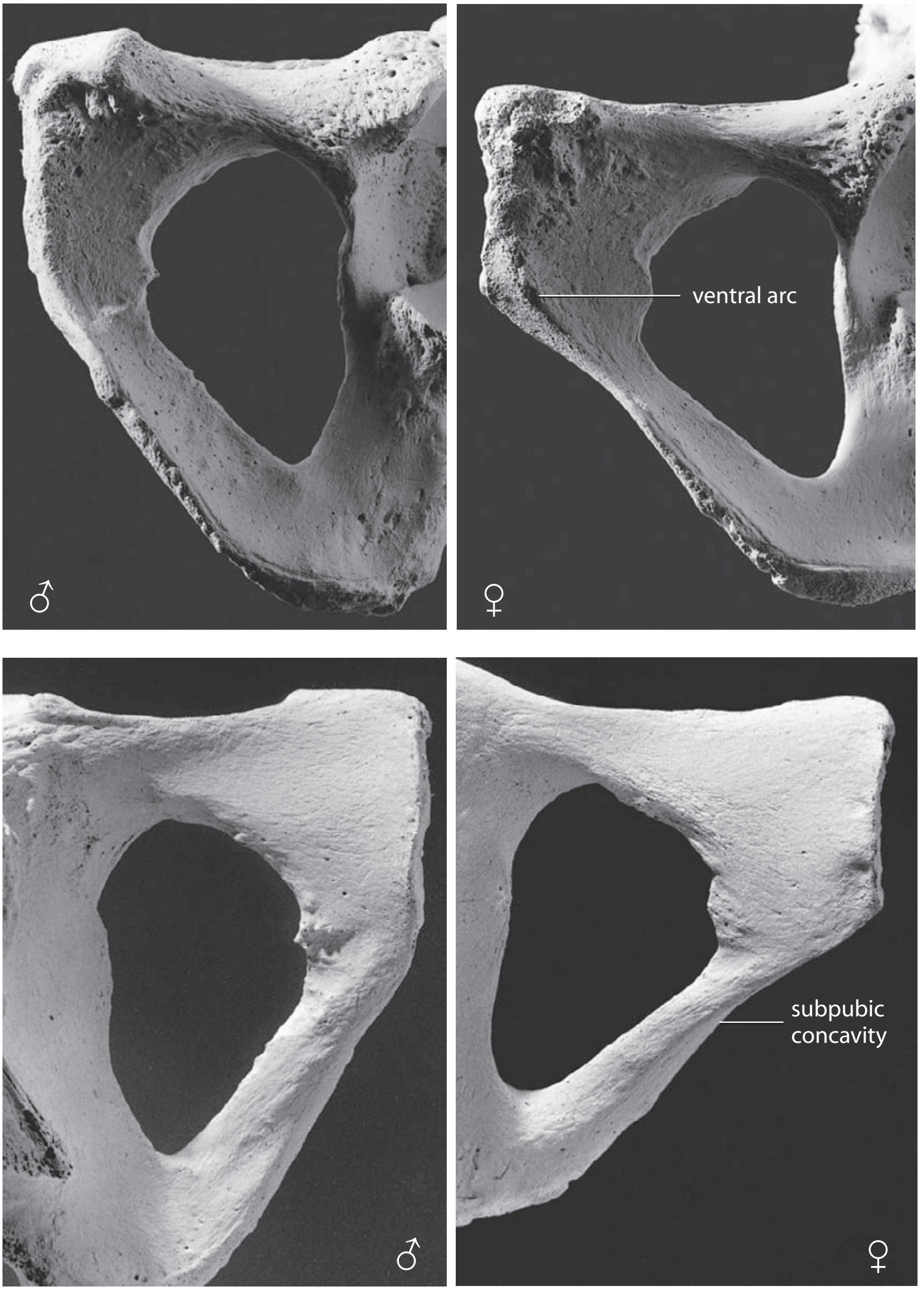


Figure 19.15 (*above* and *opposite*) The Phenice (1969) technique for sexing the pubic portion of the os coxae from the left side. In each comparison, the male is on the left and the female is on the right. These ossa coxa are the ones illustrated in Figure 19.14. Three-quarters natural size.

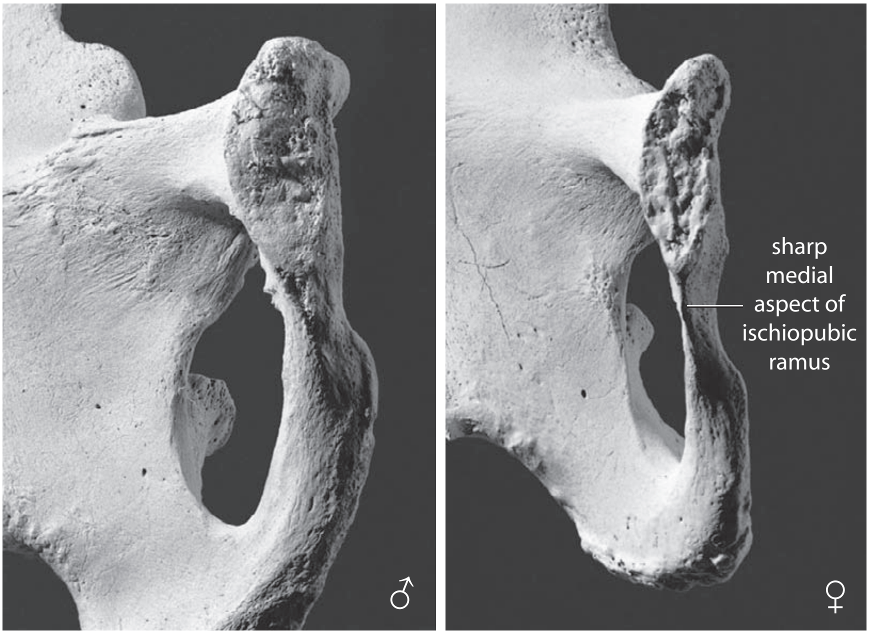


Figure 19.15 (continued)

Ventral arc. Orient the pubis so that its rough ventral surface faces you and you are looking down along the plane of the pubic symphyseal surface. The ventral arc is a slightly elevated ridge of bone that sweeps inferiorly and laterally across the ventral surface of the pubis, merging with the medial border of the ischiopubic ramus. Thus, the ventral arc, when present, sets off the inferomedial corner of the pubic bone in ventral view. It is present only in females. Male ossa coxa may have elevated ridges in this area, but these do not take the wide, evenly arching path of the female's ventral arc, nor do they set off the lower medial quadrant of the pubis.

Subpubic concavity. Turn the pubis over, orienting it so that its smooth, convex dorsal surface faces you and you are once again sighting along the midline. Observe the medial edge of the ischiopubic ramus in this view. Female ossa coxa display a subpubic concavity here; the edge of the ramus is concave in this view. However, males show no evidence of a concavity here. Male edges are straight or very slightly concave.

Medial aspect of the ischiopubic ramus. Turn the pubis 90°, orienting the symphyseal surface so that you are looking directly at it. Observe the ischiopubic ramus in the region immediately inferior to the symphysis. The medial aspect of the ischiopubic ramus displays a sharp edge in females. In males this surface is fairly flat, broad, and blunt.

men is a "perfect" male or female. When there is a criterion that does not obviously sex the specimen, discard that criterion. When there is some ambiguity concerning one or two of the criteria (most often in the medial aspect of the ischiopubic ramus, and least often in the ventral arc), usually one of the remaining criteria will clearly attribute the specimen to a sex. After sexing the specimen with this procedure, observe the more traditional features outlined earlier to see if they correspond to (corroborate) your diagnosis. For any case in which they do not confirm, recheck your observations. Remember that female individuals are most likely to be intermediate in displaying the Phenice features.

The Phenice method should only be used for fully adult material. Accuracy of sexing based on this method ranges from 96 to 100%, the highest ever achieved in the skeleton, but Lovell (1989) has suggested that accuracy might be reduced in the case of older adult specimens. In 1990, MacLaughlin and Bruce tested the Phenice characters for accuracy of sex identification on skeletal series from London, Leiden, and Scotland. They were unable to confirm the accuracy obtained by Phenice and others, achieving success on only 83% of the English, 68% of the Dutch, and 59% of the Scottish. They found the subpubic concavity to be the single most reliable indicator. Using 1284 pubic bones from the Los Angeles County Coroner's collection, Sutherland and Suchey (1991) reported that they achieved 96% sexing accuracy using the ventral arc alone. They note that this feature first appears at age 14 but does not become marked until age 20. The discrepancy between these two major tests of the Phenice technique remains unexplained, but Ubelaker and Volk (2002) note that experience plays a role in conditioning results from the use of this technique. The best advice for sexing of the os coxae, as for aging the skeleton, is to use all of the available data.

19.5 Estimation of Stature

Estimating individual stature from bone lengths has a long history in physical anthropology. The fact that the height (stature) of the human body correlates with limb bone length across all ages allows the osteologist to reconstruct an individual's stature from different skeletal elements. Unfortunately, the correlation is imperfect within living populations and varies between populations. Based on studies of skeletons from individuals of known stature, several investigators have derived regression equations useful in estimating stature in different human populations.

To estimate stature, based on the maximum length of a male femur from a Mesoamerican archeological site, for example, the osteologist would apply the formula derived by Genovés from modern Mexican samples and published in 1967. This formula is as follows:

$$\textit{stature}\ (\text{cm}) \pm 3.417 = 2.26 \times \textit{femur length} + 66.379$$

If femur length is known, stature may be calculated with about a 68% probability that the calculated value falls within 3.417 cm of the actual stature of the individual. This formula, of course, can be validly applied only to Mexican samples, but Bass (1995) and Bennett (1993) provide useful tables for stature estimation in different human groups. Most of these formulae are based on the lengths of one or more bones.

Trotter and Gleser (1958) developed formulae for estimating stature based on the Korean War dead, extending their earlier work on World War II remains in an anatomical collection. Formulae were presented for "racial" groups. The Genovés (1967), Trotter and Gleser (1958), and Trotter (1970) formulae for stature estimation are the most frequently used methods in North America. Table 19.2 is taken from the latter publication. As Feldesman and Fountain (1996) note, if the specimen's ancestry (race) is unknown, it is best to use generic equations of stature. Formicola (1993) evaluated various stature formulae on 66 archeological skeletons from seven European countries. They found that the Trotter and Gleser formulae for blacks worked better than those for whites.

