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Bones Of The Knee Joint And Individual Features That can Be Used For Forensic Identification

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To the Graduate Council:

I am submitting herewith a dissertation written by Emily Anne Craig entitled "Bones Of The Knee Joint And Individual Features That can Be Used For Forensic Identification." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

William M. Bass, Major Professor

We have read this dissertation and recommend its acceptance:

K.A. Rule, Lyle Konigsberg, R.L. Jantz

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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William M. Bass, Ph.D., Major Professor

We have read this dissertation and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and Dean of The Graduate School

BONES OF THE KNEE JOINT

AND

INDIVIDUAL FEATURES THAT CAN BE USED FOR

FORENSIC IDENTIFICATION

A Dissertation
Presented for the
Doctor of Philosophy Degree

The University of Tennessee, Knoxville

Emily Anne Craig

August, 1994

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DEDICATION

This dissertaion is dedicated to my parents
Emily Josephine and Dr. Reuben Allen Craig.
These two gave me life
and the courage to think for myself.

and to
Dr. Jack C. Hughston
who taught me more than I ever wanted to know
about the human knee.

ACKNOWLEDGMENTS

I would like to thank my major professor, Dr. William Bass, for his guidance, patience, and dedication. He turned every task into a learning experience and a valuable lesson in the science of human identification. I would also like to thank the other committee members, Dr. Richard Jantz, Dr. Lyle Konigsberg, and Dr. Kenneth Rule for their help and assistance over the past three years. I would also like to thank the staff of medical professionals at the Hughston Orthopaedic Clinic, The University of Tennessee Medical Center, and the Student Health Center who assisted with hundreds of radiographs.

ABSTRACT

This dissertation describes the normal osteology of the bones of the knee joint in correlation to the surrounding soft tissues. Traumatic and surgical modifications of the normal osteological features are also discussed in reference to their significance for anthropological analysis as well as for forensic identification. As a primary focus, a new method of racial determination from the distal femur is described in detail.

This new method involves the measurement of the intercondylar shelf in relation to the posterior shaft of the femur. The intercondylar shelf is a feature of the distal femur that shows significant difference between American Whites and Blacks. The intercondylar shelf is the "roof" of the intercondylar notch, and in lateral radiographs the posterior cortex of the femur and the intercondylar shelf can be seen as distinct lines of dense bone. The angle between the posterior shaft of the femur and intercondylar shelf can be easily defined and measured. For this study, lateral knee radiographs of 240 White and 183 Black subjects were measured. The White mean was 147 degrees (std. dev. 4.28) and the Black mean was 138 degrees (std. dev. 4.18). This difference is statistically significant ($p<.0001$) and yields a correct classification of 87%. The same measuring technique was performed as a blind test on radiographs of known skeletal material with similar results.

Variations in the intercondylar shelf angle are presumed to be independent of the size or shape of the femur. In addition, the measurement of this angle is not restricted or altered by arthritis in the notch or by trauma to the articular surfaces. Fragmentary femora can be measured. This is a non-invasive technique that can be used in forensic cases as well as archaeological cases where there are intact soft tissues.

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PREFACE

The bones of the knee hold endless fascination for those who understand the anatomy and its functional significance. During the evolution of man the knee had to undergo changes to allow the movements associated with bipedal locomotion, and to this end the knee became the largest and most complex joint in the human body. It developed into a system of musculoskeletal elements that provide incredible stability while at the same time allowing a wide range of motion. There are myriads of subtle differences in the knee joint in all individuals, and many of these can provide evidence to help determine the sex and age of that individual. There have also been many studies that can provide evidence about pathological conditions in extant populations. This dissertation will add to this body of knowledge by presenting several new and specific features of the knee joint that can be used for forensic identification in modern populations. The importance of the knee for forensic identification has often been overlooked because other skeletal elements, especially those of the cranium, have more unique features from which to ascertain identity. However, in cases where other skeletal elements are missing, or in cases where there is conflicting or ambiguous evidence regarding the identity of an individual, analysis of the bones of the knee can often provide key elements to complete the puzzle of victim identification.

CHAPTER 1

BONES OF THE KNEE

INTRODUCTION

The bones that come together and form the knee joint create a synergistic biomechanical complex that has intrigued scientists for centuries.

Until recently, anatomists were content to describe the general morphology of the bones in relation to their topography and their major ligamentous and muscular attachments. Orthopaedic surgeons now recognize the added importance of capsular structures and retinacular expansions of the musculotendinous insertions. Documentation of the location and functional significance of all of these bony attachments increases the amount of osteological information about the knee.

Knowledge of the basic embryology and the details of osteology is a critical first step to understanding the knee and the many clues it can hold for anthropology and the science of human identification (Bass, 1987).

EMBRYOLOGY, GROWTH AND DEVELOPMENT

In the developing embryo, the 4 limb buds begin as small elevations from a lateral ridge that extends along both sides of the trunk. The upper extremities develop from the fore-limb buds and the lower extremities develop from hind-limb buds. The hind-limb buds are level with the lumbar and upper sacral segments at this stage, and are not much more than a slight accentuation of the lateral ridge.

The limb buds have an ectodermal ridge (or cap) which appears to be necessary for the continued development of successive accretions of mesenchyme in the growing bud, and this ectodermal ridge seems to induce the mesodermal development of the successive segments of the limb in a proximo-distal sequence. The ectoderm must also proliferate to accommodate the growing limb, and this appears to come from the body wall ectoderm (Bardeen, 1904; Gray, 1973).

The nerve supply to the hind-limb bud is established when the mesenchyme is invaded by the ventral rami of the adjoining spinal nerves, and the vasculature develops from a number of vessels that contribute to a primitive capillary plexus. Large portions of these primitive arteries ultimately disappear as the embryo develops, and some are incorporated into the permanent pattern of arteries and veins.

In the human embryo the mesoderm germ layer gives rise to mesenchymal cells, and these are the cells which produce the cartilage and fibrous membranes that form the embryonic skeleton. These fibrous membranes and cartilages are eventually replaced by bone in a predictable sequence of events. The musculature develops in situ from the mesenchyme surrounding these skeletal elements.

In the early stages of development, the fore-limb and hind-limb buds are quite similar except that the fore-limb precedes the hind-limb in development by a few days. Near the end of the sixth week the long axis of each limb bud is approximately orthogonal to the trunk and the prominences of the elbows and knees are directed laterally. During the seventh and eighth weeks differential growth rates bring the limbs into a position of adduction toward the ventral aspect of the trunk, and flexion is increased at the knees and elbows. By the eighth week, the elbow points caudally, and the knee points cranially in the so-called fetal position. This rotation of the limb about its axis is most pronounced in the lower limb, and is evidenced by the "barber pole" arrangement of the dermatomes. This divergence in position occurs before any joints are fully defined (Bardeen, 1904; Gray, 1973; Gray and Gardner, 1952).

It is during this eighth week that ossification of the long bones usually begins, and primary ossification centers form at about 12 weeks. The appearance of these ossification centers are spread over a long period of time, ranging from the eighth week of intrauterine life to the tenth year of childhood.

The long bones of the lower limb that eventually come together to form the knee are ossified from several foci. The femur, tibia, and fibula each have a central area of ossification near the middle of the shaft. There is progressive ossification towards both ends, and in turn the ends are ossified by separate centers. These terminal ossification centers, or epiphyses, continue to develop until the late teens.

The synovial knee joint forms around these terminal ossification centers. Plates of interzonal mesenchyme persist around the adjacent skeletal elements as they become defined from continuous mesenchymal masses. In the knee, the interzonal mesenchyme is trilaminar, due to the appearance of a more tenuous intermediate zone between two dense strata next to the cartilaginous ends of the femur and tibia. This intermediate stratum merges with the general mesenchyme of the lower limb, which is vascularized. From this, a cuff condenses to form the fibrous capsule of the knee joint. Cavitation of the intermediate zone accompanies chondrification and ossification of the other elements of the joint, and establishes the cavity or discontinuity of the joint. The synovial mesenchyme forms the synovial membrane, and all other intra-synovial structures, such as tendons, ligaments, and menisci (Gray, 1973).

Each bone that makes up the knee has an individual pattern of ossification and growth.

FEMUR: The femur is ossified from five centers. There is one for the shaft, head, greater trochanter, lesser trochanter and the distal end. Only the distal end and the distal shaft are included in the growth and development of the knee.

The shaft begins to ossify in the seventh week of intrauterine life, and is largely ossified at birth. The distal end of the femur appears during the ninth month of intrauterine life, and eventually forms the medial and lateral condyles and epicondyles. The distal epiphysis joins the shaft of the femur during the 18th or 20th year.

It is interesting to note that the ossification of this distal epiphysis constantly starts exactly at the time of birth, and in medico-legal investigation, the presence of this ossification center is evidence that a newborn child found dead was viable (Gray, 1973).

TIBIA: The tibia usually ossifies from three centers, one for the shaft and one for each end. There is sometimes an additional center of ossification for the anterior, proximal tibia in the area of the anterior tibial tuberosity. The ossification of the shaft begins during the seventh week of intrauterine life, and develops from the center of the shaft. The ossification center for the proximal end is usually present at birth, and this usually fuses with the shaft during the 16th to 18th year.

FIBULA: The fibula also ossifies from three centers. There is one for the shaft, and one for each end. The shaft begins to ossify around the eighth week of intrauterine life. In females the upper end begins to ossify during the third year, and in males this ossification begins during the fourth year. Fusion occurs between the 17th and 19th year in both males and females.

PATELLA: In the third to the sixth years, the patella rapidly ossifies from several centers. Accessory marginal centers appear later and fuse with the central mass. (Gray, 1973).

OSTEOLOGY

THE FEMUR:

The femur is the longest bone of the human body. It consists of a rounded proximal head that articulates with the acetabulum at the hip, a nearly cylindrical shaft, and a distal metaphysis that forms two large rounded condyles that articulate with the tibia [FIGURE 1-1A].

The distal portion of the femur will be the focus of this section as it relates to the osteology of the knee joint. This distal portion is widely expanded to provide a large surface for the transmission of body weight to the top of the tibia. It is made up of two large condyles which are partially covered by articular cartilage. These two condyles are separated posteriorly by a large deep gap, the inter-condylar notch, but they are united anteriorly where they provide an articular surface for the patella. There are distinct articular areas of the condyles, divided into a patellar surface and a tibial surface. This tibial surface is divided into medial and lateral parts.

The patellar surface forms one of two major divisions of the anterior articular surface. This surface is concave from side to side, and grooved in its long axis. It is higher on the lateral side, and is separated from the tibial surfaces by two relatively indistinct grooves [FIGURE 1-1B].

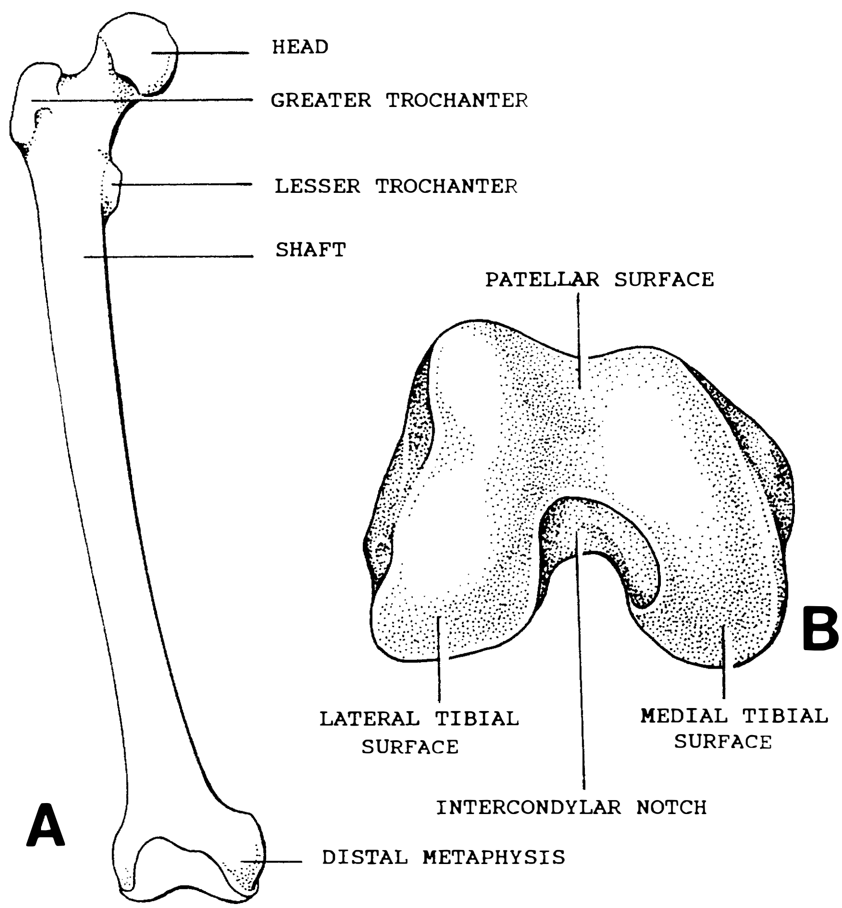

FIGURE 1-1. ANTERIOR FEMUR

(A) Anterior view of the entire femur.
(B) The distal articular surface shows the patellar surface and the anterior tibial surfaces.

Anteriorly these tibial surfaces are continuous with the patellar surface, but posteriorly they are separated by the intercondylar notch. They are convex from side to side and from front to back, and they both project posteriorly past the plane of the posterior shaft of the femur. All of these articular surfaces are covered with cartilage that protects the bony condyles of the distal femur.

These two condyles are separated posteriorly by the intercondylar notch, or intercondylar fossa. This fossa is widened posteriorly where it is not in apposition with the tibia. In the most posterior portion it connects to the intercondylar line, a distinct ridge of bone that provides attachments for the capsular ligaments and a portion of the semimembranosus retinaculum. The lateral femoral condyle is comparatively narrow posteriorly where it is not in weight bearing apposition with the tibia [FIGURE 1-2] (Hughston, 1993).

The medial femoral condyle is larger and more rounded than the lateral, and it projects downward and medially to such an extent that the lower surface of the lower end of the bone is practically horizontal (Gray, 1973) [FIGURE 1-3A].

The lateral femoral condyle is less prominent, but is longer from front to back [FIGURE 1-3B]. It is wide and steeply sloped from medial to lateral where it creates a large weight bearing surface against the interspinous eminence of the lateral tibial plateau [FIGURE 1-2].