There is growing debate on how to accommodate old data sets to the modern forensic world (Jantz, 1992, 1993; Giles, 1993). As Jantz (1992) notes, the most commonly used female stature formulae were derived from the Terry Collection, skeletons from people who died in the early 1900s. To what extent should formulae based on those samples be modified to reflect the secular changes in bone length and body height undergone during the last century? Giles (1991) makes further comments regarding stature loss in the elderly. Jantz and colleagues (1995) also note that the Trotter and Gleser stature formulae involving tibial length produce stature estimates averaging 2–3 cm too great when used with properly measured tibiae. They show that the original

Table 19.2

Equations Used to Estimate Stature, in Centimeters, with Standard Error, from the Long Bones of Various Groups of Individuals between 18 and 30 Years of Age[a]

White Males						**Black Males**					
3.08	×	Hum	+	70.45	± 4.05	3.26	×	Hum	+	62.10	± 4.43
3.78	×	Rad	+	79.01	± 4.32	3.42	×	Rad	+	81.56	± 4.30
3.70	×	Uln	+	74.05	± 4.32	3.26	×	Uln	+	79.29	± 4.42
2.38	×	Fem	+	61.41	± 3.27	2.11	×	Fem	+	70.35	± 3.94
2.68	×	Fib	+	71.78	± 3.29	2.19	×	Fib	+	85.65	± 4.08
White Females						**Black Females**					
3.36	×	Hum	+	57.97	± 4.45	3.08	×	Hum	+	64.67	± 4.25
4.74	×	Rad	+	54.93	± 4.24	2.75	×	Rad	+	94.51	± 5.05
4.27	×	Uln	+	57.76	± 4.30	3.31	×	Uln	+	75.38	± 4.83
2.47	×	Fem	+	54.10	± 3.72	2.28	×	Fem	+	59.76	± 3.41
2.93	×	Fib	+	59.61	± 3.57	2.49	×	Fib	+	70.90	± 3.80
East Asian Males						**Mexican Males**					
2.68	×	Hum	+	83.19	± 4.25	2.92	×	Hum	+	73.94	± 4.24
3.54	×	Rad	+	82.0	± 4.60	3.55	×	Rad	+	80.71	± 4.04
3.48	×	Uln	+	77.45	± 4.66	3.56	×	Uln	+	74.56	± 4.05
2.15	×	Fem	+	72.57	± 3.80	2.44	×	Fem	+	58.67	± 2.99
2.40	×	Fib	+	80.56	± 3.24	2.50	×	Fib	+	75.44	± 3.52

[a] To estimate stature of older individuals, subtract 0.06 (age in years, 30) cm; to estimate cadaveric stature, add 2.5 cm. From Trotter (1970). The tibia is not included; see text for rationale.
All lengths used are maximum lengths

formulae involving tibiae are based on mismeasured tibiae (the malleolus was omitted in maximum length measurements). Finally, Owsley (1995) notes that stature can be defined in several ways, ranging from forensic (e.g., from a driver's license) to biological (from cadavers or living individuals). He suggests that biological stature estimations based on long bone lengths are generally less precise than many have assumed. Table 19.3 is from Owsley (1995).

19.6 Estimation of Ancestry

Imagine a sample of 1000 people—a sample composed of 400 native Nigerians, 300 native Chinese, and 300 native Norwegians. If these people seated themselves randomly at a lecture, the speaker would be able to tell, simply by looking at their faces, whether their ancestry was Asian, African, or European. The sorting accomplished on the basis of soft tissue facial features would correspond perfectly to the geographic origin of the three major components of the sample.

Table 19.3

Regression Equations for Estimating Forensic Stature (Estimating from Skeletal Remains)[a]

	Factor	Bone measurement in mm	Constant	90% PI	N
White Males	0.05566	Femur Max L + Tibia L	21.64	± 2.5"	62
	0.05552	Femur Max L + Fibula L	22.00	2.6"	54
	0.10560	Femur Max L	19.39	2.8"	69
	0.10140	Tibia L	30.38	2.8"	67
	0.15890	Ulna L	26.91	3.1"	62
	0.12740	Humerus L	26.79	3.3"	66
	0.16398	Radius L	28.35	3.3"	59
White Females	0.06524	Femur Max L + Tibia L	12.94	2.3"	38
	0.06163	Femur Max L + Fibula L	15.43	2.4"	42
	0.11869	Femur Max L	12.43	2.4"	48
	0.11168	Tibia L	24.65	3.0"	43
	0.11827	Humerus L	28.30	3.1"	45
	0.13353	Ulna L	31.99	3.1"	40
	0.18467	Radius L	22.42	3.4"	38
Black Females	0.11640	Femur Max L	11.98	2.4"	18
Black Males	0.16997	Ulna L	21.20	3.3"	14
	0.10521	Tibia L	26.26	3.8"	19
	0.08388	Femur Max L	28.57	4.0"	17
	0.07824	Humerus L	43.19	4.4"	20

[a] Note that the bone measurements should be in millimeters, but that all constants were converted to predict statures and prediction intervals in inches because most North American forensic applications record stature in inches. For example, if the maximum length of the femur from a probable white male is 454mm, the forensic stature is estimated by: 0.10560 (454) + 19.39 = 67.33±2.8 inches. This person, if a white male, would have a roughly 90% chance of having a forensic stature between 64.5 and 70.1 inches (5 feet 4½ inches to 5 feet 10 inches).

This kind of sorting within the species *Homo sapiens* is usually termed racial sorting. However, there are no "pure" human races (A.A.P.A., 1996). By definition, all members of the same species have the potential to interbreed, and hence any subspecific classification is arbitrary. Defining the term "race" has proven difficult in the history of physical anthropology because concepts of race have often been based on composites of biological, social, and ethnic criteria used in a typological fashion. The confusion arising from these difficulties has persuaded some anthropologists to conclude that the very use of the term "race" is counter-productive. In osteological work, particularly work in forensic contexts, the determination of race, or geographic ancestry, is usually an important consideration.

The title of a paper by physical anthropologist Kenneth Kennedy (1995) asked, "But Professor, Why Teach Race Identification if Races Don't Exist?" Typological race concepts in physical anthropology have gone the way of the dinosaurs, but human populations are routinely divided into separate races (Blacks, Whites, Native Americans, and Hispanics) in governmentally mandated programs, the popular media, and the forensic sciences. As St. Hoyme and İşcan (1989) note, human osteologists who examine human bones must communicate with law-enforcement personnel, students, and the general public. How people are categorized by others depends on law and custom. The United States government's bureaucratic approach to race is quite specific in this regard, noting that its classifications (American Indian or Alaskan native; Asian or Pacific Islander; Black; Hispanic; White; or Other) "should not be interpreted as being scientific or anthropological in nature."

Most forensic applications bring the human osteologist into contact with medical examiners, law enforcement, or other government personnel who expect missing and/or found persons to be classified in terms of their bureaucratic races as defined by the government. These racial categories, of course, mix historical and social phenomena with biology. Gill (1995) provides an example of this by pointing out that in the United States, a person who is of 75% European descent, but has a black African grandparent is considered black rather than white. Today, it is common for parents of completely different geographic ancestry to have children whose anatomical configurations will defy assessment of ancestry. How does the osteologist deal with these social and biological realities?

The osteologist's role, particularly in the forensic setting, is often to individualize an unknown's osteological remains by assessing the age, sex, stature, and race of the individual. The ability to determine the geographic ancestry of a skeletal unknown is useful for narrowing the possibilities and leading to a positive identification in many cases. Yet as a biological scientist, the human osteologist knows that all variation is continuous, not discrete. As Kennedy (1995) notes, there is a paradox in the scientific rejection of "race" and its survival in medico-legal contexts. As Kennedy says (1995, p. 798), "Forensic anthropologists are keenly aware that neither the medical examiner, the judge, the attorney client nor the sheriff would appreciate a lecture on the history of the race concept in Western thought. These professionals want to learn if the skeleton on our laboratory table is a person of Black, White, Asian or Native American ancestry." To conduct analysis of ancestral background, the osteologist may use osteological traits known to vary among different human populations in different parts of the world.

As Brace (1995, p. 172) explains, "Skeletal analysis provides no direct evidence for skin color for example, but it does allow an accurate estimate of original geographical origins. African, eastern Asian, and European ancestry can be specified with a high degree of accuracy. Africa of course entails 'black,' but 'black' does not entail African." Marks (1996) notes that the tendency for Americans to classify people in three races is an artifact of history and statistics — immigrants to North America have come mostly from ports where seafaring vessels in earlier centuries could pick them up. Hence, the American notion of "black" is actually west African, and the notion of "Asian" is actually east Asian. People from south Asia (India and Pakistan — people with darker skins and facial resemblances to Europeans) immigrated in smaller numbers and therefore did not merit as much bureaucratic concern.

A real example of the dilemma facing human osteologists in the area of "racial" identification comes from the work of Katz and Suchey (1989) on their sample of Los Angeles male pubic symphyses. These workers, in a paper entitled "Race Differences in Pubic Symphyseal Aging Patterns in the Male," assess the Los Angeles County Coroner sample used to generate the Suchey-Brooks system of symphyseal aging (see section 19.3.6). They segregated the symphyses into "racial" categories. They did not use the California death certificates made out by coroner investigators. As Katz and Suchey note, these examiners used nonuniform mixtures of biological, cultural, and linguistic variables in their determinations. Rather, Suchey divided the autopsied individuals into 486 Whites, 140 Blacks, and 78 Mexicans and noted that her Mexican category is a category showing Mexican ancestry coupled with a strong American Indian racial component. Katz and Suchey found that pubic symphyseal metamorphosis was accelerated in Blacks and Mexicans, but they could not address the issue of causality.

When DNA can be extracted from a subject's osteological remains, accurate determination of the ancestral population and even familial relationships becomes possible. DNA typing of skeletal remains has the potential to provide the best available information regarding the populational affinity of the individual. Mitochondrial DNA (mtDNA) is a small portion of the human genome that is inherited only from the mother. Several regions of mtDNA are highly variable within modern humans, and the sequencing of these regions can permit the estimation of the ancestral maternal population (Connor and Stoneking, 1994). Archeologically, these techniques have been used to assess the relationships of prehistoric New World populations with various modern Native American groups (Stone and Stoneking, 1993; Hauswirth *et al.*, 1994; Kaestle, 1995). Forensically, the analysis of mtDNA has been used to help identify the remains of U.S. military personnel in Vietnam (Holland *et al.*, 1993).

Whereas molecular and soft tissue characteristics such as skin color, hair form, and facial features often allow unambiguous attribution of geographic ancestry among living people, the hard tissues display less-reliable signatures of affinity. There are, in fact, no human skeletal markers that correspond perfectly to geographic origin. The problems in using discrete cranial and dental features to determine ancestry are perhaps best appreciated by considering what most osteologists agree is a racial marker: the shovel-shaped incisors seen in high frequency in modern Asian populations. A review and compilation of data on incisor shoveling by Mizoguchi (1985) show wide ranges of expressivity and incidence values in different extant human groups. Suffice it to say that incisors from Asian populations show a high incidence of shoveling, but also that the presence of shoveled incisors is hardly grounds for confident identification of a dentition as Asian.

The skull is the only part of the skeleton that is widely used in estimating geographic ancestry [but see İşcan and Cotton (1985) for a consideration of the pelvis as a racial indicator and Baker *et al.* (1990), Trudell (1999), and Gill (2001) for femoral techniques. Holliday *et al.* (1999) provide a discriminant function for multiple elements]. Even with this element, all workers agree that racial estimations are usually more difficult, less precise, and less reliable than estimations of age, sex, or stature. Despite decades of research, much more osteological work on geographic differentiation within *Homo sapiens* remains to be done and is urgently needed. Work on modern skulls of known origin has revealed certain tendencies.

Howells (1995) notes that the human species lacks well-defined subspecies but has clear local tendencies of variation. It is simply not possible to attribute every human cranium to one or another geographically defined group on the basis of its morphology or measurements—populations of the human species are morphologically too continuous for this. Howells conducted exhaustive and long-term studies on a selected sample of 2504 human crania from around the world. He used 57 measurements on each skull and employed multivariate statistical techniques and a computer to show clearly that human variation in cranial shape, as represented by his measurements, is patterned and that "target" skulls of unknown affinity could often be unambiguously placed in a parent "population."

Compared to populations of African or European origin, Asian populations display skulls characterized by narrow, concave nasal bones, prominent cheek bones, circular orbits, and shoveled incisors. Compared to Asians and Europeans, African crania have been characterized as showing wide interorbital distances, rectangular orbits, broad nasal apertures with poor inferior definition, gracile cranial superstructures, and pronounced total facial and alveolar prognathism. European crania have been characterized as displaying narrow nasal apertures with sharp inferior borders (sills), prominent nasal spines, heavy glabellar and supraorbital regions, receding cheek bones, and large, prominent nasal bones.

Given the limitations of using such subjective criteria for recognizing geographical ancestry, some have turned to cranial metric methods for the assessment of racial status (Giles and Elliot, 1962; Howells, 1969b). One such attempt is that of Gill (1984, 1986), which addresses the problem of sorting European from Native American crania.

Gill (1995) provides a compendium of traits useful in assessing ancestry in an American context in his article "Challenge on the Frontier: Discerning American Indians from Whites Osteologically." He notes that the Giles-Elliot discriminant function approach has been shown to be ineffective at sorting crania, particularly in the Northwestern Plains area where he works in both forensic and archeological contexts. Gill considers races to be statistical abstractions of trait complexes, not pure entities or rigidly definable types. Table 19.4 is a list of useful nonmetric traits of the dentition and cranium taken from his paper. See Tyrrell (2000) for another consideration and Edgar (2005) for a consideration of racial prediction from dental anatomy.

The attention now being given to the origin of anatomically modern *Homo sapiens* in the later Pleistocene (Mellars and Stringer, 1989; White *et al.*, 2003) should stimulate more work on skeletal differentiation within geographically separated populations of the species. Meanwhile, all of the techniques noted here, both visual and metric, should be applied only on adult remains and with comparative material. See Gill (1986), Krogman and İşcan (1986), and İşcan (1988) for further discussions on this topic.

Table 19.4
Useful Nonmetric Traits in Determining Ancestry Based on the Cranium

	"American Indians"	"Whites"	"Blacks"
Incisors	shovel-shaped	blade-form	blade-form
Zygomatics	robust, flaring	small, retreating	
Prognathism	moderate	very limited	marked alveolar & facial
Palate	elliptic	parabolic	hyperbolic
Cranial sutures	complex	simple	simple
Nasal spine	medium, "tilted"	long, large	small
Chin	blunt, median	square, bilateral, projecting	blunt, median, retreating
Ascending ramus	wide, vertical		narrow, oblique
Palatine suture	straight	jagged	arched
Zygomatic tubercle	present		
Incisor rotation	present		
Nasal profile	concavo-convex	straight	
Sagittal arch	low, sloping		
Wormian bones	present		
Nasals	low, tented	highly arched, steeplelike	low, flat
Nasal aperture	medium		wide
Zygomaticomaxillary suture	angled	curved	curved
Dentition		small, crowded	large molars
Nasal sill		very sharp	very dull or absent
Nasion		depressed	
Cranial vault		high	low
Mandible		cupping below incisors	
Inion hook		present	
Postbregmatic depression			present

From Rhine (1990) and Gill (1995).

19.7 Identifying the Individual

In paleontological and prehistoric archeological contexts, fossils are sometimes given nicknames like 'Dear Boy' or 'Lucy,' but we will never know how members of their own species identified them. In historic archeological contexts, it is possible that skeletal remains may be identified as unique individuals, such as named Egyptian pharaohs or people buried beneath headstones in historic cemeteries. In the forensic realm, the human osteologist is often presented with unidentified skeletal remains. The positive identification of human skeletal remains — the unequivocal matching of teeth, crania, or postcranial remains with unique, named individuals — is often the most important step in the analysis. The identification of age, sex, stature, and ancestry all narrow the windows of possible identification — possible matching — to known individuals (often missing or unaccounted for). The last step in the process of identification sometimes involves matching unique features of the "unknown" skeleton with unique characters of the "known" missing.

DNA analysis is the best method for testing hypotheses about the identity of skeletal remains. The general approach is to compare DNA from the skeleton with the DNA of the presumed relatives. For a number of variable regions of the DNA, the odds of a match between unrelated individuals are extremely low. Exactly how low is a matter of debate for cases involving blood samples from living individuals (Devlin *et al.*, 1994), but in osteological contexts this is rarely, if ever, a concern. DNA typing has been used to identify skeletonized individuals in contexts involving mass deaths (the Branch Davidian incident in Waco, Texas: Houck *et al.*, 1996), mass graves (Guatemala and former Yugoslavia: Boles *et al.*, 1995; Primorac *et al.*, 1996), remains of military personnel (Vietnam: Holland *et al.*, 1993), war criminals (Josef Mengele: Jeffreys *et al.*, 1992), and numerous forensic cases involving murder victims (e.g., Hagelberg *et al.*, 1991; Sweet and Sweet, 1995). Even though the determination of familial relationships is most applicable in forensic or historical contexts, archeological analysis of mortuary rituals and burial practices can often be advanced if the general relationships of the interred individuals can be established (Stone and Stoneking, 1993). Establishing the familial relationships between individuals in the same prehistoric population requires more detailed analysis than is usually attempted.

Identification at the species level, sometimes a problem with extremely fragmentary remains, is also made possible through DNA analysis. However, the determination of whether fragmentary skeletal remains are human or nonhuman can usually be done quickly, cheaply, and accurately by visual inspection of the morphology, rendering DNA analysis unnecessary for this question in most osteological contexts. In paleontological settings, though, morphological methods for determining the species affiliation of hominid fossils often produce ambiguous results. In the case of Neanderthals, for example, paleoanthropologists disagree as to whether there was gene flow between Neanderthals and contemporaneous early modern humans. A comparison of Neanderthal DNA with the DNA of early modern humans would provide a crucial test of hypotheses about their relations. The first step in this was taken by Krings *et al.* (1997), who successfully retrieved a portion of the mtDNA from a Neanderthal humerus. This result was replicated in another laboratory, and the sequence obtained is quite distinct from any known modern human sequence. Even though the processes of fossilization and DNA degradation preclude the application of DNA techniques to most of the fossil record, questions about species and evolutionary relationships within the last few hundred thousand years may be addressed using this method.

Fingerprint analysis, of course, is a means by which forensic specialists routinely match criminals with their crimes. As the soft tissue features of the body decay or are incinerated, however, the use of fingerprints, hair, and personal items to individuate the deceased becomes impossible. Teeth, the skeletal structures most resistant to such destruction, are often used to identify people in mass disasters. Such individuation via teeth and their modifications, usually by dentists, has traditionally been accomplished by **forensic odontologists**, specially trained experts accomplished at such identifications. Radiographs and other dental records kept by dentists are matched against modifications on the deceased's teeth, often resulting in a positive identification (Kogon and MacLean, 1996).

Another means of establishing a positive identification on unknown skeletal remains is the comparison of those remains with medical radiographs taken when the individual was alive. Fractures, of course, can heal, but there are often trabecular and cortical points of identity through which a positive identification can be established. Postcranial skeletal characters (Owsley and Mann, 1992; Kahana *et al*., 1998) and frontal sinus morphology (Ubelaker, 1984; Kirk *et al*., 2002; Smith *et al*., 2002; Christensen, 2004) have been shown to be individually specific. The success of radiographic identification of unknown human remains, like that of many other techniques in human osteology, depends on the experience of the interpreter. Hogge *et al.* (1994) showed that the most-accurate identifications came from cranial remains and the cervical spine and chest, whereas the least-accurate identifications were made on the lower leg.