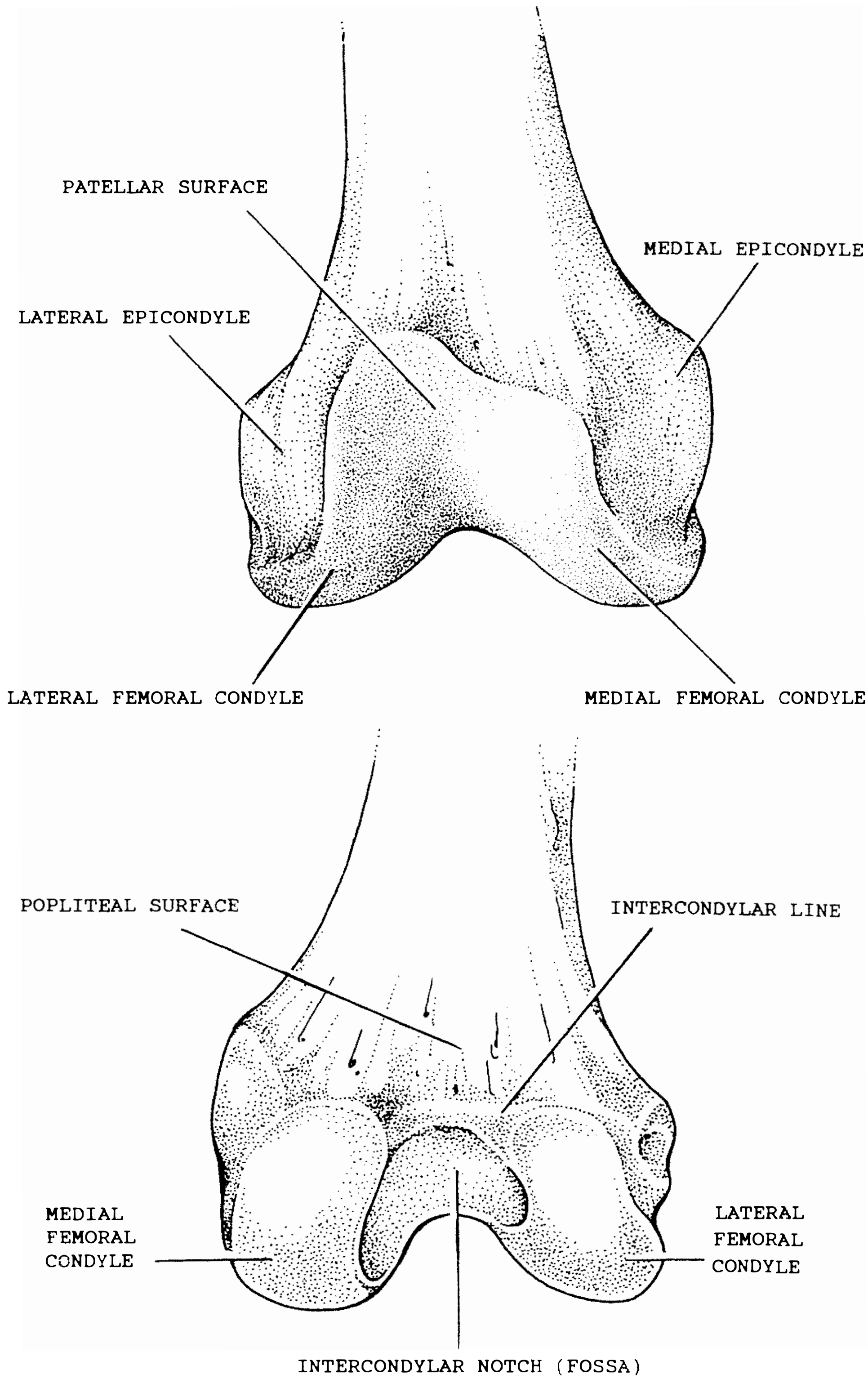

FIGURE 1-2. ANTERIOR AND POSTERIOR VIEWS OF THE DISTAL FEMUR

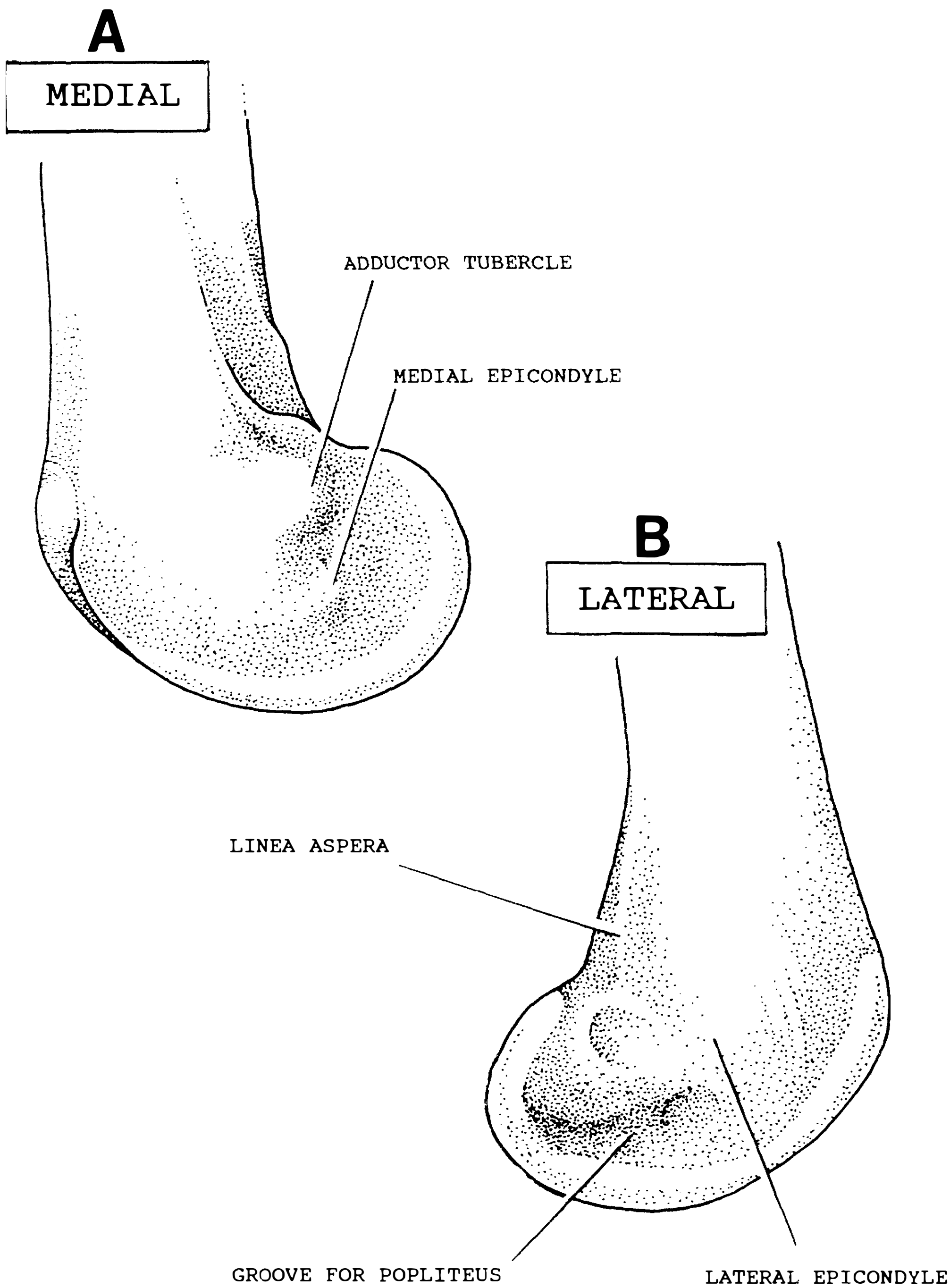

FIGURE 1-3. SIDE VIEWS OF THE MEDIAL AND LATERAL DISTAL FEMUR

A) Medial side. B) Lateral side

A large portion of the intercondylar notch is rough and pitted by vascular foramina, but where it provides attachment for ligaments, it is relatively smooth. The attachment areas for the cruciate ligaments and the ligaments of Humphrey and Wrisberg are best seen in sagittal section [FIGURE 1-4].

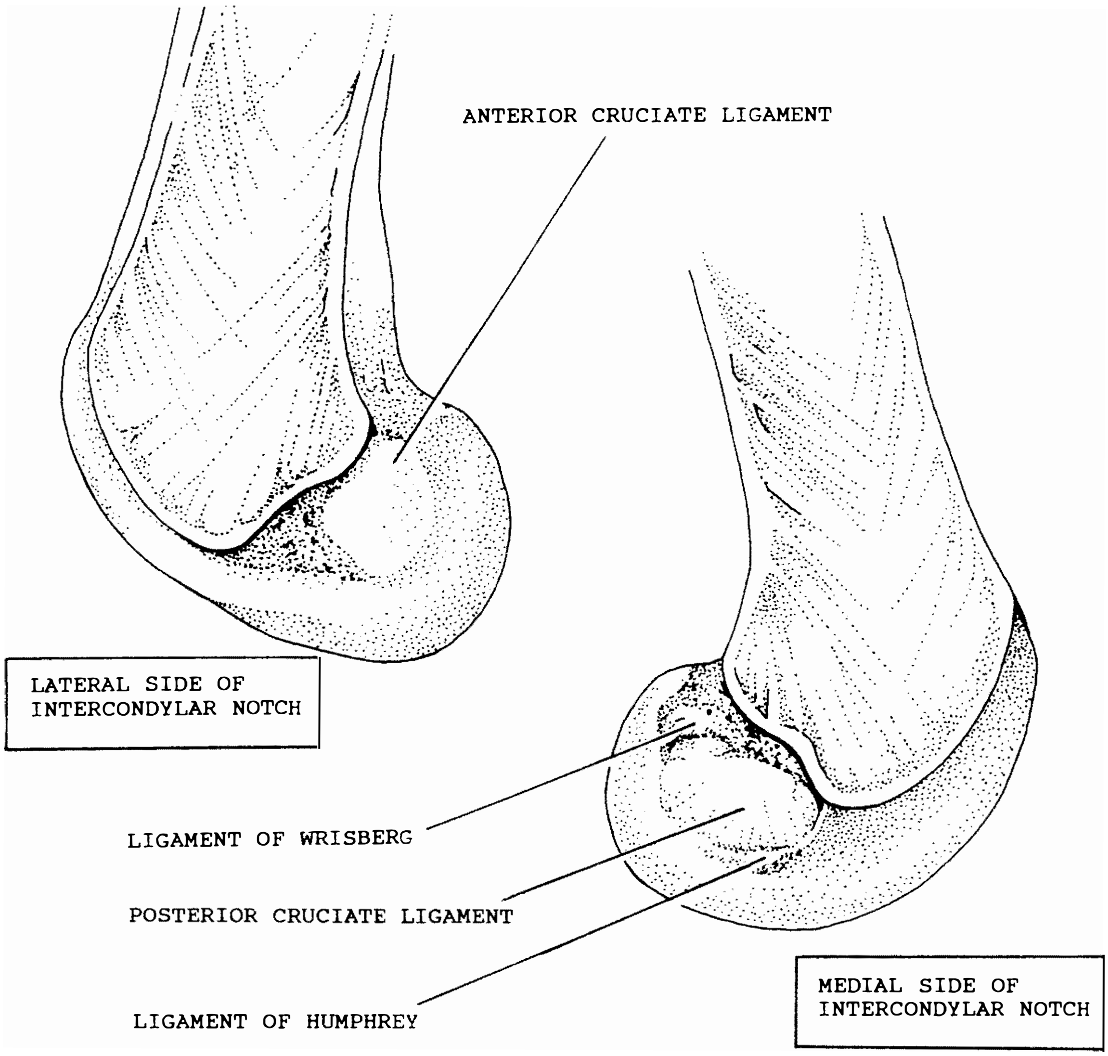

FIGURE 1-4. SAGITTAL SECTIONS OF FEMUR

Sagittal sections of the femur expose the attachment sites for the cruciate ligaments as well as the ligaments of Humphrey and Wrisberg (Hefzy et al., 1989).

Immediately superior to the femoral condyles are tubercles and epicondyles which give attachments to many muscles, tendons, and capsular ligaments. Some of these attachments sites are well defined on the bone, but others are much more subtle.

The medial epicondyle provides attachment for the tibial collateral ligament. This is a distinct raised area immediately anterior and inferior to the adductor tubercle. The adductor tubercle is the attachment site for the adductor tendon as well as the vastus medialis obliquus muscle. Just inferior to the medial epicondyle is the attachment site for the mid-third medial capsular ligament, and slightly posterior to this is where the posterior oblique ligament inserts on the femur.

The lateral epicondyle provides attachment for the fibular collateral ligament, the tendon of the popliteus muscle, fibers of the iliotibial tract, and the lateral capsular ligament. Just superior and posterior to the epicondyle is the most distal extent of the linea aspera. [FIGURE 1-5]. This raised area of bone provides attachment for the iliotibial tract, vastus lateralis, and short head of the biceps. Between the lateral epicondyle and the linea aspera is the attachment site for the lateral head of the gastrocnemius. The so-called "cheek" of the femur (Hughston, 1993) provides attachment for the synovium and separates both epicondylar areas of bone from the articular surfaces.

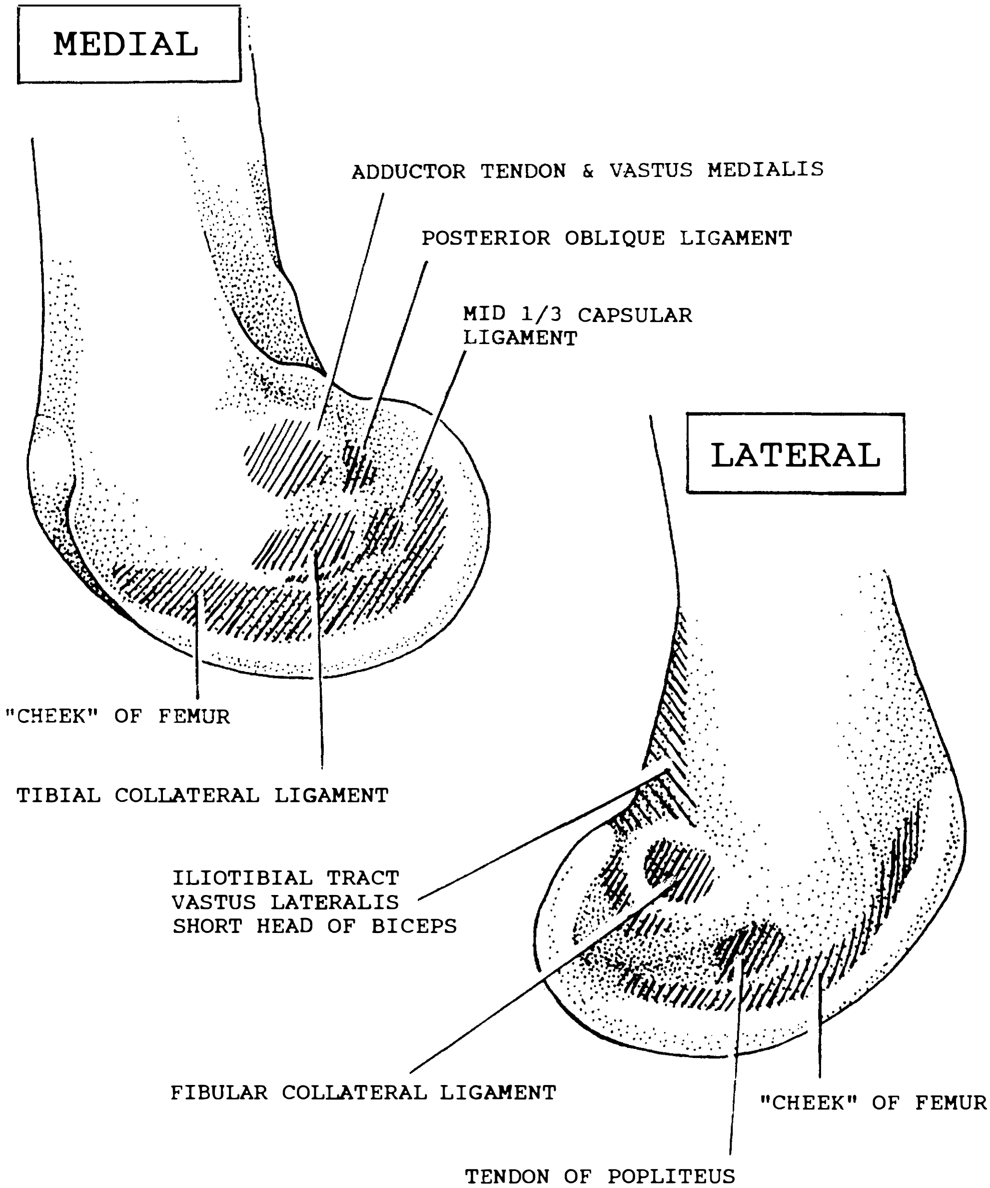

FIGURE 1-5. ATTACHMENT SITES FOR SOFT TISSUES

Just above the articular surfaces, the distal femur has numerous sites of attachment for periarticular soft tissues (Blackburn and Craig, 1981; Fulkerson and Gossling, 1980).

A large portion of the posterior distal femur is described as the popliteal surface. It is the floor of the upper part of the popliteal fossa, and is covered by fat which separates it from the popliteal artery (Gray, 1973). It is a relatively flat, slightly concave surface that is deeply pitted with vascular foramina. Lateral to this is a raised area of bone where the plantaris, lateral head of the gastrocnemius, and arcuate ligament attach. Medial to the popliteal surface, the bone expands to provide attachment for the medial head of the gastrocnemius, the adductor aponeurosis, and the semimembranosus retinaculum. [FIGURE 1-6].