More recently, techniques that superimpose the skull of an unknown deceased individual on old photographs, motion pictures, or videotapes have been developed (İşcan and Helmer, 1993). Austin-Smith and Maples (1994) have tested the reliability of such superimposition methods and provide a good review of the techniques, limitations, and successes. When anterior dentition is recovered with the skull and a smiling photograph with the teeth in focus is available, the shapes of individual teeth and their relative positions are often distinctive enough for an identification to be made. Using only one photograph, Austin-Smith and Maples found a 9% chance of false identification, but when two photographs representing a difference of about 90° in the angle of the face to the camera were used for superimposition, the chance of false identification dropped to less than 1%.

A final means of personal identification based on skeletal remains involves forensic three-dimensional facial reconstruction. A series of techniques exists for the "restoration" of the soft tissue cover of a human skull (İşcan and Helmer, 1993; Neave, 2000). A recent review of the history of development and current status of such techniques by Tyrrell and colleagues (1997) notes that facial reconstruction still stands on the threshold between art and science. These authors conclude that current methods are useful, but insufficiently reliable to serve as evidence of positive identification in a court of law. Clement and Ranson (1998) provide a broad overview of craniofacial identification in forensic work and DeGreef and Willems (2005) review progress and prospects in this field.

19.8 Discrete Traits

One of the first and most important observations that every osteology student makes is that each human skull is different from every other human skull and can be recognized and differentiated on the basis of size, shape, and various bumps, grooves, foramina, or surface textures. Much of this variation may be partitioned according to the factors responsible for it — age, gender, and pathology. However, much of the variation is idiosyncratic and some of it is attributable to ancestry.

Minor variants of the human skeleton were noted by the ancient Greek scholar Hippocrates, who described wormian bones in human cranial sutures over 2000 years ago. Also called **discontinuous morphological traits**, **epigenetic variants**, or **discrete traits**, nonmetric variation is variation observed in bones and teeth in the form of differently shaped and sized cusps, roots, tubercles, processes, crests, foramina, articular facets, and other similar features. El-Najjar and McWilliams (1978) and Saunders (1989) provide reviews of work on these kinds of features in human osteology. Suffice it to say that the genetic basis for these traits, particularly nondental ones, is unknown.

Rosing (1984) provides a concise, critical review of the use of nonmetric skeletal traits, concluding that standards for their determination are poor or lacking.

Although all of the labels applied to nonmetric variation imply that it is discrete, this is not necessarily the case. As Mizoguchi (1985) points out, it is rare that nonmetric "traits" are really discontinuous and discrete, even though they are usually scored by osteologists in a nonmetric fashion (either as scored values or by presence/absence). The expression of many of the traits can, indeed, be quantified. These dental and skeletal nonmetric traits can be useful in gauging affinity of extinct human populations. The kinds of nonmetric variation sometimes described in human osteology and used in assessing population affinity are introduced here [for a more complete review of human skeletal nonmetric traits, see El-Najjar and McWilliams (1978), and Saunders (1989)]. Saunders (1989) divides discrete traits into eight categories: 1) Hyperostotic; 2) hypostotic; 3) foramina/canals/grooves; 4) supernumerary vault sutures; 5) craniobasal structures; 6) spinal structures; 7) prominent bony processes; and 8) facet variations. The Buikstra and Ubelaker Standards volume (1994) recognizes two basic categories of skeletal nonmetric traits presented in Table 19.5. Some nonmetric skeletal traits, such as the oval window in the middle ear, have proven valuable to forensic osteologists in establishing "racial" affinities of unknown crania (Napoli and Birkby, 1990).

19.8.1 Dental Nonmetric Variation

Because teeth are often the most abundant elements in archeological skeletal series and because tooth size and morphology are often more directly tied to underlying genetics than are other osteological features, teeth have been examined in detail and used widely in osteological analysis. Dental anthropologists use nonmetric variation of tooth crowns to assess biological affinity. Supernumerary teeth, crown fissure patterns, cusp numbers, accessory crown features, and root number, size, and shape combine with a variety of other traits under the heading of nonmetric dental variation. Dahlberg's casts of dental nonmetric traits, available in many human osteology laboratories, provided a standard for work in this area. The Arizona State University Dental Anthropology System is the current, most widely employed set of standards in dental anthropology (Turner *et al.* 1991; Scott and Turner, 1997). Figure 19.16 illustrates two nonmetric variants possessed by the same individual. Occasionally there is insufficient space in the jaw for tooth eruption, and **crowding** or **impaction** of teeth are the consequences. These, in turn, can result in pathology of associated soft and hard tissues.

19.8.2 Cranial Nonmetric Variation

A wide variety of nonmetric variants in and between the bones of the skull have been used to differentiate skulls and groups of skulls. El-Najjar and McWilliams (1978) describe forty-four such nonmetric traits, whereas Hauser and De Stefano (1989) characterize eighty-four. A few examples suffice to show the nature of the characters in question: presence or absence of a metopic suture (Figure 19.17), parietal foramina, extra

Table 19.5
Skeletal Nonmetric Traits*

PRIMARY TRAITS	SUPPLEMENTAL TRAITS, CRANIAL
Metopic suture	Frontal grooves
Supraorbital notch	Ethmoidal foramina
Supraorbital foramen	Supratrochlear notch or foramen
Infraorbital suture	Trochlear spine
Infraorbital foramen	Double occipital condylar facet
Zygomatico-facial foramina	Paracondylar process
Parietal foramen	Jugular foramen bridging
Sutural bones	Pharyngeal tubercle
epipteric bone	Clinoid bridges or spurs
coronal ossicle	Accessory lesser palatine foramina
bregmatic bone	Palatine torus
sagittal ossicle	Maxillary torus
apical bone	Rocker mandible
lambdoid ossicle	Suprameatal pit or spine
asterionic bone	Divided parietal bone
occipitomastoid ossicle	Os Japonicum
parietal notch bone	Marginal tubercle
Inca bone	
Condylar canal	SUPPLEMENTAL TRAITS, POSTCRANIAL
Divided hypoglossal canal	Retroarticular bridge
Flexure of superior sagittal sulcus	Accessory transverse foramen (C3 – 6)
Foramen ovale incomplete	Vertebral number shift
Foramen spinosum incomplete	Accessory sacroiliac articulation
Pterygo-spinous bridge	Suprascapular foramen or notch
Pterygo-alar bridge	Accessory acromial articular facet
Tympanic dehiscence	Unfused acromial epiphysis
Auditory exostosis	Glenoid fossa extension
Mastoid foramen	Circumflex sulcus
Mental foramen	Sternal foramen
Mandibular torus	Supratrochlear spur
Mylohyoid bridge	Trochlear notch form
Atlas bridging	Allen's fossa
Accessory transverse foramina	Poirier's facet or extension
Sepal aperture	Third trochanter
	Vastus notch
	Squatting facets, distal tibia
	Squatting facets, talus
	Talar articular surface (calcaneus)

* Buikstra and Ubelaker (1994) divide traits into "primary" (for which they provide scoring standards) and "supplemental." Their Standards volume provides illustrations and a standard recording form recommended for the compilation of data on the "primary" skeletal discrete traits, as well as references to all of these characters.

Figure 19.16 Dental nonmetric variations: shoveled incisors. Misdirected, unerupted (heterotopic) upper canines have here resulted in retention of the deciduous canines. The anomaly is bilateral, with the unerupted canine crowns visible through holes in the anterior surface of the maxillae. Prehistoric, California. Natural size.

Figure 19.17 Cranial nonmetric variation. A metopic suture has persisted into adulthood in this male individual. Prehistoric, North America. Natural size.

bones at pterion, wormian bones, multiple mental foramina, and mylohyoid bridges have all been used in nonmetric analysis. Developmental anomalies of the skull, such as scaphocephaly (long narrow skulls caused by premature closure of the sagittal suture), have also been considered by some to represent nonmetric variants. Others simply consider them to be developmental anomalies. A skeletal anomaly is usually considered to be pathological if it is disadvantageous to the individual.

19.8.3 Postcranial Nonmetric Variation

Finnegan (1978) provides a description of thirty nonmetric traits observed in the postcranial skeleton. He emphasizes postcranial traits because they show bilateral expression and because the appropriate skeletal elements are often preserved in the archeological context. Finnegan (1978) lists features such as the talar facets, femoral third trochanters, and bipartite cervical transverse foramina. Many of the listed features relate to the presence, shape, size, and orientation of articular surfaces. Many of the traits identified by Finnegan (1978) may be highly susceptible to environmental influence, in contrast to dental nonmetric traits. For this reason, dental nonmetric traits are the most widely and successfully used skeletal indicators in gauging populational affinity.

19.9 Estimating Biological Distance

The assessment of affinity (biological relationship) based on skeletal form has a long history in physical anthropology (Armelagos *et al.*, 1982). Larsen (1997) provides a good review of such studies. Osteologists who study the skeletal remains of anatomically modern humans often work on microevolutionary problems. To estimate the degree of genetic relatedness between populations, the osteologist works under an important assumption: populations that display the most similarity are the most closely related. The degree to which this assumption is met in practice depends on two major factors: adequacy of sampling and choice of characters (osteological traits) for comparison (Ubelaker, 1989).

Osteologists observe only samples of biological populations. The populations themselves are no longer available for study. Therefore, the strength of osteologically based conclusions about affinity depends on the degree to which the samples accurately reflect the real populations that once existed. The conclusions about relationship can be weakened if the sample is too small or if its composition has been altered in some systematic way. Ubelaker (1989) recommends unbiased adult samples of 100 individuals for each group being compared in biodistance studies.

Osteological assessment of the biological relationships among past populations must be made on the basis of anatomical traits. These traits should ideally be directly and exclusively controlled by genes. The more susceptible to environmental (including cultural) influence a skeletal trait is, the less valuable it is in establishing affinity. For example, flattening of the occipital by the cultural practice of cradleboarding can be observed in distantly related people, but to conclude that two populations manifesting cradleboard-induced occipital flattening were biologically closely related would be misleading. Unfortunately, no single skeletal trait is free from environmental influence.

Osteologists have traditionally used both metric and nonmetric traits in their assessments of biological distance between skeletal populations (Pietrusewsky, 2000). Multivariate statistics have been employed, mostly with cranial measures, to gauge relatedness. Nonmetric characters have also been used, alone or in combination.

Dentition has been used most effectively to assess relationships between modern and ancient populations for several reasons. Teeth exhibit a variety of anatomical details that have been demonstrated to be stable through time, to have a high genetic component to their formation, and to differentiate living human populations. Teeth are often better preserved than bone. In addition, the post-formation effects of environment, gender, and age have less influence on tooth morphology than on most bony anatomy. For these reasons, teeth have figured prominently in reconstructing the biological history of various human populations. Standardization of traits and the methods for scoring them (e.g., Carabelli's cusp, fissure patterns, number of cusps, and incisor shoveling) have considerably facilitated and enhanced the accuracy of dental nonmetric analysis (Turner *et al.,* 1991; Scott and Turner, 1997).

It is increasingly apparent that the molecular revolution in osteology holds the potential to become the definitive arbiter of much biodistance work with human skeletal remains. However, as Kolman and Tuross (2000) note, even in the new millennium, ". . . the analysis of DNA is still an excruciatingly slow and meticulous process." Other biochemical and geochemical analyses can also be brought to bear on problems of population origin and movement, early examples being work on the origin and movements of the Alpine Iceman (Müller *et al.*, 2003), and on commingled remains from Vietnam (Beard and Johnson, 2000).

19.10 Diet

One of the primary goals of archeological research is the reconstruction of subsistence patterns in past human populations. A multidisciplinary approach is usually taken in this endeavor, with specialists analyzing floral, faunal, and fecal material recovered in habitation sites, and still other archeologists examining the remains of technology used to exploit different food resources. Such an approach uses information from many disciplines to elucidate the past. The osteologist can make contributions to understanding the diet of prehistoric people by examining skeletal pathologies, analyzing dental wear, and, more recently, through the analysis of trace and major elements extracted from the skeletal remains themselves.

The interaction between nutrition and skeletal pathology is a complex, difficult subject area and the focus of a great deal of current research. For a comprehensive review of the topic, see Martin *et al.* (1985) and Larsen (1997). Indicators such as Harris lines, dental hypoplasia, and dental asymmetry may be used on a populational basis to determine nutritional adequacy in prehistory. Unfortunately, however, stress markers in bone are nonspecific, and only patterns and trends of nutritional stress at the populational level can be ascertained. On the opposite end of dietary reconstruction, the focus can be individual and the results very specific, for example, when colon contents can reveal a meal (Shafer *et al.*, 1989).

Dental wear and dental caries have long been used in attempts to characterize prehistoric diet. Teeth interface directly with foodstuffs, and the physical and chemical composition of food has a direct influence on wear and decay. Prehistoric people who incorporated large amounts of grit into their diet through food-preparation techniques, such as grinding food between stones, exhibit pronounced dental wear. The limitations of using dental wear to assess diet are easily understood by considering two imaginary prehistoric populations eating exactly the same diet. If one population used sandstone grinders to prepare the bulk of its diet, while the other group used wooden mortars, the rate and nature of dental wear would be very different, even though the nongrit content of the diet was identical.

Microscopic examination of worn teeth reveals pits and striations in the enamel and dentine. Use of the scanning electron microscope has made it possible to carefully study microscopic wear on teeth (Walker, 1981; Teaford, 1991, 1994). As with paleopathology, study of dental wear must be done on a populational basis to yield reliable dietary reconstructions. This is particularly true with microwear analysis because the microscopic signature of the individual's last meal or set of meals may not be indicative of what the average diet was over the life of the individual. Much additional research in this area is required. It is clear, however, that dental microwear study is an important compliment to macroscopic wear, bone chemistry, and pathological assessment in dietary analysis.

Unlike dental wear, dental caries are a pathological condition whose incidence is under the influence of many factors, including diet. The incidence of caries, for example, has been shown to be generally higher in agricultural than in hunting and gathering economies. Smith (1984) and Schmucker (1985) summarized studies aimed at elucidating prehistoric diet through the analysis of tooth wear, and they both found that hunters and gatherers can be distinguished from farmers on the basis of macroscopic tooth wear. Powell (1985) reviews the use of dental wear and caries in reconstructing prehistoric diet.

Dental caries is the disease process characterized by demineralization of dental hard tissues by organic acids produced when bacteria ferment dietary carbohydrates (especially sugars). Because carious lesions are readily apparent on teeth, there is a very large literature associated with them, even for prehistoric populations. Osteologists have been studying temporal trends in caries since the 1800s. Changes in processing technology and food had important implications for the oral health of past human populations. Cariogenic foods obviously lead to a higher prevalence of caries in a population. Within a population, sex and status differences in the amount of cariogenic food eaten may play important roles in determining the frequencies of caries (Walker and Hewlett, 1990). Larsen (1997) reviews the use of caries frequencies in studies of modern and archeological skeletal samples.

Developments in the chemical analysis of osteological remains have opened new windows on the past. Analysis of trace elements and isotopes in human osteology has played an increasingly important role in dietary reconstruction during the last two decades (for reviews, see Price, 1989; Sandford, 1993; Schoeninger, 1995; Larsen, 1997; Katzenberg, 2000; and Sandford and Weaver, 2000).

Traditionally, the issues of diet and affinity have been approached in human osteology via morphological assessment. The application of chemical methods of analysis has been mostly directed toward osteological remains from archeological contexts. As

Larsen (1997) notes, documentation of diet in the past provides the context for studies of growth, stress, disease, and subsistence activities. Conventional approaches to diet utilized archeological materials, particularly plant and animal remains. The archeological record has long been known to be biased in its preservation of food remains, however, with plant remains often approaching invisibility due to difficulties in preservation. The prospect of an independent and objective means to generate consumption profiles of different foods eaten in the past is therefore an enticing one.

Organisms comprise common elements such as hydrogen (H), carbon (C), oxygen (O), nitrogen (N), calcium (Ca), and less common (trace) elements such as strontium (Sr). Many elements come in different isotopes. These isotopes differ in how many neutrons they possess. Some isotopes are unstable and radioactive, and by measuring their decay, geochronologists are able to determine the age of many materials. Heavier isotopes have more neutrons in their nuclei. Lighter isotopes (^{12}C relative to ^{13}C, for example) break and form chemical bonds more rapidly than heavier isotopes. These facts of chemistry mean that ratios of the stable isotopes can be examined in efforts to deduce aspects of paleoecology and human behavior, including diet. Carbon and nitrogen are the elements that have received most attention in studies of human osteological chemistry.

There are two stable isotopes of carbon: ^{12}C and ^{13}C. Ratios of these isotopes in mammalian bones reflect diet (e.g., plant tissues consumed during life). Plants use two photosynthetic pathways. The so-called C3 plants discriminate against the heavier isotope of carbon, and their tissues are enriched in ^{12}C. Organisms eating more of these plants will therefore show higher $^{12}C/^{13}C$ ratios in their bones. Maize and other C4 plants do not discriminate as much and have more of the heavier isotope, decreasing this ratio of carbon isotopes in the bone collagen of consuming organisms. Similarly, the heavier ^{15}N isotope of nitrogen concentrates as it travels up through the food chain. Marine plants have higher concentrations of this isotope than land plants, and animals higher up in the marine food chain have, as a consequence, higher $^{15}N/^{14}N$ ratios in their bones. People feeding on marine mammals are thus expected to have higher ratios than those subsisting on terrestrial food sources. Thus, the isotopic compositions of the bone tissue may be indicators of diet. By taking a tiny sample of bone tissue, the osteologist can convert the sample into a gas and measure the isotope values with a mass spectrometer. The isotopic ratio values can be compared between different skeletons. With these tools, in theory, osteologists are positioned to evaluate subsistence changes through time by direct reference to the chemical composition of skeletal remains.

The initial chemical studies of bone (in the 1970s) were received with great enthusiasm because the techniques appeared to provide direct quantitative means for reconstructing diet (Sandford, 1993). By the 1980s, trace element and stable isotope research was heralded as a breakthrough, and more researchers began to conduct these studies. As Sandford (1993) notes, however, the early optimism was soon curbed by studies that demonstrated that elemental concentrations are influenced by many complex and often-interrelated processes. By the late 1980s authors were referring to the "abuse of bone analyses for archeological dietary studies" (Hancock *et al.,* 1989) and proclaiming that there were "no more easy answers" (Sillen *et al.*, 1989).

During life, elemental deposition in the skeleton is governed by more than just the abundance of elements in the diet. After burial, bones can be subjected to diagenesis. Concerns over how these variables influence bone's chemical composition have generated a great deal of additional research. As Radosevich's "The Six Deadly Sins of Trace Element Analysis: A Case of Wishful Thinking in Science" (1993, p. 318) states: "It is possible that a viable field of trace element analysis of bone in this field can still be constructed, but examinations of basic geochemistry and taphonomy of soil-buried bone must be carried out first, not as an afterthought." As Ambrose (1993) has pointed out, studies of stable isotopes have been developed mostly in geochemistry and plant physiology rather than in anthropology. The most substantial insights into prehistoric diet and land use have been achieved in areas involving the introduction of C_4 plants such as maize, the demonstration that diets of high-status individuals were different from lower-status individuals in some societies, and the assessment of marine versus terrestrial food webs. Larsen (1997) reviews the results of these applications, and Ambrose and Katzenberg (2000) provide a comprehensive overview of biogeochemical approaches to paleodiet. As with the use of biomolecules in human osteology, stable isotope and trace element analyses require thorough grounding in chemistry, biochemistry, physiology, physics, and other laboratory sciences.