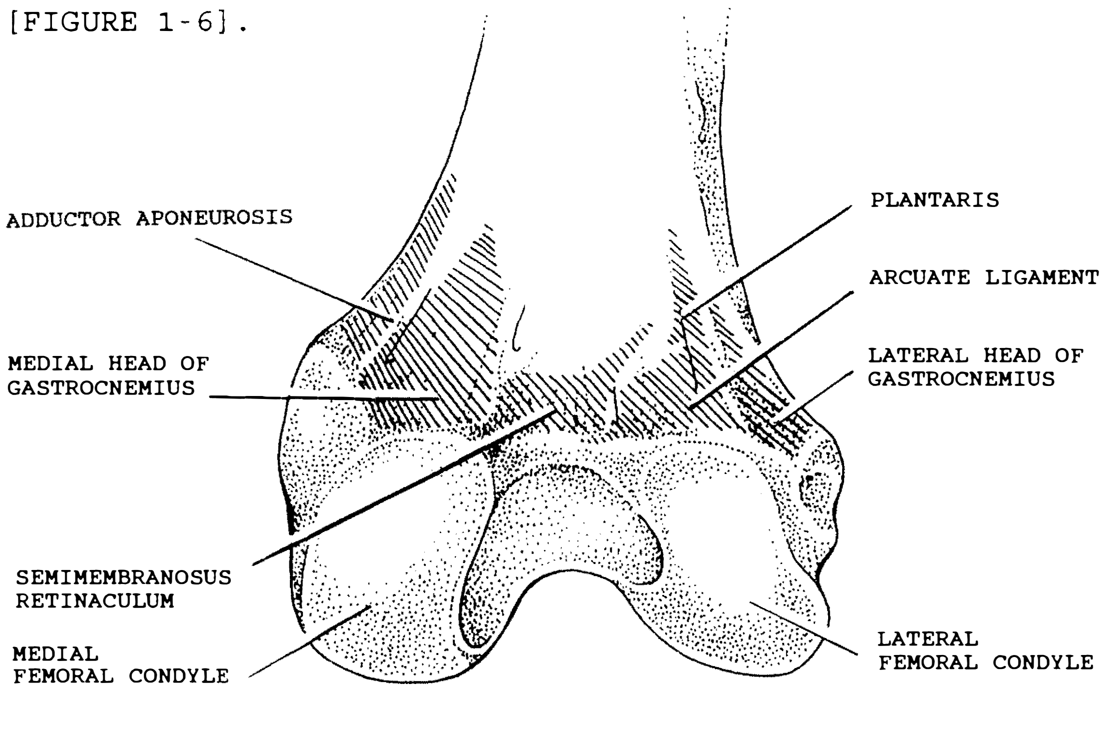

FIGURE 1-6. POSTERIOR FEMUR

The posterior portion of the distal femur consists of a central popliteal surface with attachments for periarticular structures on either side.

THE TIBIA:

The tibia is the larger of the two bones of the lower leg, and except for the femur, it is the longest bone of the skeleton. The proximal end is flattened and expanded to provide a large surface to bear the body weight transmitted through the lower end of the femur. The shaft is prismoid in section, especially in the proximal third. The distal end is smaller than the proximal end, and medially there is a stout process, the medial malleolus [FIGURE 1-7]. The proximal end forms a large portion of the knee joint, and its structure will be described in detail in this section.

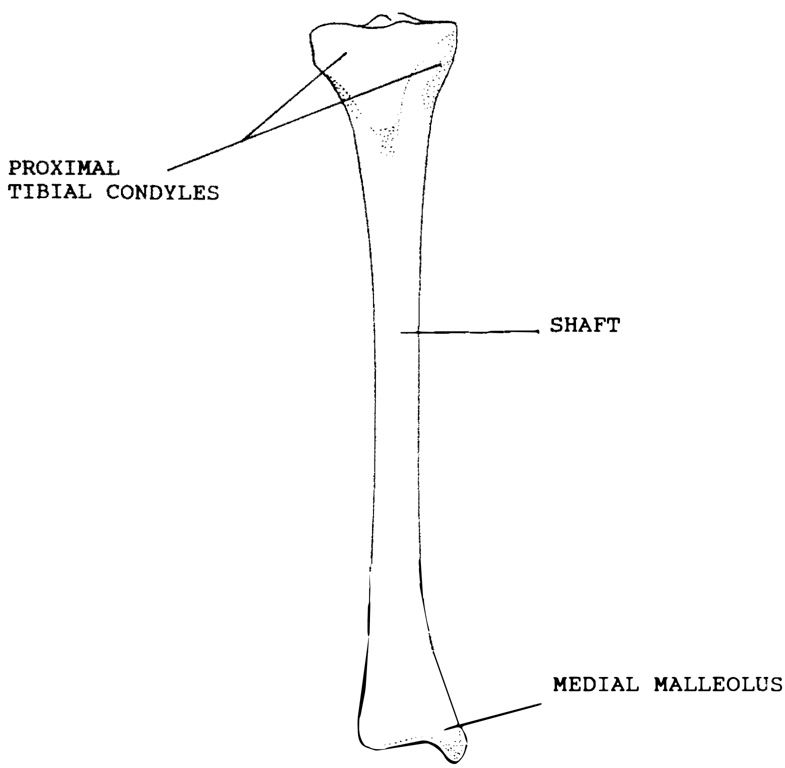

FIGURE 1-7. ANTERIOR VIEW OF THE TIBIA

The uppermost portion of the tibia is expanded, especially in the transverse axis, into two prominent condyles. The articular surface of the larger medial condyle is concave and essentially ovoid in shape. It is flattened where it comes in contact with the medial meniscus, and the imprint of the cartilage often remains on the bone. The condyle rises medially to form the medial part of the inter-condylar eminence, and a sharp projection of this eminence forms the medial intercondylar spine.

The articular surface of the lateral tibial condyle is more circular in outline, and it likewise bears a flattened imprint of the corresponding lateral meniscus. It slopes upward sharply on the medial side to an elevation termed the lateral intercondylar spine. The most posterior third of the lateral condyle has an acute posterior slope [FIGURE 1-8].

The central division between the medial and lateral articular surfaces is roughened anteriorly and is the area of attachment for the anterior cruciate ligament. As the anterior articular margins of the two condyles recede from each other, the middle of the tibial plateau broadens into a fairly flat, smooth area. The infrapatellar fat pad covers this portion and separates it from the patellar ligament. The medial and lateral meniscus insert between this smooth, flat area and the articular surfaces.

Immediately posteriorly to the intercondylar eminences there are attachment sites for the posterior horns of the medial and lateral menisci. Behind that, the posterior intercondylar area slopes sharply downward and provides an attachment site for lower end of the posterior cruciate ligament. It ends in a ridge to which the posterior capsular structures are attached [FIGURE 1-9].

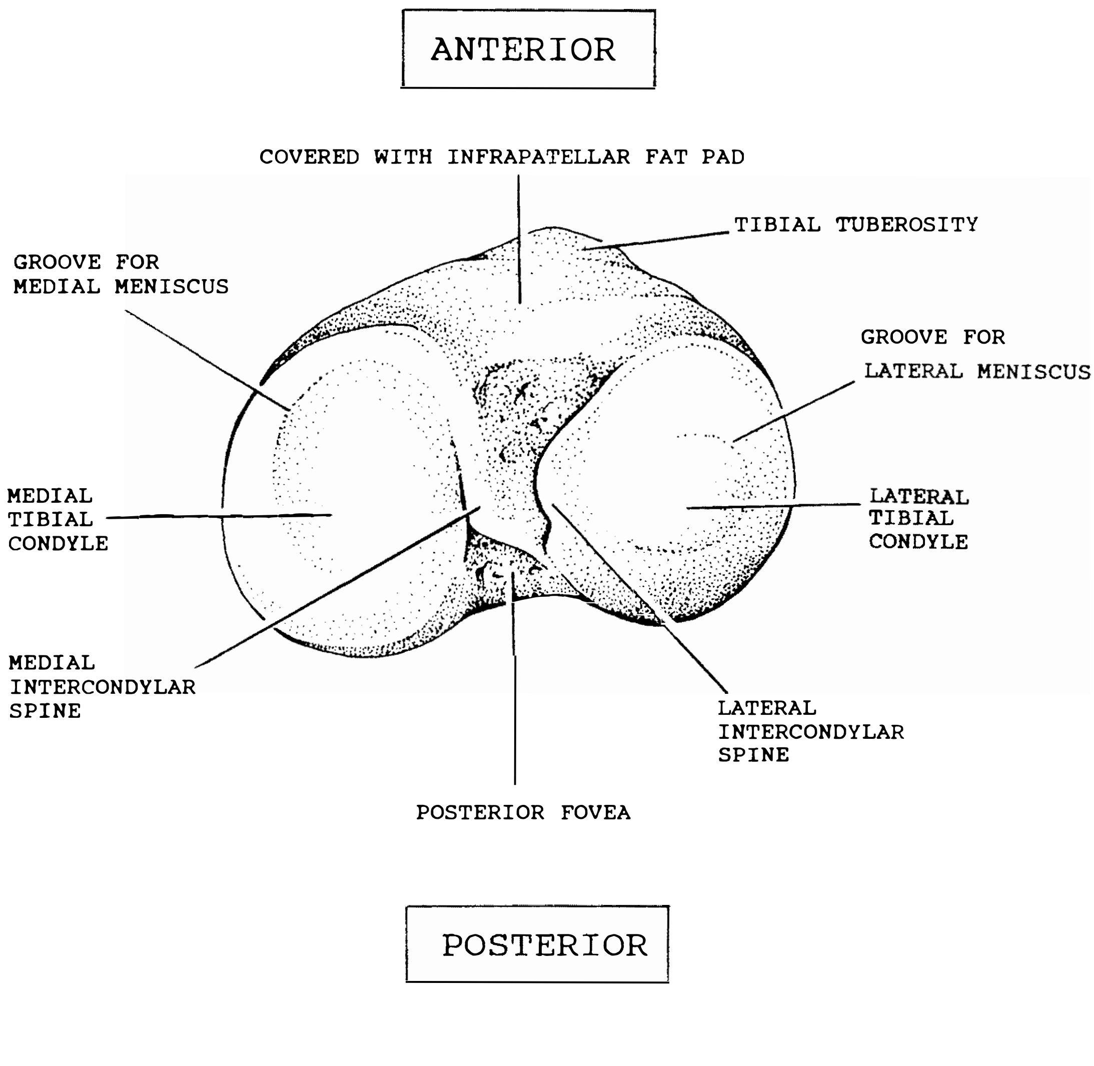

FIGURE 1-8. PROXIMAL SURFACE OF THE TIBIA AS SEEN FROM ABOVE

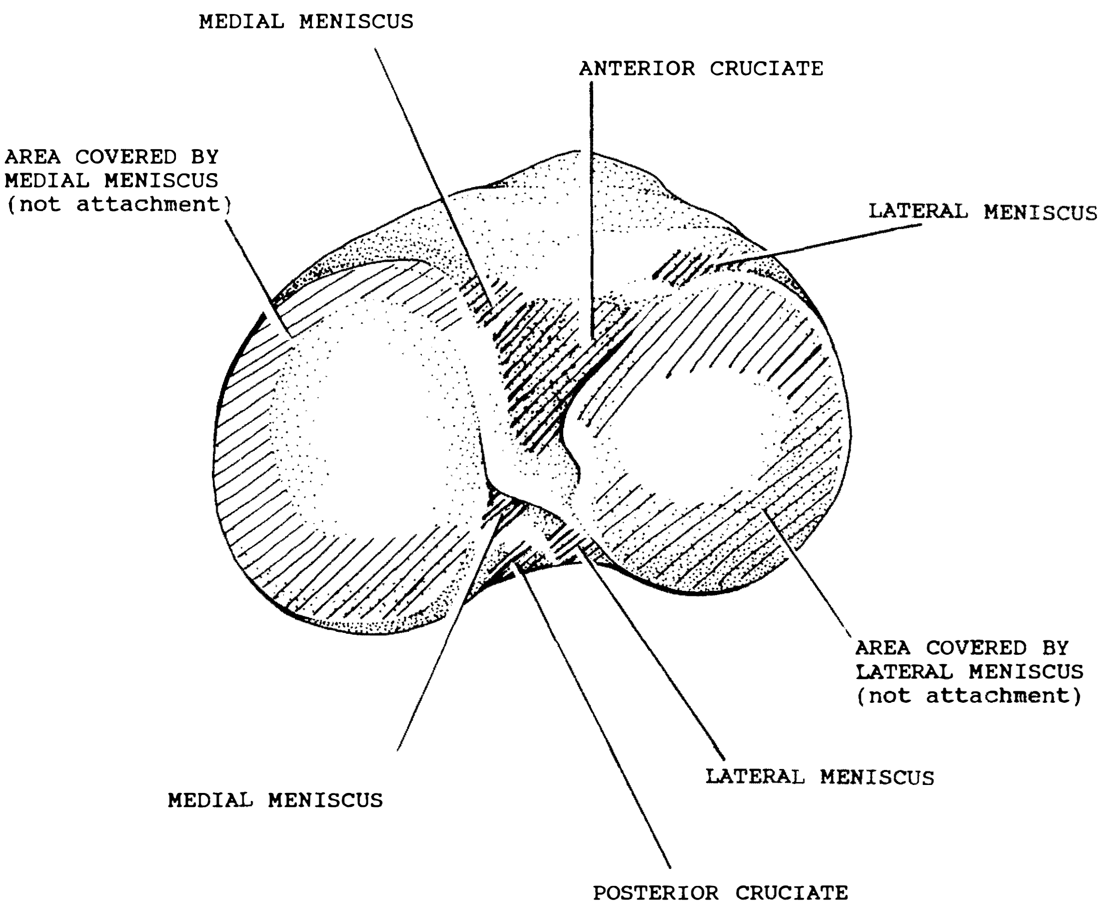

FIGURE 1-9. PROXIMAL END OF THE TIBIA SHOWING ATTACHMENT SITES FOR SOFT TISSUE STRUCTURES

On the anterior surface of the proximal tibial shaft is a large tuberosity that is divided into a lower roughened region and a smooth upper region. The lower region is where the patellar ligament inserts. It projects anteriorly in an area that is the truncated apex of the triangular area on the front of the bone where the anterior surfaces of the two condyles become continuous. The upper surface of this tuberosity is tilted backwards relative to the long axis of the shaft. This tilt is maximal in the newborn and decreases with age; it is also more marked in habitual squatters (Gray, 1973; Kate and Robert, 1965).

The medial condyle, prominent and rounded adjacent to the articular surface, drops off sharply and angles anteriorly to produce the medial surface of the tibial tuberosity.

Lateral to the tibial tuberosity, the tibia first forms a ridge that provides attachment for the lateral capsule and fibers from the iliotibial tract. The strongest, direct attachment for the iliotibial tract however, is on the tibial tubercle. Just lateral to this tibial tubercle the lateral condyle progresses posteriorly and creates a prominent ridge that provides an attachment site for the lateral capsular ligaments.

The lateral tibial condyle is somewhat flattened below and articulates with the head of the fibula posteriorly. This fibular facet is easily seen in a lateral view [FIGURE 1-10].