19.11 Disease and Demography

The study of populations, **demography**, is concerned with the vital statistics of populations — life expectancy, mortality rates, birth rates, and population growth, size, and density. Demographers interested in modern people use data collected by census takers who census the living. Paleodemography is the study of the demography of prehis-

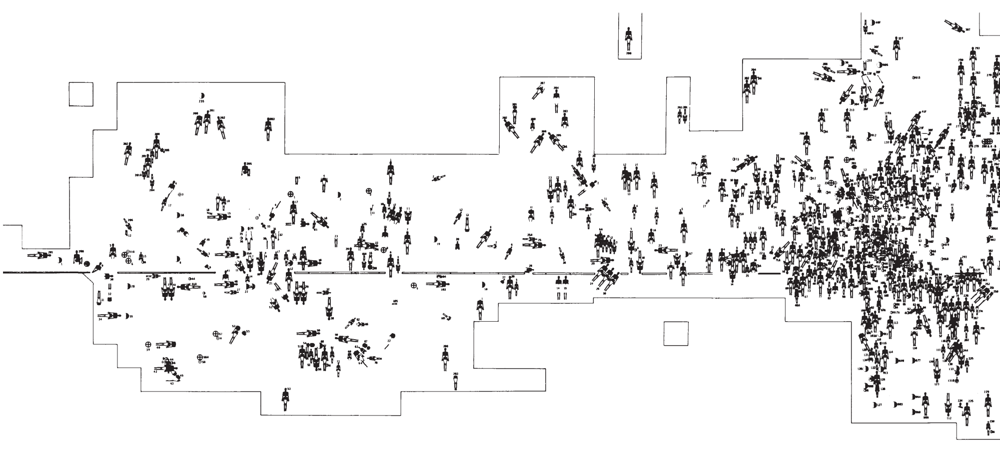
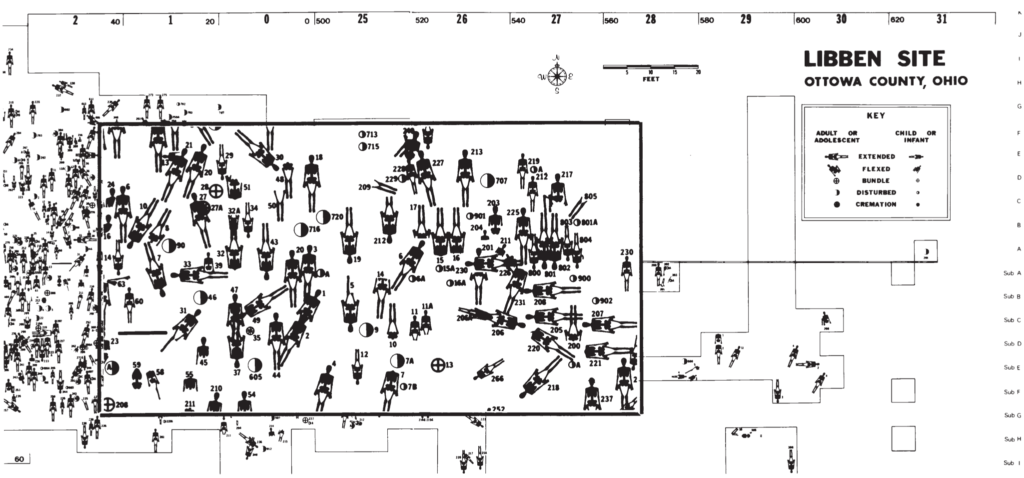


Figure 19.18 Plan of the prehistoric Libben site, Ottawa County, Ohio. Studies of skeletal populations such as this one can lead to insights into demographic aspects of early human populations. The area in bold outline is a blowup of part of the plot. From Lovejoy *et al.*, 1985a.

toric populations. The vital statistics of these populations can be reconstituted by use of their skeletons. The osteologist can reconstruct these populations by censusing the dead. A major assumption used here by the osteologist is that the rates of growth and aging established for modern humans can be applied appropriately to individuals who lived in the distant past. The more ancient the populations under study, the less valid this assumption is likely to be.

The reliability of demographic reconstructions built on skeletal material depends on the accuracy of individual age and sex estimations of the skeletons. In addition, their reliability depends on how accurately the sample of skeletons represents what was once the living population. Van Gerven and Armelagos (1983), Greene *et al.* (1986), Boddington (1987), Bocquet-Appel and Masset (1982), Wood *et al.* (1992), Jackes (1992, 2000), Konigsberg and Frankenberg (1994, 2002), Chamberlain (2000), Milner *et al.* (2000), and Hoppa and Vaupel (2002) provide good reviews of the assumptions and limitations of archeological data in demographic reconstructions. Wright and Yoder (2003) provide a more recent review of the subject and literature. Figure 19.18 is an illustration of a large cemetery excavated during the 1960s in the midwestern United States. Here, 1327 articulated skeletons were recovered, ranging in age from *in utero* individuals to elderly adults. The excavators estimate that this represents a 300-year occupation (Lovejoy *et al.*, 1985a).

To better understand the constraints and limitations of demographic reconstructions based on skeletal remains, imagine an ancient population in which all of the dead were buried in a single cemetery over the span of one hundred years. In this imaginary case, no people died away from home or were cremated or eaten by carnivores. None of the skeletons were disturbed after burial by biological or physical agents. Further-



more, imagine that the entire cemetery was preserved intact through the centuries. Finally, imagine that all of it was excavated and that all of the individuals, including very young infants, were recovered. Provided that recovery was complete, record keeping was good, none of the skeletal material was lost subsequent to excavation, and the osteologist could accurately age and sex all of the individuals, these data might be used directly to reconstruct demographic attributes of the population.

As Ubelaker (1989) notes, demographic reconstruction from skeletal remains is not difficult mathematically. For example, consider survival through time, beginning with live births. At birth, survival would be 100%. By age 5, with high infant mortality, perhaps only 60% of the original population would have survived. This would mean that 40% of the cemetery population would have been made up of children in the 0- to 5-year-old age range. By plotting the age estimates for these and the other burials in 5-year intervals through time, one could reconstruct a survivorship curve for the population (Figure 19.19). One might examine survivorship by sex or make deductions about life expectancy in the population. In short, it would be possible to examine the paleodemography of the population under study.

It is important to derive demographic facts for past human groups. One must note, however, that accurate and reliable demographic reconstruction was only achieved under the specified conditions in the imaginary case outlined earlier. Most archeologically derived skeletal samples do not meet these conditions, and survivorship curves that they generate are prone to systematic error as a result. For example, many human groups differentially dispose of the dead. If there is bias in their burial practices, the demographic profile of that population cannot be determined accurately. Many cemeteries show differential preservation that favors young adult individuals over children or elderly adults because bones of the former are stronger and less prone to destruction by taphonomic agents [evidence for bias due to preservation can be found by careful analysis of the sample (Walker *et al*., 1988)]. Many cemeteries are excavated nonrandomly or sampled incompletely. Only intact specimens are saved subsequent to collection in many archeological excavations. Many skeletal samples are curated poorly, with the loss of much material. In short, most archeologically derived skeletal populations are inadequate to provide accurate paleodemographic reconstructions. If an understanding of paleodemographic aspects of ancient populations is the goal of a research project, it is imperative that the osteologist work closely with the archeologist to see that sampling strategy does not bias the ultimate results.

Waldron (1991, p. 24) expresses the linkages and pitfalls of studying demography and disease in skeletal populations as follows:

> *The underlying assumption that is inherent in any attempt to use a death assemblage to predict something about the living is that the dead population is representative — or at least typical — of the live population. Given all the non-random events that surround death and burial, not to mention preservation and recovery, this is at best an approximation, and at worst the two (the live and the dead) bear no epidemiological relation to each other whatsoever. However, it is clearly important to know where on this spectrum a particular group, or set of groups, lies, especially if the data derived from their study are to be used to construct life tables, to make inferences about changing patterns in disease or dietary habits, or to draw any of the other demographic conclusions that are so commonly bandied about.*

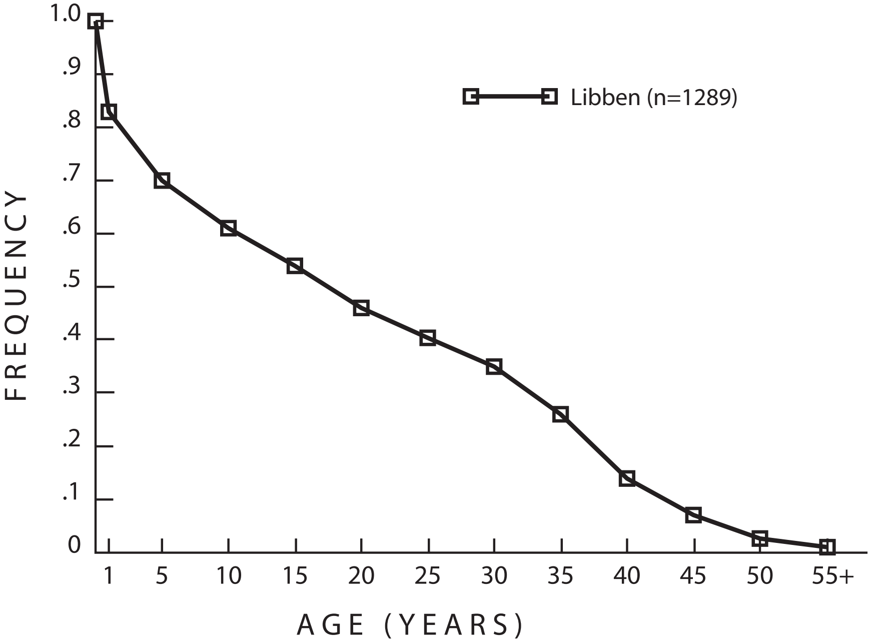


Figure 19.19 Survivorship curve based on the prehistoric Libben skeletal population. Data from Lovejoy *et al.* (1977).

The relationship between adoption/intensification of agriculture and population size and health has been an object of anthropological inquiry for many decades. Paleodemographic and paleopathological data have been brought to bear on this subject for many years, and as of the beginning of this decade, the idea that agriculture brought with it a decreased quality of life and increased mortality rates was widely accepted. In a sobering and influential contribution, Wood and colleagues (1992) reminded anthropologists that the study of prehistoric populations and their health is a complex undertaking, never straightforward or simple. These authors question a basic assumption made by many osteologists regarding lesions on skeletal remains. They argue that rather than reflecting declining community health, such lesions indicate that the affected individuals survived some disease, that such survival might actually indicate an improvement in health, and that individuals who lived long enough to manifest pathological lesions on their skeletons were advantaged relative to people who succumbed to disease before their skeletons were affected. Furthermore, these authors note that large numbers of immature skeletons may indicate more about fertility than mortality. These observations are in sharp contrast to the received wisdom in paleopathology and paleodemography. How, then, are osteologists to interpret paleopathology on a populational basis? Wood *et al.* (1992) say that considerably more critical research is required, but that in the meantime, the skeletal evidence pertaining to the transition from hunting and gathering to settled agriculture is equally consistent with an improvement or a deterioration of health (see also Cohen, 1994).