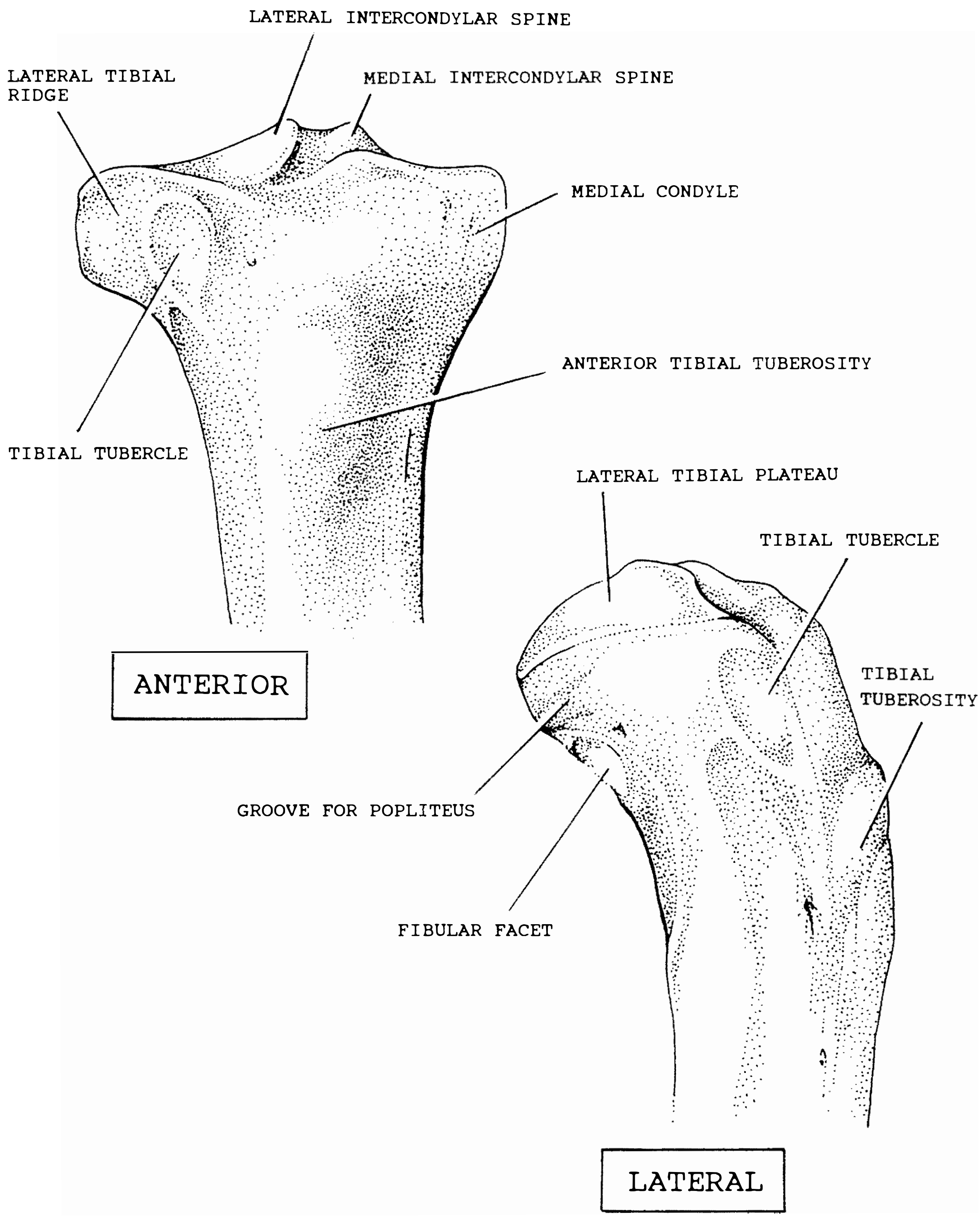

FIGURE 1-10. ANTERIOR AND LATERAL VIEWS OF THE PROXIMAL TIBIA

The fibular facet is directed downwards and laterally, to match the articular surface of the head of the fibula. Medial and posterior to this facet, the tendon of the popliteus produces a distinct groove. The posterior border of the tibial plateau ends in a sharp ridge medial to this popliteal groove, and inferior to the ridge is the area where the posterior popliteal ligament inserts [FIGURE 1-11].

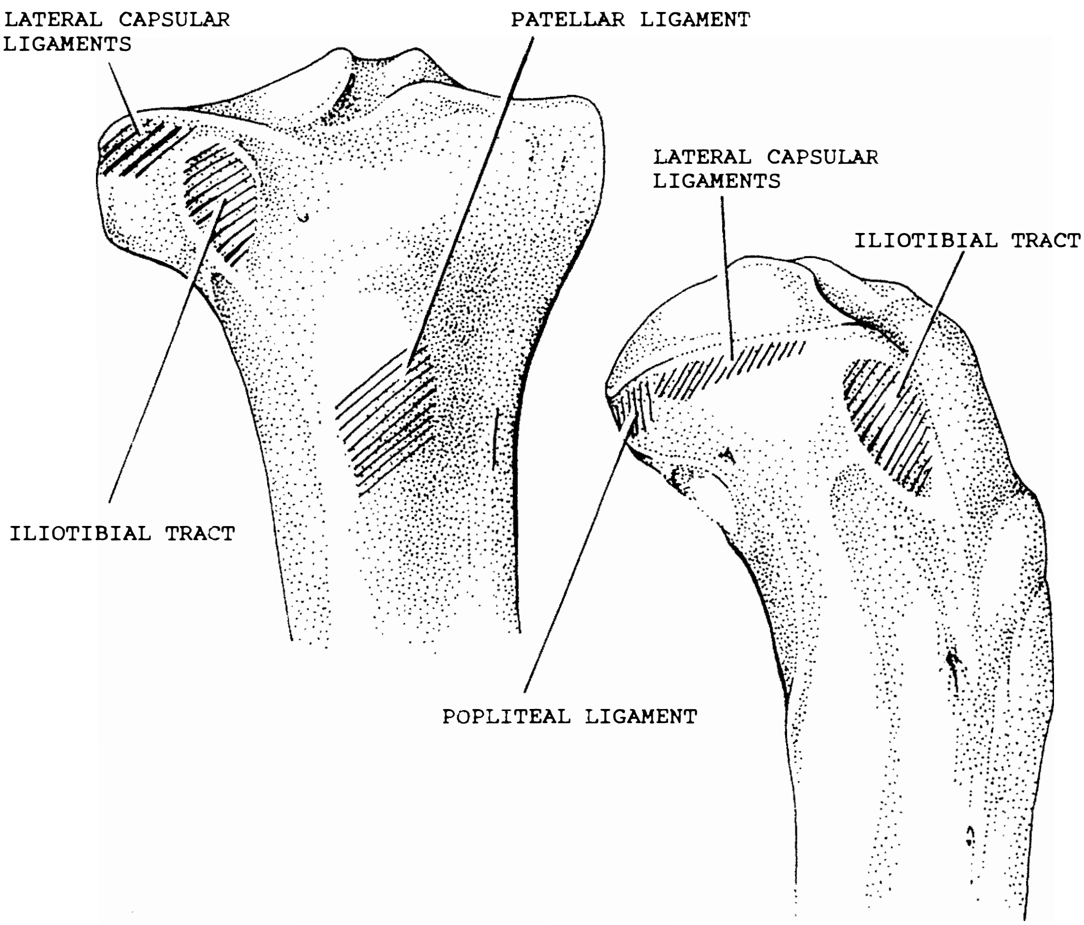

FIGURE 1-11. ANTERIOR AND LATERAL VIEWS OF THE PROXIMAL TIBIA SHOWING THE SOFT TISSUE ATTACHMENT SITES

The posterior portion of the proximal tibia is expanded posteriorly and it angles upward obliquely from medial to lateral. Distally it ends abruptly as the shaft of the tibia drops off to form a deep depression to accommodate the bulk of the popliteus muscle. A deep fovea in the central part of the posterior proximal tibia marks the lower site of attachment for the posterior cruciate ligament. A distinct osseous ridge extends from just below the posterolateral tibial plateau and runs obliquely toward the medial border of the tibial shaft. This is the bony origin of the soleus muscle. The medial tibial condyle projects posteriorly much farther than does the lateral, and the entire non-articular surface provides an extensive attachment site for the tendon and retinaculum of the semimembranosus. The superior, posteromedial edge of this condyle has a distinct groove for the direct arm of the semimembranosus, and just above this groove is the tibial attachment for the posterior oblique ligament and the mid-third medial capsular ligament. The most medial portion of the medial tibial condyle is raised to create a smooth projection that secures a bursa over which the tibial collateral ligament glides. This ligament produces a distinct ridge that extends down the medial shaft of the tibia [FIGURE 1-12 and FIGURE 1-13].

The posterior edge of the fibular facet is located on the posterolateral portion of the proximal tibia, just below the posterolateral tibial plateau.

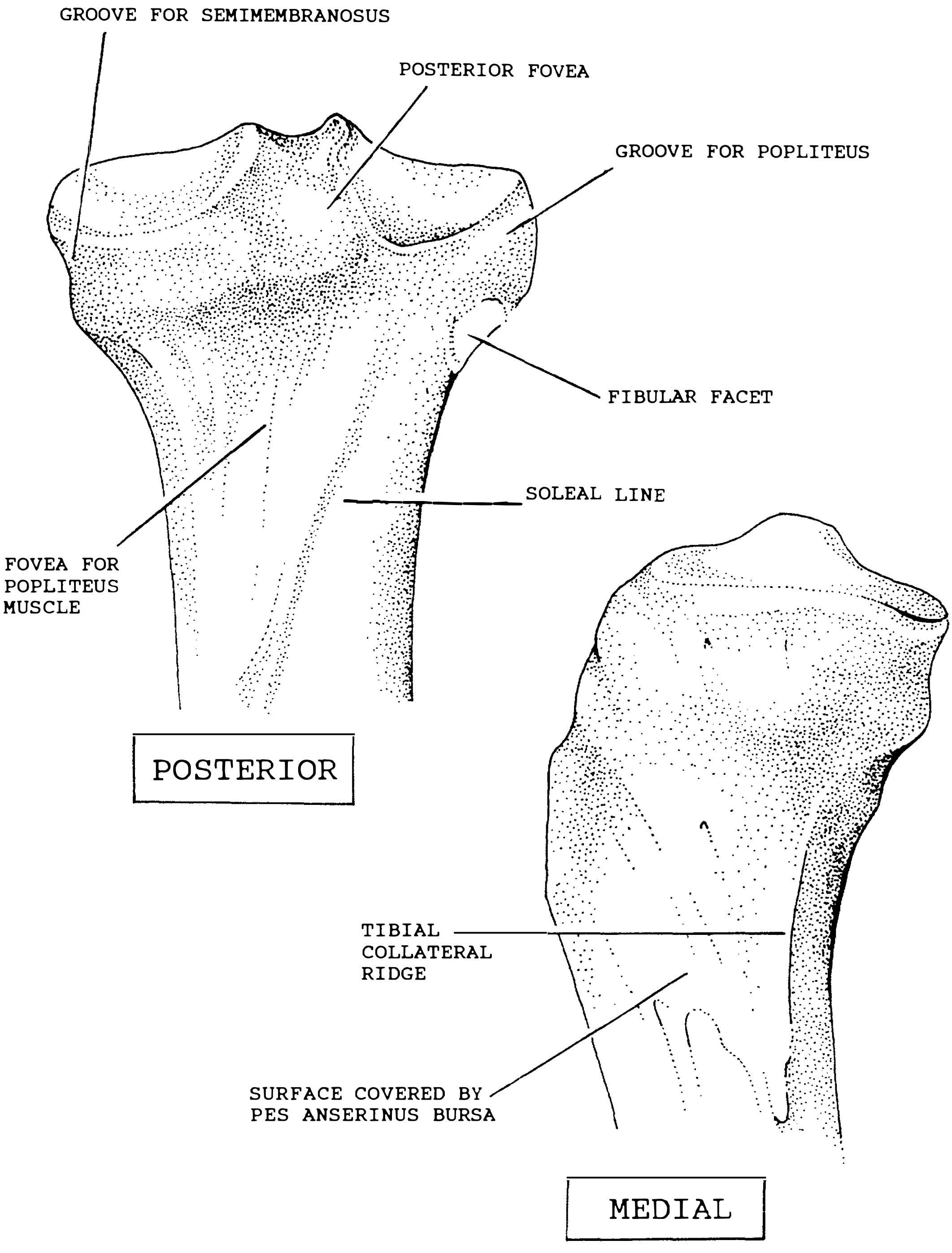

FIGURE 1-12. BONY TOPOGRAPHY OF THE POSTERIOR AND MEDIAL PROXIMAL TIBIA

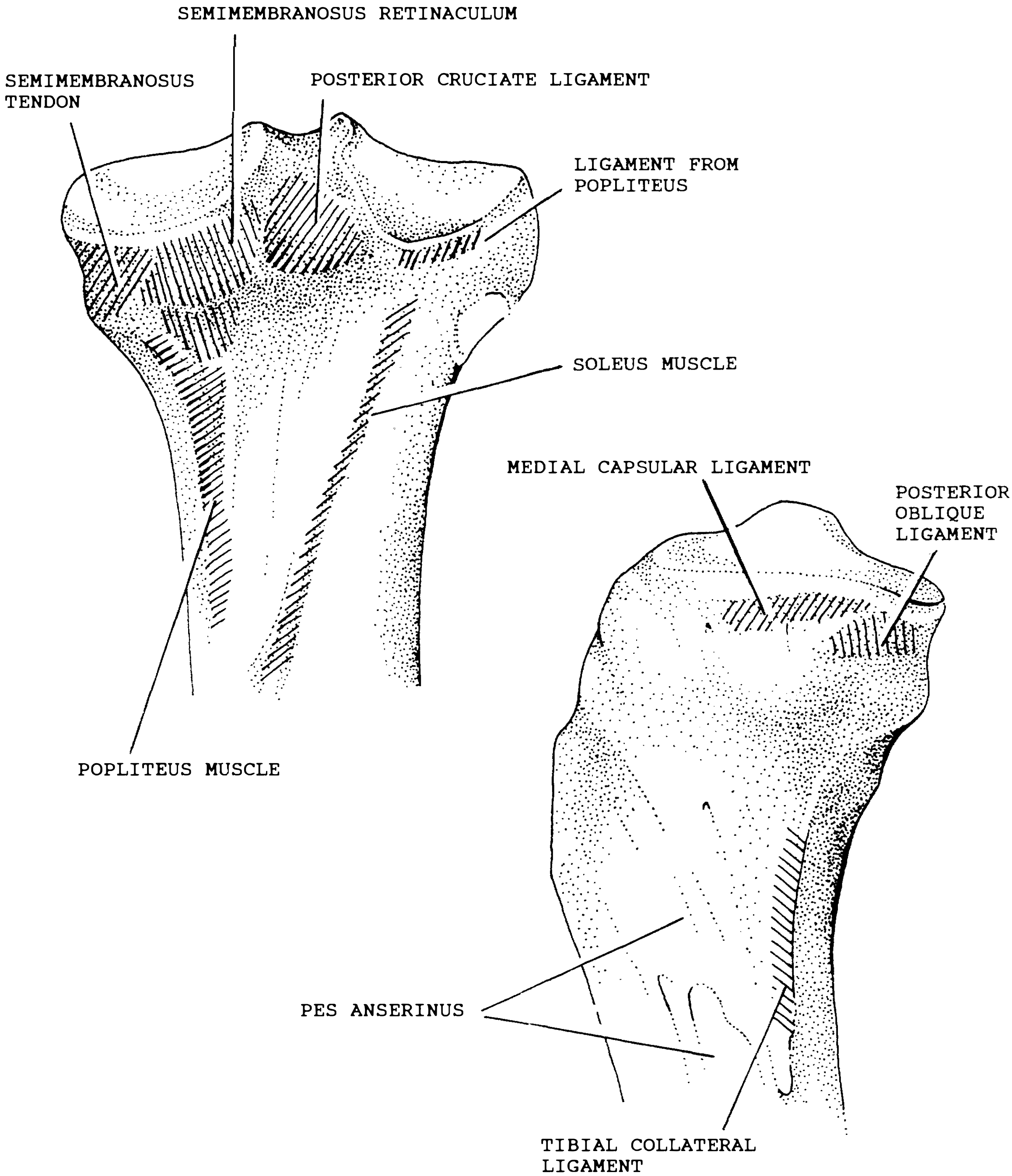

FIGURE 1-13. PROXIMAL VIEW OF THE POSTERIOR AND MEDIAL TIBIA SHOWING SITES OF SOFT TISSUE ATTACHMENTS

THE FIBULA:

The fibula, the lateral bone of the leg is more slender than the tibia. It does not share in the transmission of body weight, and it functions primarily to anchor the muscles of the lower leg. The shaft is long and slender with a variable shape that is molded by the muscles to which it gives attachment. It ends distally as the lateral malleolus.

The head of the fibula is the only portion that contributes to the structure of the knee joint. The head of the fibula is extremely variable in shape, and is expanded in all its diameters in relation to the shaft. Its upper surface contains an articular facet that joins onto the inferior lateral tibial condyle but the exact location of the articulation with the tibia is not constant.

The styloid process projects upwards from the lateral part of the superior surface of the fibular head, and is the site of attachment for the arcuate ligament. Anterior to this, is a small depression that marks the attachment of the fibular collateral ligament. Short, strong ligaments totally surround the tibiofibular articular surfaces and create what is called an almost immovable "plane joint" between the two bones (Gray, 1973, Grant, 1972). The tendon of the combined long and short heads of the biceps femoris insert on the anterior surface of the head of the fibula (Hughston et al., 1976b; Kaplan, 1961, 1962; Seebacher et al., 1982) [FIGURE 1-14]

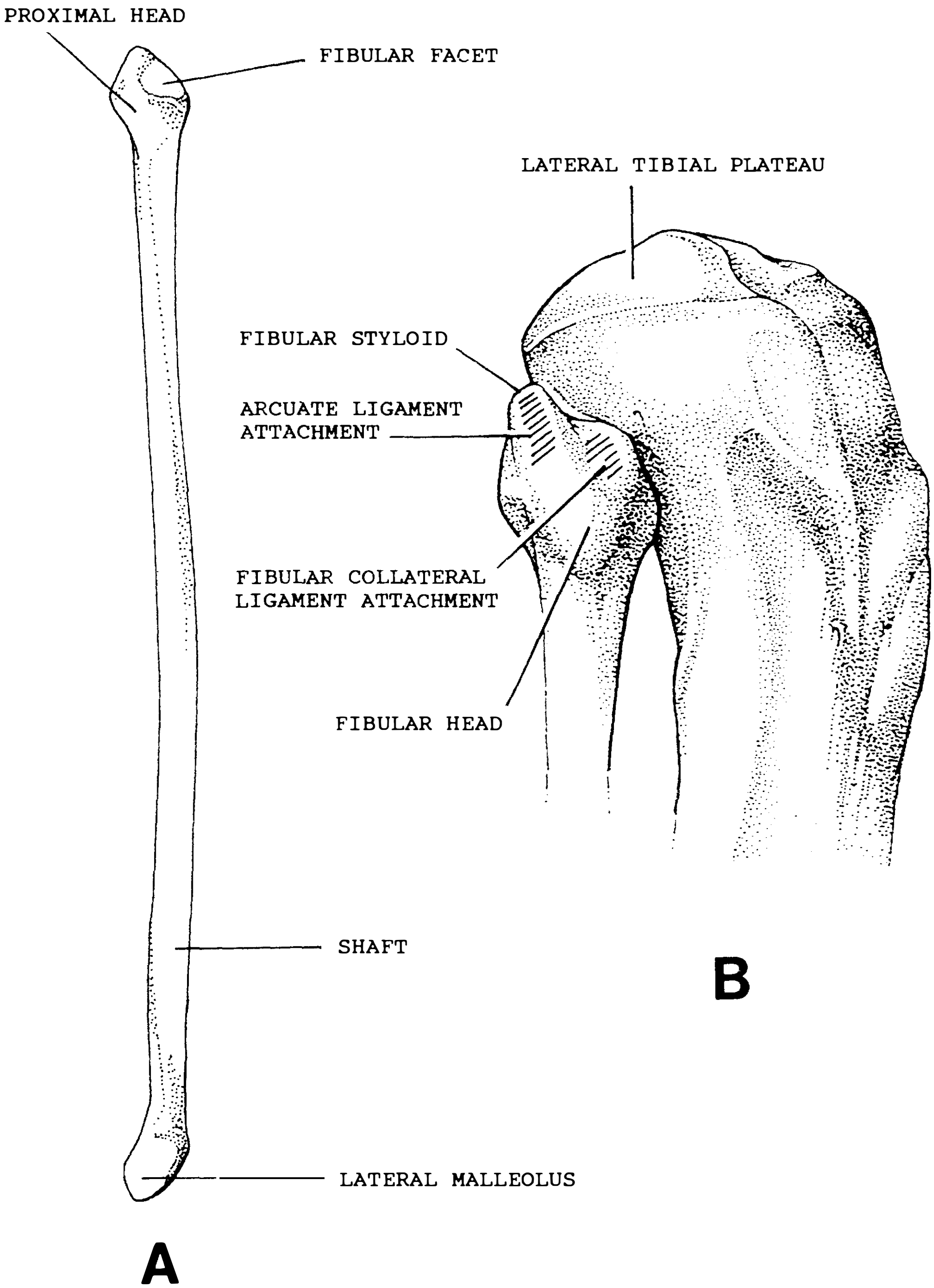

FIGURE 1-14. THE FIBULA

(A) Anterior view of the entire fibula.
(B) Lateral view of the fibula and its relation to the tibia.

THE PATELLA:

The patella is a large sesamoid bone located within the quadriceps femoris tendon, and it articulates with the patellar surface of the distal femur.

The anterior surface is flattened with just a slight convex curve. It is perforated with many nutrient foramina, and it is marked with numerous rough, longitudinal striae. The inferior half is roughly triangular in shape and the superior border is rounded (Bass, 1987; Terry, 1989).

An articular surface covers most of the posterior patella. It is a smooth oval area made up of a large medial and lateral facet, a central ridge, and a single, small, medial facet, sometimes referred to as the "odd" facet (Hughston et al., 1984). The lateral facet is the largest and deepest of the three facets.

Just inferior to the articular surface is an area known as the apex. Its superior surface is covered by the infrapatellar fat pad and an extension of synovium termed the ligamentum mucosum. The inferior border is roughened, and provides attachment for the patellar ligament.

The medial and lateral borders are relatively thin but provide substantial areas for musculotendinous attachments. The superolateral border is the site of attachment of the vastus lateralis tendon, and here there is often a distinct notch, or even the presence of an accessory ossification center [FIGURE 1-15].

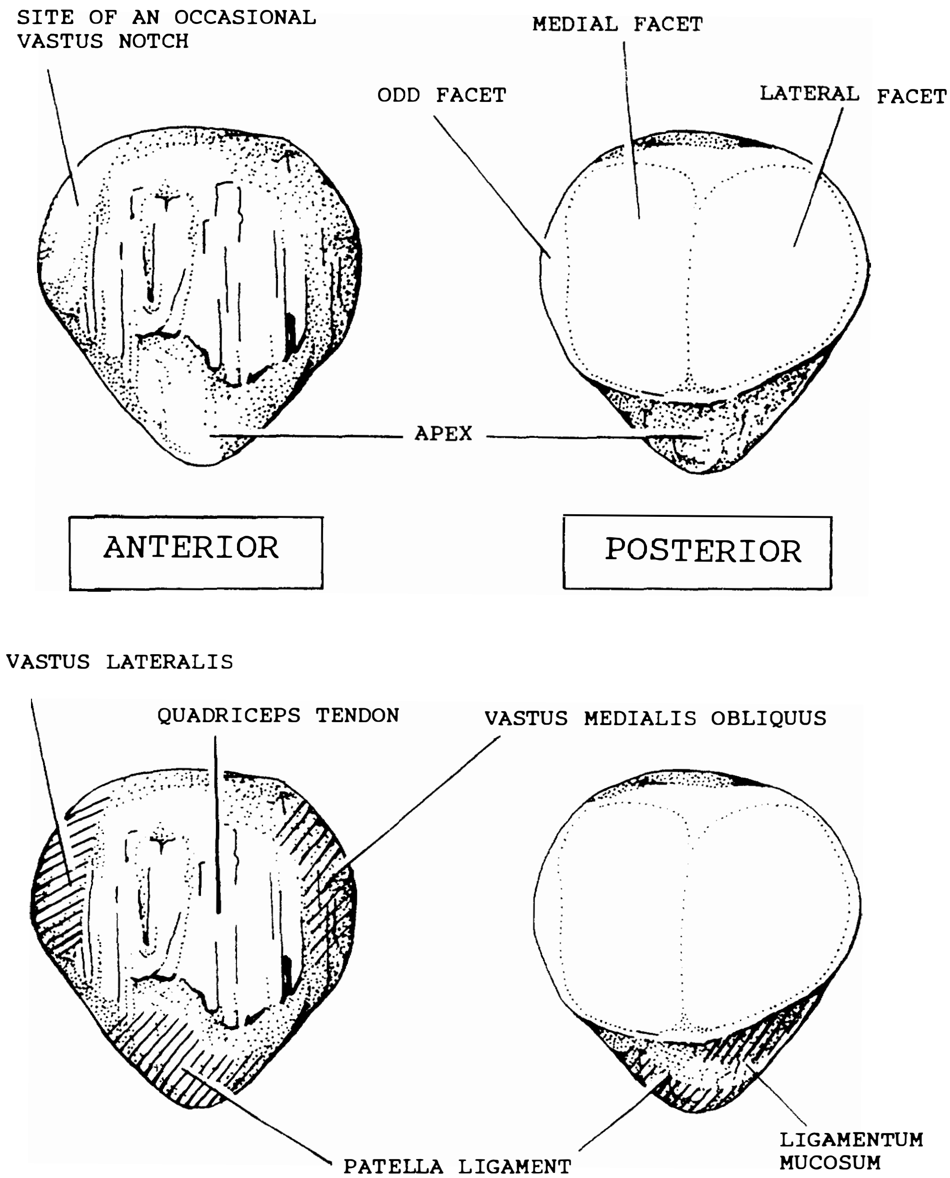

FIGURE 1-15. ANTERIOR AND POSTERIOR VIEWS OF A RIGHT PATELLA

The top two views show the bony topography of the patella, the bottom two views indicate the attachment sites of soft tissues.

THE FABELLA:

Fabella is a term derived from the Latin word for "little bean", and this "little bean" is a sesamoid bone buried in the lateral head of the gastrocnemius muscle near the musculotendinous junction. The fabella first appears as an island of cartilage at about age 10 but does not completely ossify until age 12 or 15 (Flecker, 1932; Sutro et. al, 1935; Zimney, 1972). The fabella averages approximately 13.5 mm in length and 3.5 mm in width (Frey et al., 1987; Sutro et al., 1935) but it can be as large as 22 x 14 mm (Mangieri, 1973). Data on the frequency of the occurrence of a fabella vary greatly, and this frequency reportedly ranges from 9.8% to 22% in the normal population, (Frey et al., 1987; Grant, 1972; Sutro et al., 1935) and up to 35% in patients with clinically significant osteoarthritis of the knee (Pritchett, 1984). In those individuals who have a fabella, it is found to be bilateral in 71% to 85% of cases (Pritchett, 1984; Friedman and Naidich, 1978).

The anterior surface of the fabella is covered with cartilage and forms an articulation with the posterior surface of the lateral femoral condyle. The fabella articulates with only a portion of the lateral femoral condyle when the knee is in extension, and the concave curve of the fabella touches only a small arc of the condyle. This limited contact area produces a fabella articular surface that curves very gently in superior-inferior as well as medial-lateral directions. The overall shape of the fabella is variable, but the curve of the anterior articular surface is very consistent, and is its most distinguishing feature. This curve distinguishes a fabella from a toe sesamoid. Where the toe sesamoid forms a joint with the first metatarsal, the curve is opposite that of the fabella-femur articulation [FIGURE 1-16].

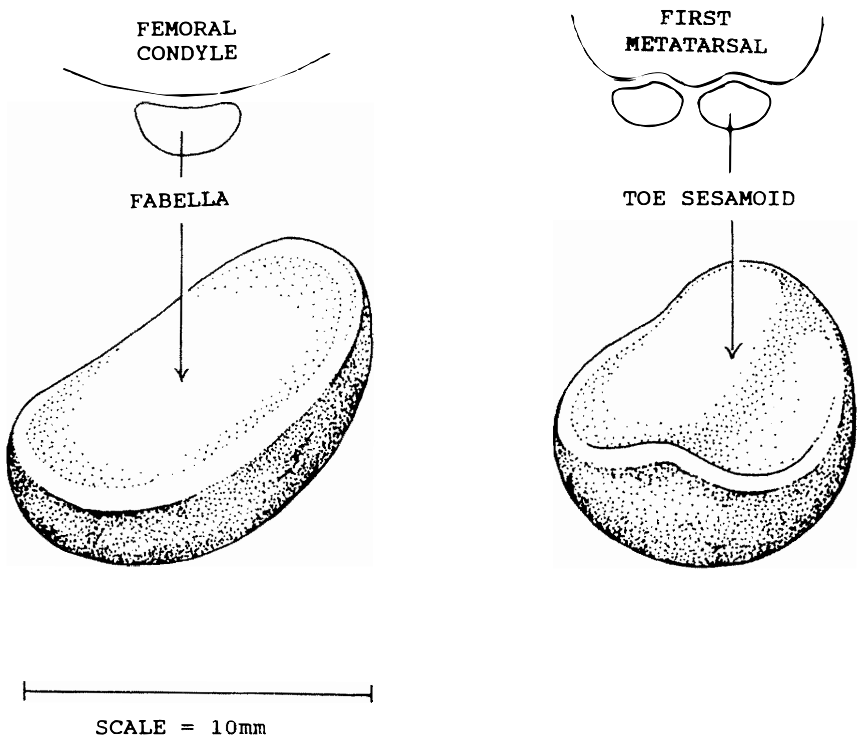

FIGURE 1-16. BASIC OSTEOLOGY OF A FABELLA AND A TOE SESAMOID

The articular surface of the fabella is gently concave in superior-inferior and medial-lateral directions. There is a central convex curve in a toe sesamoid.

RADIOGRAPHIC ANATOMY

Radiology and the knowledge of radiographic anatomy allows clinicians to evaluate patients for certain bone disorders and other maladies that cannot otherwise be visualized in living persons without resorting to exploratory surgery. Radiographs present negative images of the internal structures of the human body, and show different structures in varying shades of gray. In radiographs of the knee, the lightest gray areas represent the most dense areas of bone. The darkest gray areas are the least dense structures in the knee, and represent cartilage and the areas filled with synovial fluid and fat. Bright white areas are usually foreign materials such as metallic implants, and totally black areas are unobstructed background exposures (Meschan, 1959). All of the variations in density in a normal radiograph of the knee can be related to some anatomical structure or foreign body, and in the field of forensic anthropology knowledge of these structures can be a valuable tool when trying to solve the puzzle of human identification.

In trying to identify injuries, surgical modifications, and even racial variation in the bones of the knee the anthropologist will often have to resort to radiologic examination of the bones in question. The following figures will familiarize the reader with the basic normal radiographic anatomy of the knee [FIGURES 1-17 and 1-18].

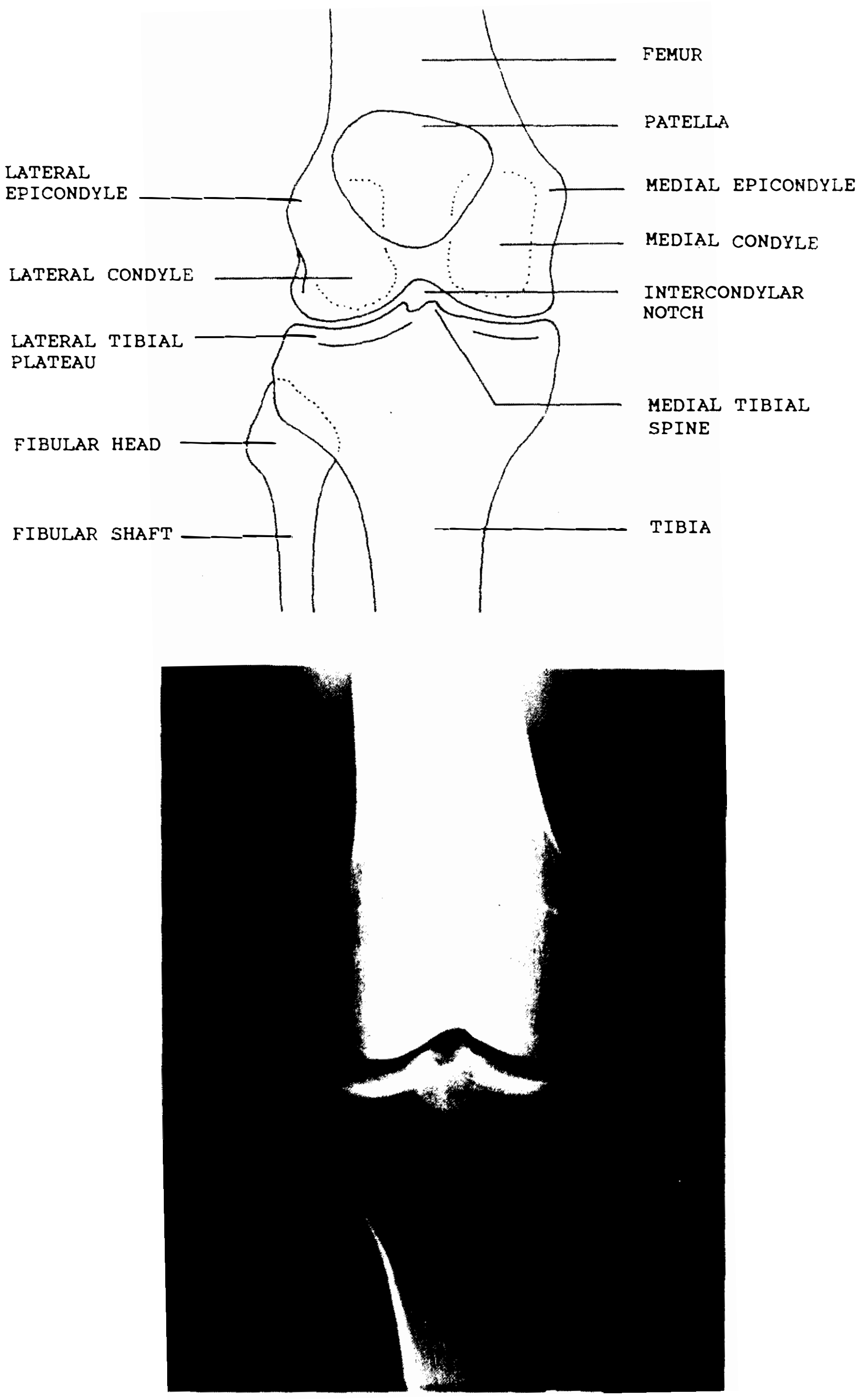

FIGURE 1-17. NORMAL RADIOGRAPHIC ANATOMY OF A RIGHT KNEE VIEWED IN THE FRONTAL PLANE.