Applying human skeletal data from historic and prehistoric contexts to important questions about culture and biology is an important avenue of anthropological investigation. Decades of such application have brought an increased understanding of the complexities involved in such studies. It is clear that anthropologists will continue to use skeletal populations in efforts to better understand the past and will do so with increasingly sophisticated techniques and heightened cautions built upon a better appreciation of the fragmentary and biased nature of the records that they study.

Glossary

Ablation The removal of part of the body; usually used when referring to the removal of teeth.

Abscess A localized collection of pus in a cavity formed by tissue disintegration; often found as cavities within alveolar bone near the tooth root apices.

Achondroplasia A hereditary form of dwarfism with limb shortening, almost normal trunk and vault development, and a small face; caused by a congenital disturbance of cartilage formation at the epiphyses.

Acromegaly A condition caused by an overly productive pituitary, but after the epiphyses are fused; the most dramatic osteological manifestation of acromegaly is growth at the mandibular condyle and a resulting elongation and distortion of the lower jaw.

Agenesis The lack of tooth formation at a given position.

Alveolar resorption The atrophy, through remodeling, of alveolar bone.

Alveolus A tooth socket.

Ameloblasts Cells that form enamel through a process known as amelogenesis.

Ankylosing spondylitis A condition in which the ligaments of the spine ossify, immobilizing the adjacent vertebrae.

Ankylosis An abnormal, complete immobility or fixation of a joint resulting from pathological changes in the joint.

Anlage The aggregation of cells indicating the first trace of an organ during embryogenesis.

Annulus fibrosus The tough, fibrous ring around the periphery of an intervertebral disk.

Antemortem Before the time of death.

Antemortem changes Alteration to the bone that occur before the death of an individual.

Antimere One-half of a pair of bilaterally symmetrical structures.

Apophysis An outgrowth or small bony projection.

Appendicular skeleton Bones of the limbs, including the shoulder and pelvic girdles (but not the sacrum).

Arthritis Inflammation of a joint.

Arthropathy Any disease affecting the joints.

Articulation A place where two adjacent bones contact.

Atrophy Wasting away and reduction in size, particularly after the tissue or organ has matured.

Attrition Wear, usually used in reference to the teeth.

Auditory exostosis A bony growth within the external auditory meatus.

Avulsion The forcible tearing away of part of a structure.

Axial skeleton Bones of the trunk, including the vertebrae, ribs, and sternum.

Ball-and-socket joint A spheroidal joint, such as the hip joint with the hemispherical femoral head fitting into the acetabulum, that allows for movement in many directions.

Basicranium Bones of the cranial base.

Buccal Pertaining to the cheek.

Calculus Tartar, a deposit of calcified dental plaque on teeth.

Callus Hard tissue formed in the osteogenic layer of the periosteum as a fracture repair tissue; normally replaced.

Calotte A calvaria without the base.

Calvaria The cranium not including the face.

Cancellous bone Spongy, porous lightweight bone found under protuberances where tendons attach, in the vertebral bodies, in the ends of long bones, in short bones, and sandwiched within flat bones; also called trabecular bone.

Caries A disease characterized by the progressive decalcification of enamel or dentine; the hole or cavity left by such decay.

Cartilage A form of connective tissue consisting of cells embedded in a matrix.

Cartilaginous joint A joint, such as that between the first rib and the sternum, in which the articulating bones are united by means of cartilage and very little movement is allowed. Synonymous with synchondrosis.

Cementum A bone-like tissue that covers the external surface of tooth roots, surrounding the dentin of the root and neck of a tooth.

Cervicoenamel line or **junction (CEJ)** The line encircling the crown of the tooth, delimiting the most rootward extent of the enamel.

Collagen A fibrous structural protein constituting about 90% of bone's organic content.

Commingled Bone assemblages containing remains of multiple individuals, often incomplete and fragmentary.

Comminuted fracture A fracture in which the bone splinters.

Compact bone The solid, dense bone that is found in the walls of bone shafts and on external bone surfaces, also called cortical bone.

Complete fracture A fracture in which broken ends of a bone become separated.

Compound fracture A fracture in which the broken bone perforates the skin.

Computed (axial) tomography (CT or CAT) A radiological technique using computer processing to generate cross-sectional scans of an object.

Congenital Acquired during development in the uterus, not through heredity.

Coronal suture The suture that lies between the frontal and parietals.

Cranial sutures Fibrous joints of the skull.

Craniosynostosis Same as craniostosis; premature fusion of cranial sutures resulting in abnormal skull shape.

Cranium The bones of the skull except for the mandible.

Cremation A mortuary practice involving the intentional burning of the body.

Cribra cranii Lesions on the endocranial surface, usually of the frontal.

Cribra orbitalia Lesions on the roof of the orbit, usually in the form of bilateral pitting of the orbital part of the frontal.

Deciduous teeth The first teeth to form, erupt, and function in the first years of life.

Dehiscence A developmental abnormality that results in a perforation of the tympanic plate of the temporal bone; sometimes called foramen of huschke.

Demography The study of population statistics.

Dental hypoplasia A condition characterized by transverse lines, pits, and grooves on the surface of tooth crowns; such disturbances are defects in dental development.

Dental plaque The matrix and its resident community of bacteria that forms on a tooth.

Dentin A special type of calcified, but slightly resilient, connective tissue; primary dentin develops during growth, whereas secondary dentin forms after root formation is complete.

Dentinoenamel junction The boundary between the enamel cap and the underlying dentin.

Deoxyribonucleic acid (DNA) The molecule of heredity that contains the genetic code.

Diachronic Changes or events considered through time.

Diagenesis Chemical, physical, and biological changes undergone by a bone through time.

Diaphysis The shaft of a long bone.

Discontinuous morphological traits Also called epigenetic variants, discrete traits, or nonmetric variation; variation observed in bones and teeth, and in the form of differently shaped and sized cusps, roots, tubercles, processes, crests, foramina, articular facets and similar features.

Discrete variables Variables composed of a finite number of values, such as nonmetric traits that are usually scored as present or absent.

Dysplasia An abnormal development of bone tissue.

Eburnation Worn, polished, ivory-like appearance of bone resulting from exposure and wear of adjacent subchondral bone at a joint.

Edentulous Lacking teeth.

Enamel A layer of extremely hard, brittle material that covers the crown of a tooth.

Endochondral ossification A process of bone development in which cartilage precursors (called cartilage models) are gradually replaced by bone tissue.

Endosteum An ill-defined and largely cellular membrane that lines the inner surface of bones.

Epiphysis The cap at the end of a long bone that develops from a secondary ossification center.

Evulse To forcibly extract

Exostosis A bony growth from a bone surface, often involving the ossification of muscular or ligamentous attachments.

External auditory meatus The ear hole.

Focal Localized.

Fontanelles Soft spots of cartilaginous membrane in the skull of a newborn that eventually harden and turn into bone.

Foramen magnum The large oval hole in the base of the skull through which the spinal cord passes.

Forensic osteology Osteological work aimed at the identification of relatively recently deceased individuals, usually done in a legal context.

Frankfurt Horizontal A plane defined by three osteometric points: the right and left porion points and the left orbitale. It is used to systematically orient the skull.

Gigantism A condition arising from an excessive production of somatotrophic hormone, causing an overstimulation of growth cartilages and resulting in gigantic proportions of the skeleton.

Gomphosis The joint between the roots of the teeth and the bone of the jaws.

Hallux The first or big toe.

Harris lines Lines of increased bone density that represent the position of the growth plate at the time of insult to the organism and formed on long bones due to growth arrest.

Haversian canals Also known as secondary osteons; freely anastomosing canals in compact bone that contain blood and lymph vessels, nerves, and marrow.

Hematopoietic Related to the production and development of red blood cells.

Hinge joint A joint, such as the knee or elbow, allowing movement that is largely restricted to a single plane.

Hyaline cartilage Smooth cartilage that covers the articular surfaces of bones.

Hydroxyapatite A dense, inorganic, mineral matrix; the second component of bone.

Hypercementosis A condition in which an excess of cementum forms on the root of a tooth.

Hyperostosis An abnormal growth of bone tissue.

Hyperplasia An excessive growth of bone or other tissue.

Hypertrophy Increase in the volume of a tissue or organ.

Hypoplasia An insufficient growth of bone or tissue; for teeth, dental enamel hypoplasia is a disturbance of enamel formation which often manifests itself in transverse lines, pits, or other irregularities on the enamel surface.

Idiosyncratic Pertaining to the individual.

Inca bone An extrasutural bone occasionally found in the rear of human crania.

Incomplete fracture or **"greenstick" fracture** A fracture in which breakage and bending of a bone is combined.

Inhumation Burial or interment.

Interment Burial.

Interobserver error Error stemming from variation in the accuracy of data recorded by different observers analyzing the same things.

Interproximal Between adjacent surfaces, especially of teeth.

Intramembranous ossification A process of bone development in which bones ossify by apposition on tissue within an embryonic connective tissue membrane.

Intraobserver error Error related to the precision of data recorded by the same observer analyzing the same things at different times.

Joint Any connection between different skeletal elements.

Kyphosis The collapse of one or several vertebral bodies causing a sharp angle in the spine.

Labial Pertaining to the lips.

Lambdoidal suture The suture that passes between the two parietals and the occipital bone.

Lamellar bone Bone whose microscopic structure is characterized by collagen fibers arranged in layers or sheets around Haversian canals.

Lesion An injury or wound; an area of pathologically altered tissue.

Lingual Pertaining to the tongue.

Lipping Bone projecting beyond the margin of the affected articular surface, usually in osteoarthritis.

Malocclusion The condition in which upper and lower teeth do not occlude, or meet, properly.

Masseter muscle Muscle originating on the inferior surface of the zygomatic arch and inserting on the lateral surface of the mandibular ramus and gonial angle.

Medial pterygoid muscle Muscle originating on the medial surface of the lateral pterygoid plate of the sphenoid and inserting on the medial surface of the mandibular gonial angle.

Medullary cavity The canal inside the shaft of a long bone.

Metaphyses The expanded, flared ends of the shaft of a long bone.

Metopic suture The suture that passes between unfused frontal halves and only rarely persists into adulthood.

Minimum number of individuals (MNI) The hypothetical minimum number of individuals that could account for all of the elements in the assemblage.

Mitochondrial DNA (mtDNA) A small, non-nuclear genome that is inherited only maternally, often used in ancient DNA analysis because it is easier to retrieve than nuclear DNA.

Morphogen A molecule that influences morphogenesis.

Morphogenesis The development of form during ontogenesis.

Morphology The form and structure of an object.

Multiple interment A burial in which more than one individual is present.

Necrosis Physiological death of a cell or a group of cells.

Nonmetric trait Dichotomous, discontinuous, discrete, or epigenetic traits; nonpathological variations of tissues difficult to quantify by measurement.

Occlusal surface The chewing surface of the tooth.

Odontoblasts Cells that form dentin through a process known as odontogenesis.

Ontogeny The development or course of development of an individual; growth.

Ossuary A communal grave made up of secondarily interred remains of individuals initially stored somewhere else.

Osteitis A general term used to refer to any inflammation of bone tissue caused by infection or injury.

Osteoarthritis Also called degenerative joint disease; the most common form of arthritis, characterized by a destruction of the articular cartilage in a joint, and accompanied by bony lipping and spur formation adjacent to the joint.

Osteoblasts The bone-forming cells responsible for synthesizing and depositing bone material.

Osteochondroma The most common tumor of bone; benign tumors, usually asymptomatic, that always arise at epiphyseal lines and protrude at right angles to the long axis of a bone.

Osteoclasts Cells responsible for the resorption of bone tissue.

Osteocyte Living bone cell developed from an osteoblast.

Osteogenesis Bone formation and development.

Osteoma Often called "button" osteomata; a mound of compact bone, usually on the ectocranial surface.

Osteomalacia A disease that causes a softening of the bones, usually linked to general malnutrition—particularly deficiencies in protein, fat, calcium, and phosphorous.

Osteometric Relating to the measurement of bones.

Osteomyelitis An inflammation of a bone caused by bacteria that usually enter the bone initially via a wound.

Osteon A Haversian system, the structural unit of compact bone composed of a central vascular (Haversian) canal and the concentric lamellae surrounding it; a primary osteon is composed of a vascular canal without a cement line, whereas the cement line and lamellar bone organized around the central canal characterize a secondary osteon.

Osteophyte A small, abnormal bony outgrowth often found at the margins of articular surfaces as a feature of osteoarthritis.

Osteoporosis Increased porosity of bone due to a reduction in bone mineral density.

Osteosarcoma A malignant tumor of the bone cells.

Paleodemography The study of the demography of prehistoric populations.

Paleopathology The study of diseases in ancient populations as revealed by skeletal remains and preserved soft tissues.

Parasagittal section Any planar slice that parallels the sagittal plane.

Pathological fracture A fracture that occurs as a result of bones already having been weakened by other pathological or metabolic conditions, such as osteoporosis.

Perikymata Transverse ridges and grooves on the surface of tooth enamel.

Perimortem At, around, or just before the time of death.

Periodontitis The inflammation of tissues around a tooth; can involve both soft tissues and the bone itself.

Periosteum Thin tissue covering the outer surface of bones except in areas of articulation.

Periostitis A condition of inflammation of the periosteum caused by trauma or infection; can be acute or chronic.

Periostosis Abnormal bone formation on the periosteal surface of a bone.

Piriform aperture or anterior nasal aperture The opening below and between the orbits; the nose hole.

Planar joint A joint that allows two bones to slide across one another.

Pollex The thumb or first digit of the hand.

Polymerase chain reaction (PCR) An important technique that acts as a "molecular photocopy machine" to produce many copies of a section of DNA beginning with just a few molecules of DNA; this allows DNA to be retrieved from some skeletal remains.

Porosity A condition in which many small openings pass through a surface.

Porotic hyperostosis or **spongy hyperostosis** A condition exhibiting lesions, usually of the cranial vault, representing a thinning and often complete destruction of the outer table of the cranial vault.

Postcranial skeleton All bones except the cranium and mandible.

Postmortem modifications Alterations to the bone that occur after the death of an individual.

Primary bony callus Woven bone formed when a callus is subsequently mineralized.

Primary interment A burial in which all the bones are in an anatomically "natural" arrangement; an articulated skeleton buried in the flesh.

Primary ossification center The first site where bone begins to form during growth; usually in the shaft of a long bone, or the body of other bones.

Provenience The stratigraphic and spatial position of the specimen; provenance.

Pseudarthrosis A new or false joint arising between parts of a fractured bone that do not heal.

Radiograph An image produced on photographic film when exposed to X-rays passing through an object.

Reactive bone Bone in the process of being formed or lost, often in response to a pathological stimulus.

Remodeling A cyclical process of bone resorption and deposition at one site.

Resorption The process of bone destruction by osteoclasts.

Rheumatoid arthritis Inflammation and degeneration of the joints, particularly those of the hands and feet; usually chronic and accompanied by deformities.

Rickets A form of osteomalacia resulting from vitamin D deficiency.

Saddle-shaped or sellar joint A joint that is saddle-shaped, such as the joint at the base of the thumb.

Sagittal plane A plane that divides the body into symmetrical right and left halves.

Sagittal suture The midline suture that passes between the parietal bones.

Sarcoma A malignant tumor of connective tissue.

Scanning electron microscope (SEM) A device that produces an image of the surface of a metal-coated specimen by the reflection of electrons.

Secondary center of ossification Center of bone formation that appears after the primary center, such as the epiphysis of a long bone.

Secondary interment A burial in which the bones of a skeleton are disarticulated.

Serial homology Correspondence of parts in sequential bones, as in the vertebrae.

Sesamoid bones Small bones that lie within tendons near a joint.

Sexual dimorphism Differences between males and females.

Shovel-shaped incisors Incisors with strongly developed mesial and distal lingual marginal ridges, imparting a "shovel" appearance to the tooth.

Sinuses Void chambers in the cranial bones that enlarge with the growth of the face; four basic sets, one each in the maxillae, frontal, ethmoid, and sphenoid.

Skull The bones of the head, including both cranium and mandible.

Sphenooccipital or basilar suture Actually a synchondrosis; lies between the sphenoid and the occipital.

Splanchnocranium The facial skeleton.

Squamosal suture An unusual, scale-like, beveled suture between the temporal and parietal bones.

Standard anatomical position Standing with feet together and pointing forward, looking forward, with none of the long bones crossed from viewer's perspective and palms facing forward.

Subchondral bone The compact bone covered by cartilage at the joints.

Supernumerary teeth Teeth that exceed the expected number of teeth in any given category.

Sutures Articulations of the skull bones along joints with interlocking, sawtooth, or zipper-like articulations.

Symphysis A type of cartilaginous joint in which fibrocartilage between the bone surfaces is covered by a thin layer of hyaline cartilage.

Syndesmosis Tight, inflexible fibrous joint between bones united by bands of dense fibrous tissue in the form of membranes or ligaments.

Synostosis The result when any two bony elements fuse together.

Synovial joints Freely moving joints such as the hip, elbow, knee, and thumb that are coated with a thin layer of hyaline cartilage, and lubricated by synovial fluid within a fibrous joint capsule.

Talon(id) The distal (posterior) portion of a primate molar added to the modified original triangle of cusps; use suffix *-id* for lower molars.

Taphonomy The study of processes that affect skeletal remains between death and curation.

Taurodontism The condition in which the pulp chamber is enlarged relative to the normal condition.

Temporalis muscle The muscle originating on the side of the cranial vault inferior to the superior temporal line and inserting on the sides, apex, and anterior surface of the coronoid process of the mandible.

TMJ Temporomandibular joint; the jaw joint between the mandible and cranium.

Trephination (trepanation) A practice in which an artificial hole is made in the cranial vault of a living person.

Trigon(id) The mesial (anterior) portion of a primate molar comprising the modified original triangle of cusps; use suffix *-id* for lower molars.

Typology The practice of choosing one individual to characterize a species.

Wormian bone Any of the small, irregular bones along the cranial sutures; extrasutural bone.

Appendix

Electronic Resources for Human Osteology

Use words and phrases such as human osteology, forensic archeology, forensic science, human skeleton, paleopathology, skeletal biology, human bone, paleoanthropology, radiology, etc. in your Internet search engine to explore the myriad electronic resources available to the student and professional.

The following is a set of handy electronic resources involving human osteology and some of the many disciplines associated with it.

GENERAL

http://www.geocities.com/CapeCanaveral/Lab/9893/

Links to Biological Anthropological topics

http://www.tamu.edu/anthropology/news.html

Keep updated on breaking stories in anthropology

SOFT TISSUE

http://ptcentral.com/muscles/

Basics about skeletal musculature

http://www.nlm.nih.gov/research/visible/visible_human.html

The visible human project

FORENSICS

http://www.tncrimlaw.com/forensic/

Links to forensic science resources

CASTING

http://socrates.berkeley.edu/~mtblack/castingmanual/titlepage.html

A casting manual

RADIOLOGY

http://ptcentral.com/radiology/

Introduction to radiology

http://www.lib.siu.edu/hp/divisions/sci/health/mradiogr.htm

Links to radiology and radiography websites

http://www.rad.washington.edu/teachingfiles.html

Radiology site

PALEOPATHOLOGY

http://www.mic.ki.se/Diseases/index.html

Index of diseases

http://www.merck.com/mmhe/index.html

Merck Manual online

PROFESSIONAL ASSOCIATIONS

http://www.aafs.org/

American Academy of Forensic Sciences

http://www.physanth.org/

American Association of Physical Anthropologists

http://www.aaanet.org/

American Anthropological Association

http://monkey.sbs.ohio-state.edu/DAA/index.htm

Dental Anthropology Association

http://www.archaeological.org/webinfo.php?page=10016

The Archaeological Institute of America: Search worldwide for fieldwork opportunities

NATIVE AMERICAN GRAVES PROTECTION AND REPATRIATION

http://www.cr.nps.gov/nagpra/

National Park Service website for national NAGPRA

http://www.cast.uark.edu/other/nps/nagpra/

National NAGPRA online database

COMPARATIVE ANATOMY

http://web.austin.utexas.edu/eskeletons/

Comparative skeletal anatomy

INSTRUMENTS

http://www.paleo-tech.com

Instruments for physical anthropologists

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