For forensic identification, individual bones will most likely be studied, so overlapping structures will not be a concern.

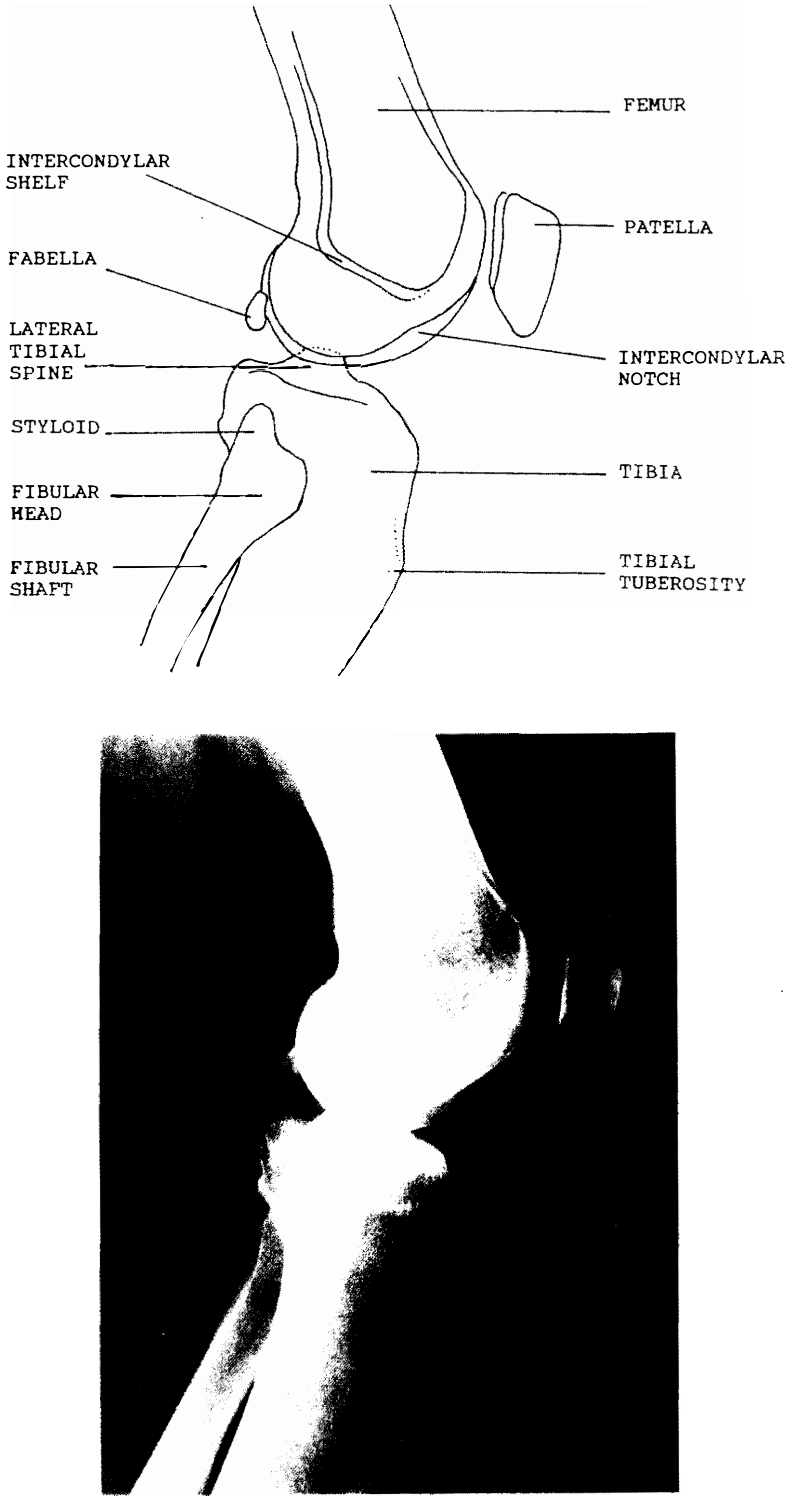

FIGURE 1-18. NORMAL RADIOGRAPHIC ANATOMY OF A RIGHT KNEE VIEWED IN THE SAGITTAL PLANE

SUMMARY

The bones can provide a wealth of information concerning the normal as well as abnormal anatomy of the knee. Starting with the embryological development of each osteological element, the skeletal evidence contained in each bone can chronicle the growth and development of an individual.

All of the bones of the knee contain specific features that are unique to that bone, and knowledge of these osteological details is necessary for the identification of these bones. It is also necessary to be able to correlate these unique osteological findings to the muscles, ligaments, and other soft tissue structures that helped create them. These individual features may provide critical evidence that can eventually lead to a positive identification in a forensic case. They can also offer clues to indicate activities and/or growth patterns in extant populations.

CHAPTER 2

SKELETAL EVIDENCE OF KNEE INJURY AND STRESS

INTRODUCTION

The knee is the largest and one of the strongest joints in the human body. It is a major weight bearing joint and it is subjected to stress and injury even during sedentary daily living. This amount of stress is increased to incredible levels during athletic competition and other strenuous activity. Some of these injuries and stresses can produce changes in the bone that become part of the osteological evidence, and thus can be used to recreate a pattern of activity. This type of analysis is commonly used in the science of physical anthropology and archaeology as it relates to the reconstruction of lifeways. In forensic cases, this type of analysis can lead to a correlation with a medical record and possibly a positive identification. It is important to be able to recognize changes in the bone that are due to injury and the stresses caused by such factors as malalignment and other mechanical forces.

Part of this chapter will be treated in an atlas format, with drawings that illustrate the most common and significant changes that can be traced to specific mechanisms of injury and diagnosis. Bony changes due to pathological conditions have been well documented (Ortner and Putschar, 1981), and will not be included here.

REMODELING RESPONSE TO INJURY

BONE PHYSIOLOGY:

The process of bone remodeling is controlled by an intricate system of deposition and resorption. Once adult size is achieved, normal growth and maintenance of bone goes on continuously by two control loops. One involves a negative feedback hormonal mechanism; the other involves gravitational and mechanical forces acting on the skeleton (Marieb, 1992). This second mechanism is of primary concern when discussing the skeletal changes that occur in response to injury and stress.

In 1683 Galileo was the first to recognize the relationship between applied load and bone morphology, but it was over 200 years later, in 1892, that Julius Wolff first linked the the two concepts of body weight and bone size (Netter, 1992). He noted that a bone grows in response to forces or stress by remodeling, but the mechanisms by which bone cells respond to these stresses are not completely understood. Nevertheless "Wolff's Law" is accepted today by most, but not all, scientists.

Deforming bone produces an electrical current proportional to the applied force; areas under tension become positively charged, and compressed or stressed regions become negatively charged. This has led to the hypothesis that newly formed matrix is deposited around negatively charged areas (Brighton, 1981; Marieb, 1992).

According to this hypothesis, the area of bone that is under compression is the area where new bone will be formed, and osteoclastic activity will remove bone from the areas under tension. In the shafts of long bones, this appears to be the normal sequence of events during an individual's entire lifetime.

Under normal circumstances, when a bone is fractured, the process of healing and bone remodeling can also be predicted. Blood vessels in and around the bone are ruptured and a hematoma forms at the fracture site. Bone cells that are deprived of nutrition begin to die and tissues around the site become inflamed. Granulation tissue forms with concomitant growth of capillaries through which phagocytic cells can invade the site and eliminate the debris. Fibroblasts and osteoclasts begin restructuring the bone, and a fibrocartilaginous callus is formed. This splints the bone while osteoblasts and osteoclasts rapidly migrate and multiply to convert the fibrocartilaginous callus to a bony callus. This bony callus is primarily spongy bone, and it will continue to form until a firm bony union is achieved, 2 to 3 months later (Marieb, 1992; Rockwood and Green, 1975).

The biomechanical principles that apply to long bone response and remodeling are not quite the same as those that apply to synovial weight-bearing joints such as the knee, but the physiological principles are similar. At the ends of the femur and tibia, the trabeculae are arranged to resist tensile as well as compressive forces. When overall body weight and/or biomechanical forces change, there is a corresponding thickening or thinning of the trabeculae. This change in trabecular thickness, rather than cortical bone remodeling, is the primary stress response at the joint.

In and around the articular surfaces of weight-bearing joints there are other forces and factors that affect the response to injury and stress. In addition to bone, cartilage is the primary connective tissue involved in and around large synovial joints. Articular cartilage covers the gliding and load bearing surfaces of the bones, fibro-cartilage attaches ligaments and tendons to the bones, and fibroelastic cartilage constitutes the bulk of the interarticular menisci.

The articular cartilage is continuous with the synovium, or synovial membrane. This synovium is a vascular mesenchymal tissue that lines the joint space and produces the joint fluid that serves to lubricate, nourish, and remove cellular debris within the joint capsule. In a synovial joint the osseous surfaces of the bones are in apposition with one another but they are not in contact.

Thus, injuries to a large synovial joint primarily affect the ligamentous, capsular, and cartilaginous structures, but these can in turn, affect the osseous structures because of the action and interaction of all associated anatomical and biomechanical factors.

Trauma to the synovial membrane and cartilaginous surfaces is a contributory factor to the later onset of degenerative arthritis. Miltner et al. (1937) pointed out that this synovial membrane becomes congested with small hemorrhages, with pannus formation at the osteocartilaginous junction. This causes fibrillar degeneration of the surface layers of cartilage on the side of injury and cell damage and fissuring of the intermediate layer of cells on the opposite side. This latter change is the primary culprit in the onset of late traumatic arthritis.

Ligament injuries may be complete or incomplete. With a complete ligament injury there will always be demonstrable instability, and if left untreated this may become permanent, and cause irreparable damage to cartilaginous and osseous structures. The same sequence of hemorrhage, pannus, and fibrillar degeneration occurs because of repeated microtrauma.

Evidence of these injuries and instabilities can be seen in and around the ends of long bones. They are sometimes overlooked, or attributed to the general condition of "arthritis". The importance of the recognition and classification of these defects will be discussed in the following sections.

ANTHROPOLOGICAL PERSPECTIVE:

For physical anthropologists, the analysis of skeletal remains must also include inspection for any remodeling response to injury or disease. Evidence of these events can provide insight into patterns of health and disease, nutrition, lifeways, trauma and warfare. In respect to injuries of the knee, recognition of acute and chronic injuries is valuable in regard to understanding the ability of individuals to function even with severe pathology. It is also valuable in order to analyze patterns of injury within populations.

FORENSIC PERSPECTIVE:

For forensic anthropologists, it is important to be able to recognize and classify evidence of knee injuries and specific stress. As a consequence of diagnosis coding protocols that have been established by the health insurance industry, the recognition and exact classification of an injury is often necessary in order to trace an individual's medical history. In some respects this can complicate efforts to locate a medical record and make a positive identification, but in other cases it can simplify the procedure.

If characteristics of a specific injury are recognized, this information can be included in the forensic analysis. Providing evidence that an individual at one time likely sustained an "acute avulsion of the anterior cruciate ligament" or a "lateral tibial plateau fracture" will prove to be an advantage when attempting to match skeletal remains with the medical records of missing persons.

The remainder of this chapter will illustrate the typical appearance of bones that have incurred stress and some of the most common knee injuries. Chapter 3 illustrates how to recognize evidence of the most common surgical procedures. Appendix I and II contain a list of injuries, procedures, and matching codes.

OSTEOLOGICAL EVIDENCE

THE FEMUR:

The distal end of the femur is a very large, strong part of the human skeleton. As part of the knee it is subjected to many injuries and large amounts of stress that can change the appearance of the bone in many ways. Many of these changes occur first in the articular cartilage, and alter the bone only after prolonged periods of stress. Others occur at the time of injury.

STRESS RELATED:

- AGE RELATED GONARTHROSIS
- INJURY RELATED GONARTHROSIS
- SUPRAPATELLAR PLICA
- FABELLA ARTICULATION
- SUBLUXING PATELLA
- OSTEOCHONDRITIS DISSECANS
- PELLEGRINI STIEDA

INJURY RELATED:

- LIGAMENT AVULSIONS

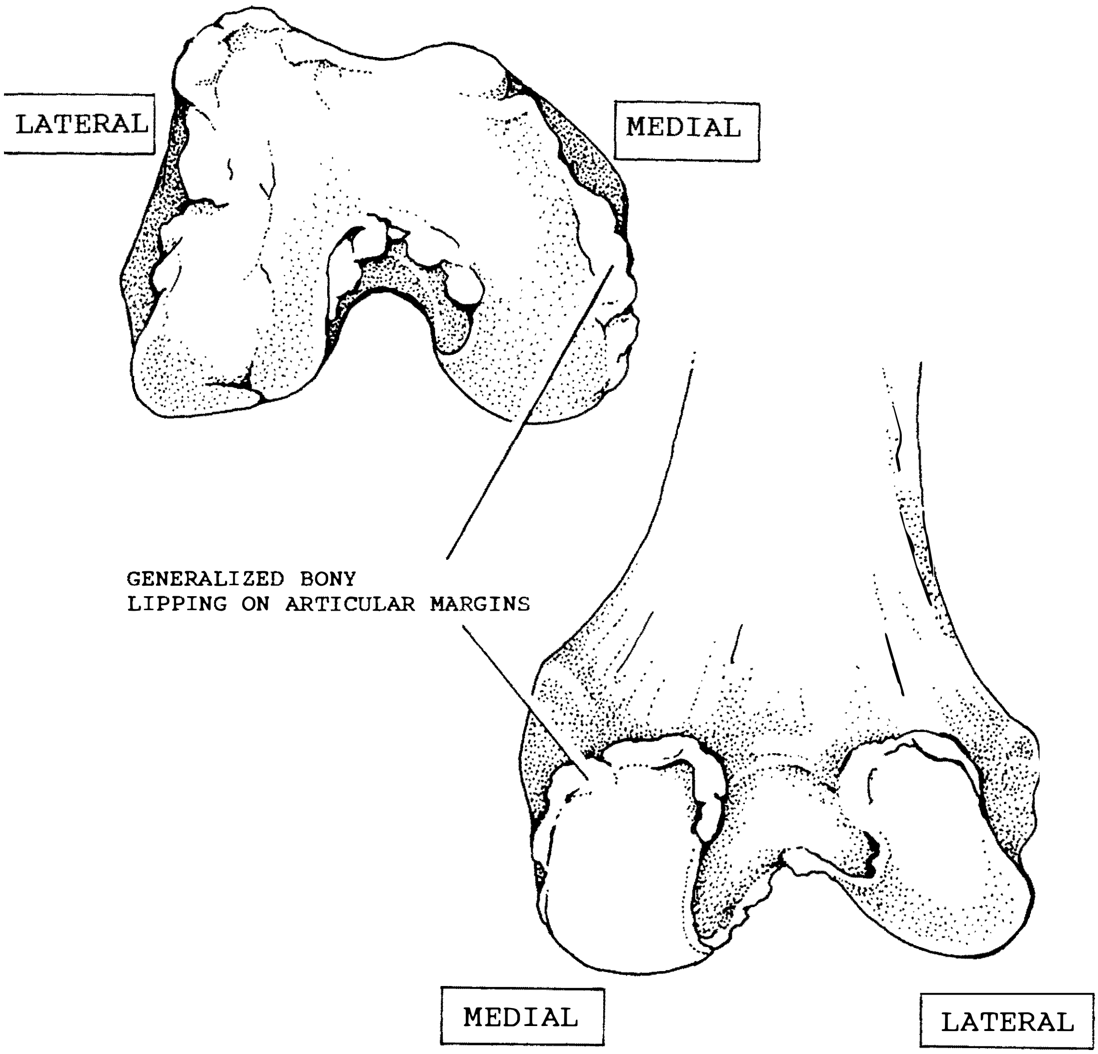

FIGURE 2-1. AGE RELATED GONARTHROSIS

Age related, degenerative gonarthrosis is undoubtedly the most commonly encountered abnormality in the femur. It first appears as a general increase of bony lipping of the articular margins, and can eventually involve all articular surfaces.

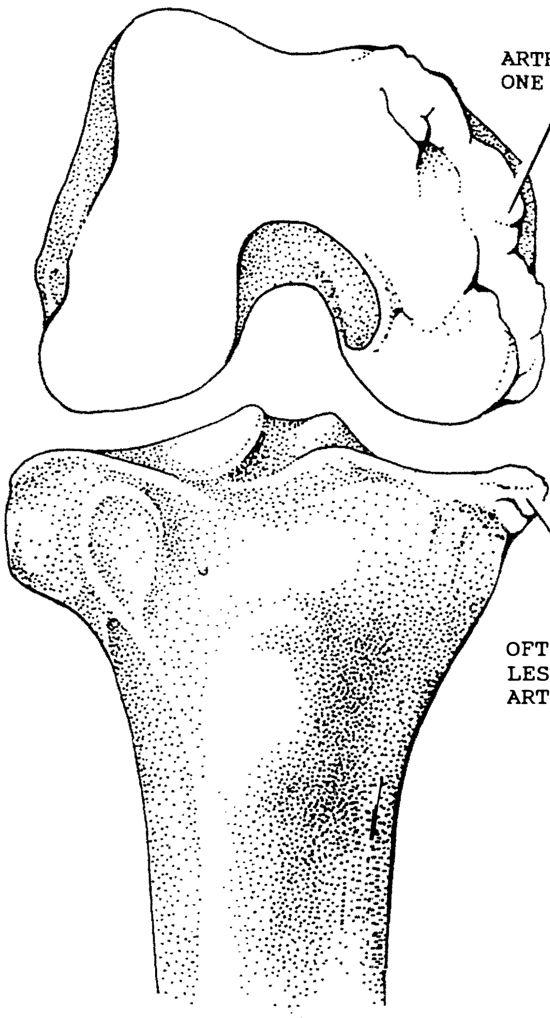

FIGURE 2-2. INJURY RELATED GONARTHROSIS

When injury to the knee results in gonarthrosis, the pattern can differ from degenerative changes. Usually a fracture or a significant ligamentous injury starts a series of events that leads to significant arthritic changes in one primary area of the articular cartilage. This may or may not lead to generalized gonarthrosis.

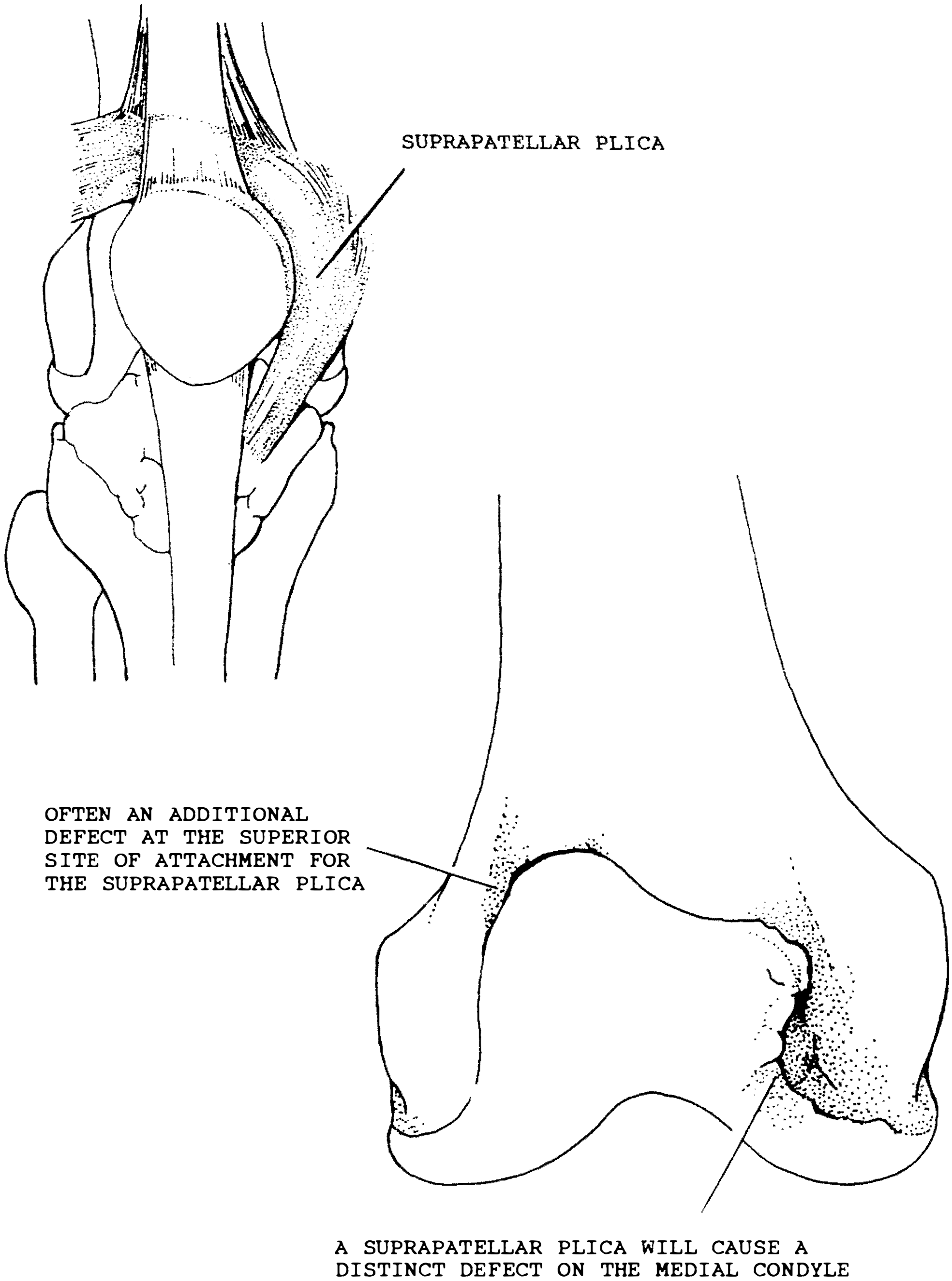

FIGURE 2-3. SUPRAPATELLAR PLICA

The suprapatellar plica is a fold of the normal synovium surrounding the knee. Trauma or repetitive irritation can produce fibrosis of the plica which in turn creates distinct scars on the femur (Hughston, 1993).

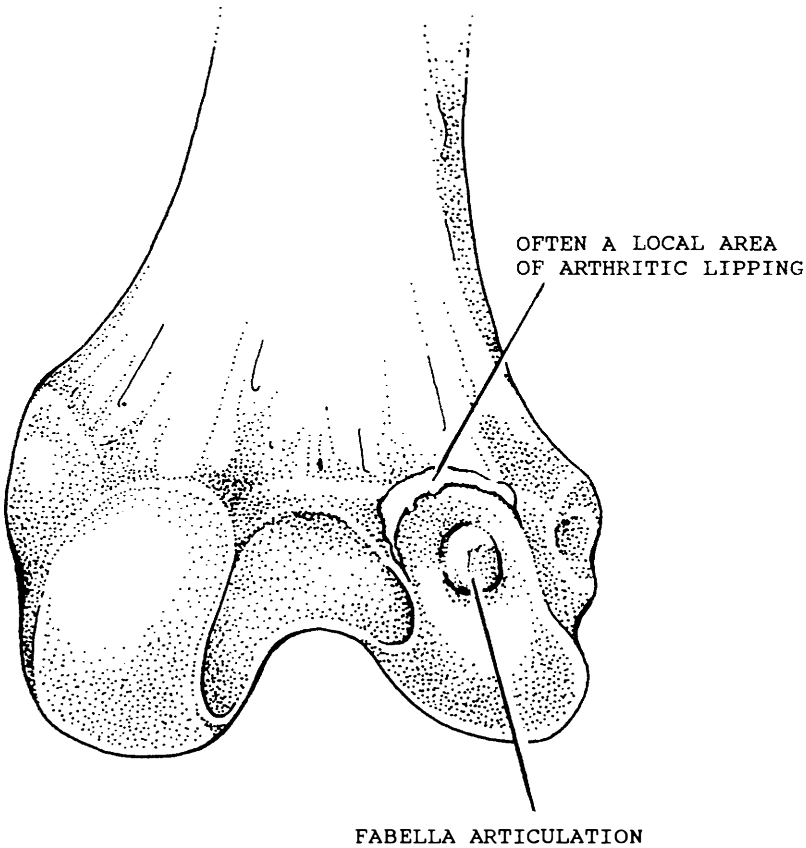

FIGURE 2-4. FABELLA ARTICULATION

The fabella articulates with a very small portion of the posterior lateral femoral condyle, and this often causes chondromalacia that can lead to a discrete bony lesion (Goldenberg and Wild, 1952; Weiner et al., 1977).

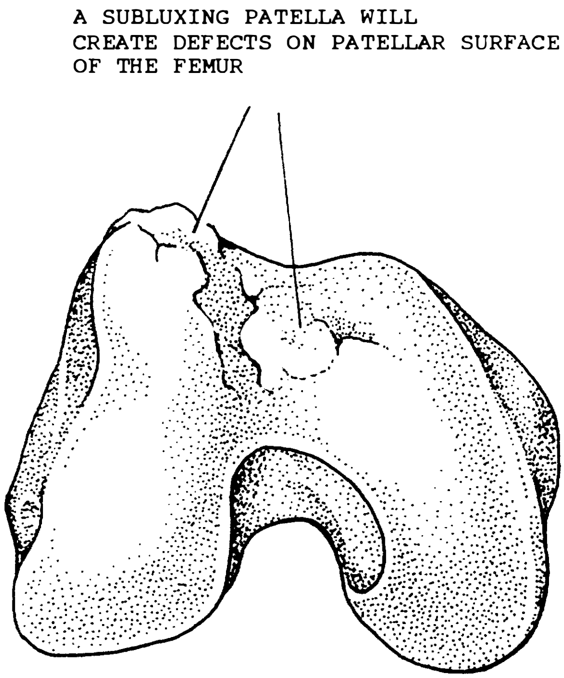

FIGURE 2-5. SUBLUXING PATELLA

Evidence of chronic patellar subluxation presents as significant degenerative arthritis on the patellar articular surface (Jacobson and Flandry, 1989).

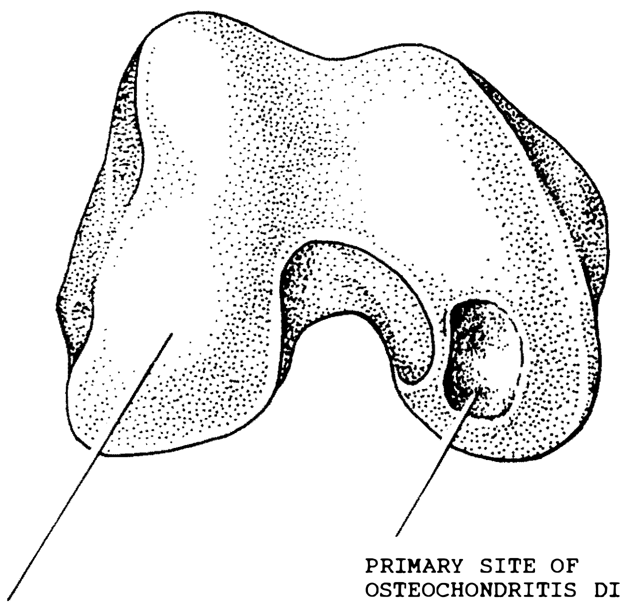

FIGURE 2-6. OSTEOCHONDRITIS DISSECANS

Osteochondritis dissecans creates a discrete lesion on the tibial articular surface. An area of subchondral bone undergoes avascular necrosis, and degenerative changes occur in the cartilage overlying it. The lesion is usually located on the medial femoral condyle, where weight is born against the medial eminence, but it can occur elsewhere on this articular surface and also on the lateral femoral condyle (Sisk, 1980). This lesion is seen most often in adolescents and young adults.

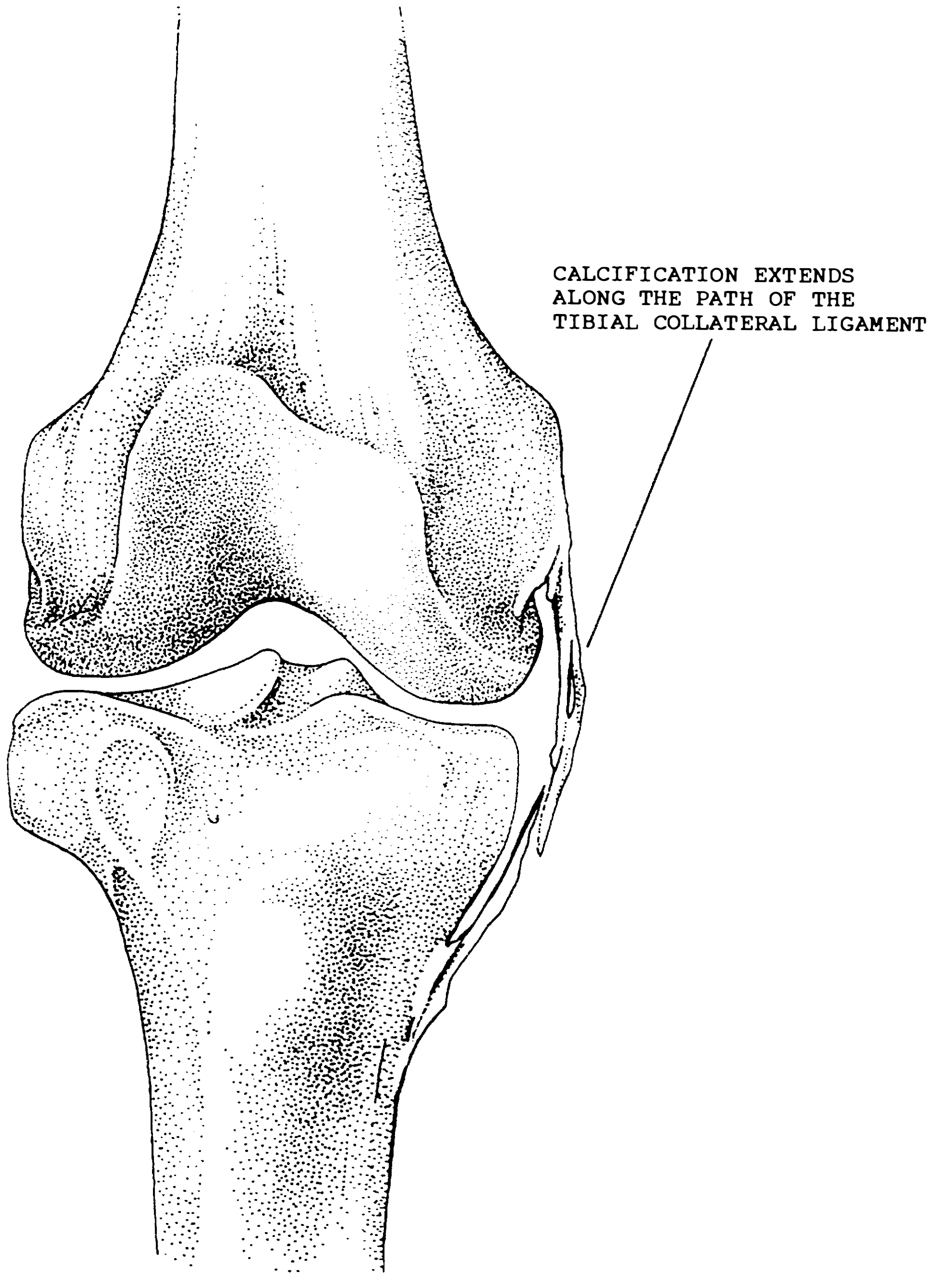

FIGURE 2-7. PELLIGRINI-STIEDA

Pelligrini-Stieda disease is characterized by a bony formation that starts in the superior portion of the tibial collateral ligament, and in severe cases can extend to the tibia. It is due to previous trauma to the medial capsular structures of the knee (Hughston, 1993; Smith et al., 1976).

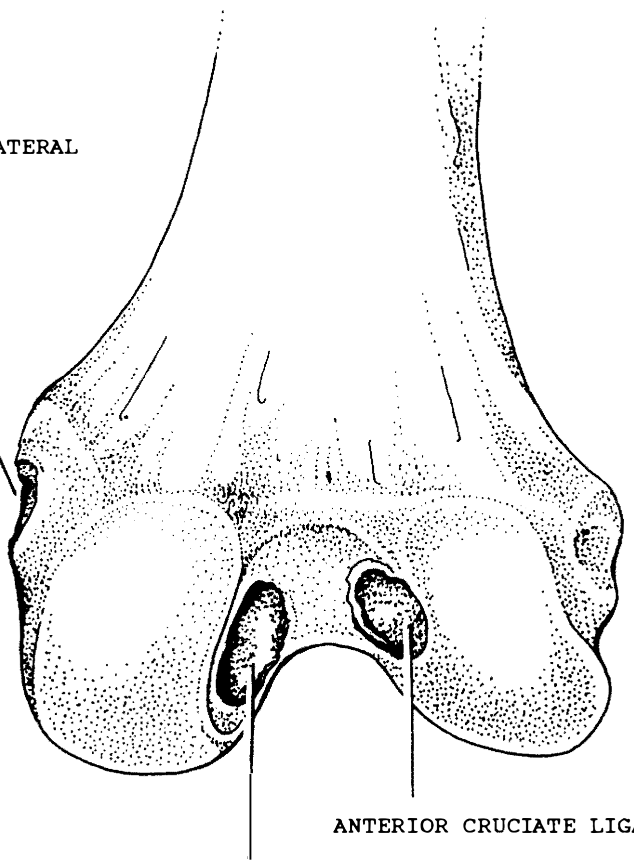

FIGURE 2-8. AVULSION FRACTURES

Avulsion fractures always occur at the site of attachment of a ligament or tendon. By referring to the osteology section in Chapter 1, the associated soft-tissue component of any avulsion fracture can be determined. Three of the most common sites of avulsion fracture are shown here. (Hughston et al., 1976a; Sisk, 1980).

THE TIBIA:

The proximal tibia, like the distal femur, is subjected to many injuries and large amounts of stress. The condyles of the tibia are especially prone to degenerative changes and trauma because they are not as massive as those of the femur, and because of the intimate relationships of the menisci on the articular surfaces. The combined bio-mechanical forces of the ligaments, the menisci, and the bones themselves often cause irreversible changes in the bone that can be recognized and classified.

STRESS RELATED:

- AGE RELATED GONARTHROSIS
- MENISCAL WEAR

INJURY RELATED:

- CONDYLAR FRACTURES
- TIBIAL PLATEAU FRACTURES
- AVULSION FRACTURES
  - Segond fracture
  - Anterior cruciate
  - Posterior cruciate
- OSGOOD-SCHLATTERS'DISEASE

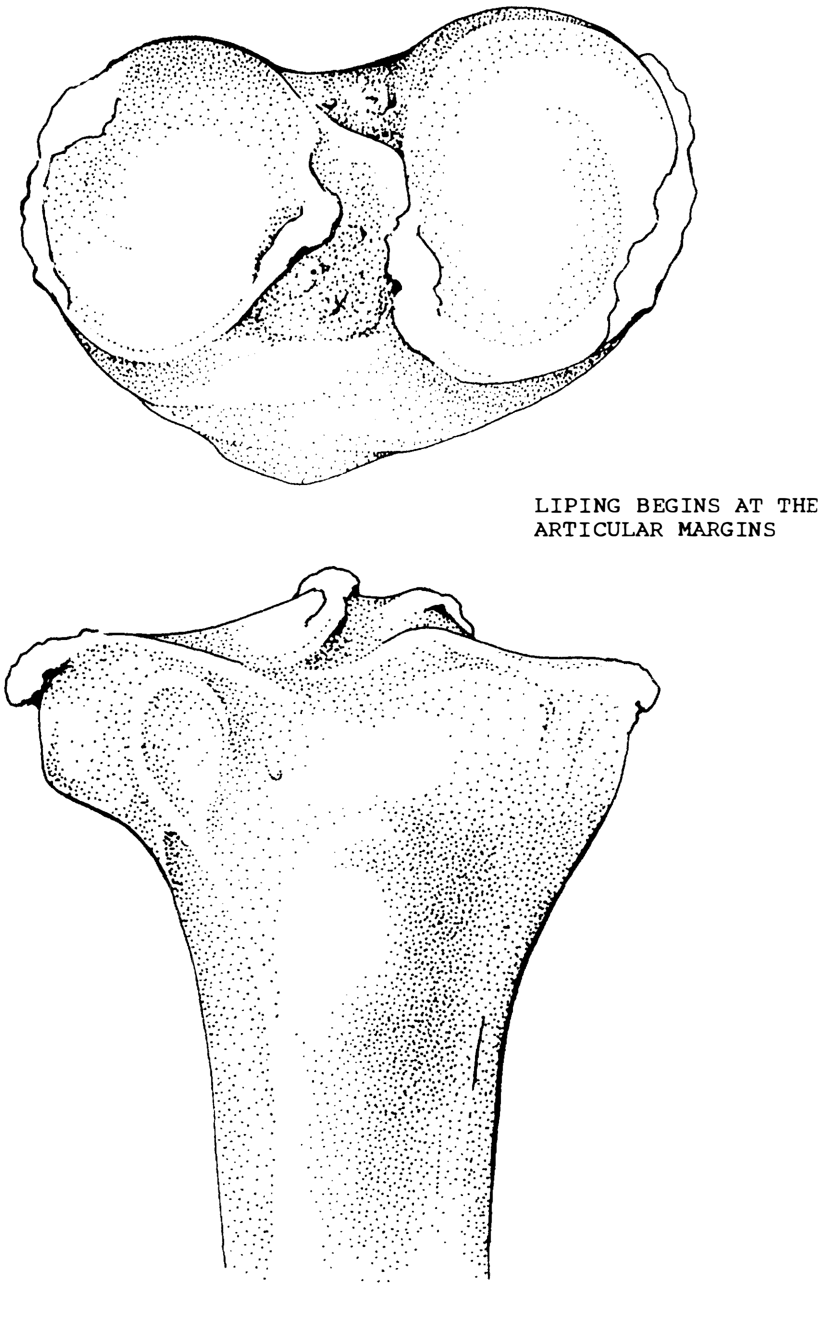

FIGURE 2-9. AGE RELATED GONARTHROSIS

Age related degenerative gonarthrosis of the tibia is a very common finding. It generally starts on the outer edge of the articular margins and against the intercondylar eminences. It slowly progresses until the entire articular surfaces are involved.

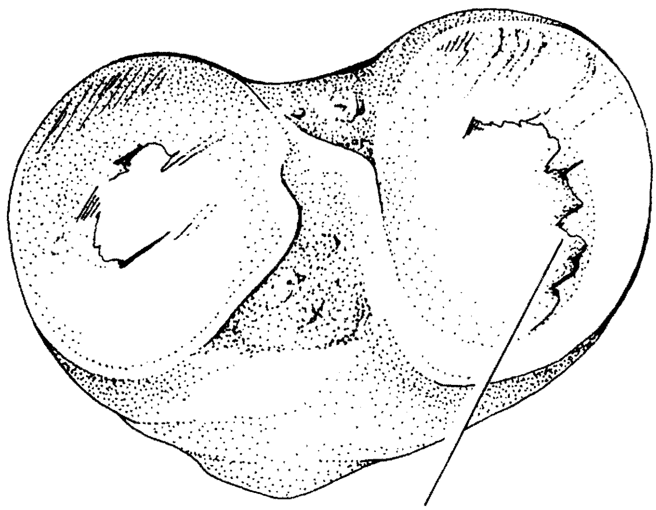

FIGURE 2-10. MENISCAL WEAR

Tears of the menisci create distinctive patterns of wear on the articular cartilage and in severe cases these torn menisci can permanently scar the articular surfaces of the bone.

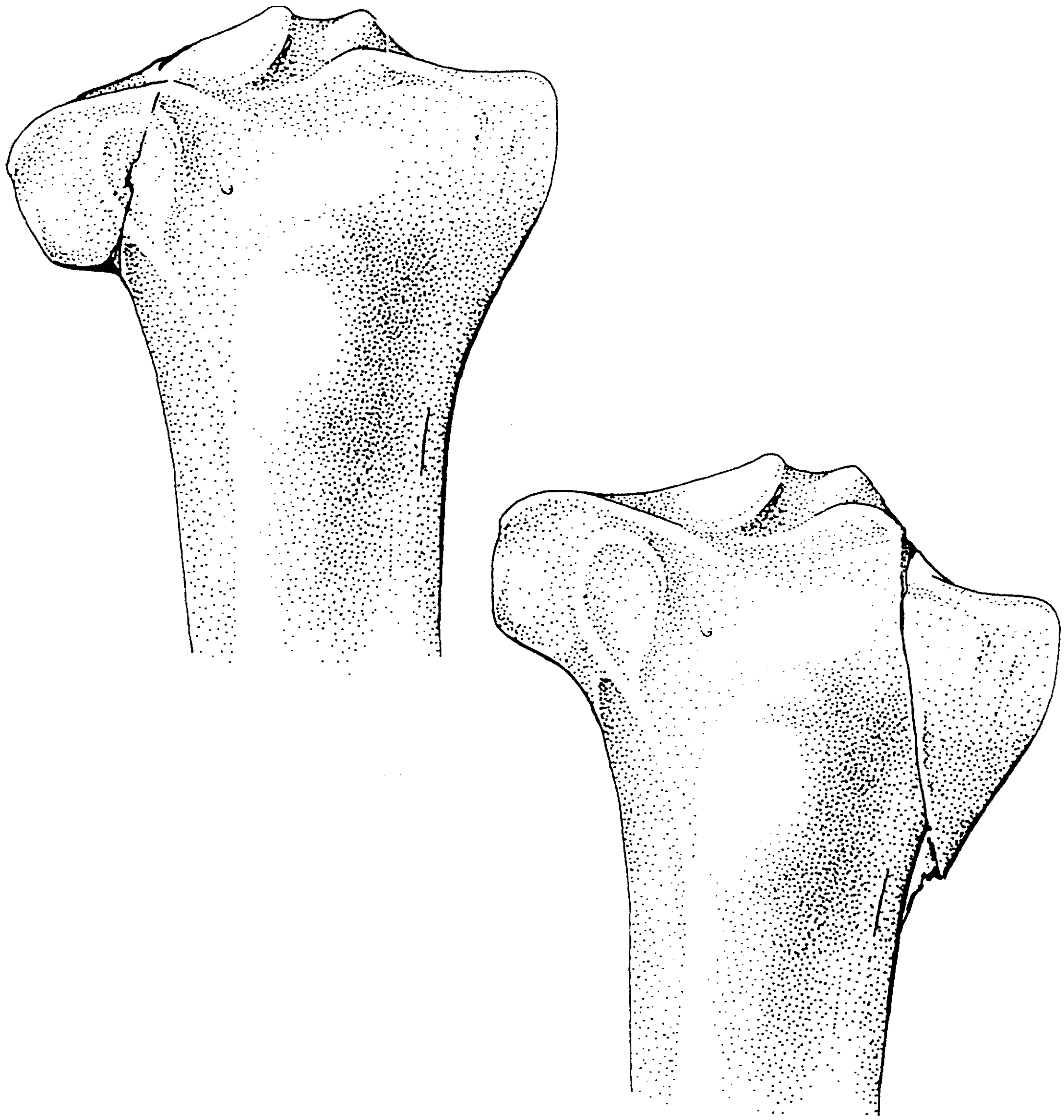

FIGURE 2-11. CONDYLAR FRACTURES

Fractures of the tibial condyles often heal with displacement. This changes the position of the weight bearing surfaces to valgus or varus weight bearing alignment, an increase in joint space, and usually some rotational deformity (Smith, 1980). The most commonly used classification for tibial condylar fractures is that described by Hohl (1967: 557)

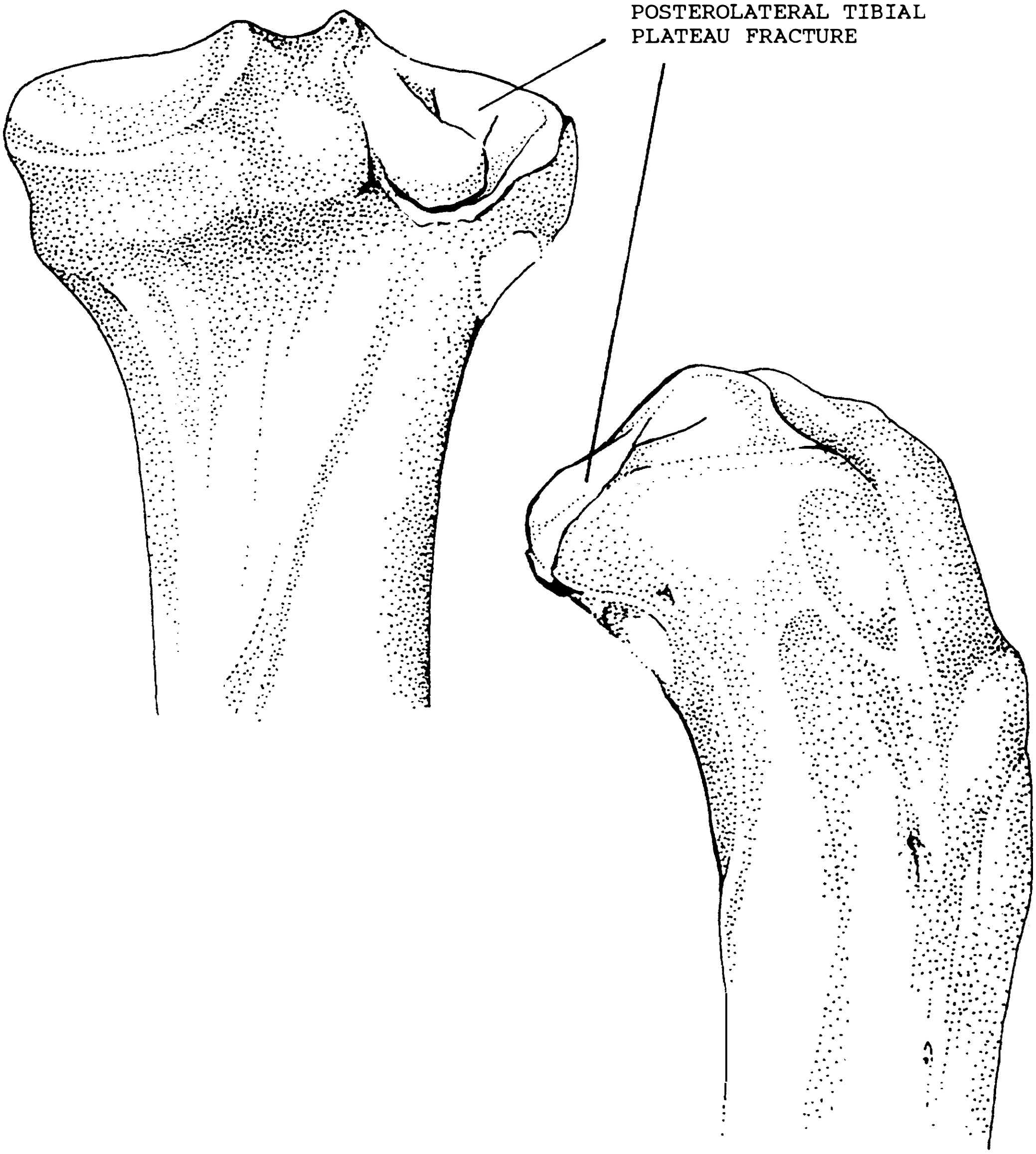

FIGURE 2-12. TIBIAL PLATEAU FRACTURES

Tibial plateau fractures are technically just variations of tibial condylar fractures, but they are much more subtle in the clinical situation, and as evidence in the skeletal record, they are more difficult to recognize and classify (Hughston, 1993). Corresponding diagnoses in clinical coding will likewise be different .

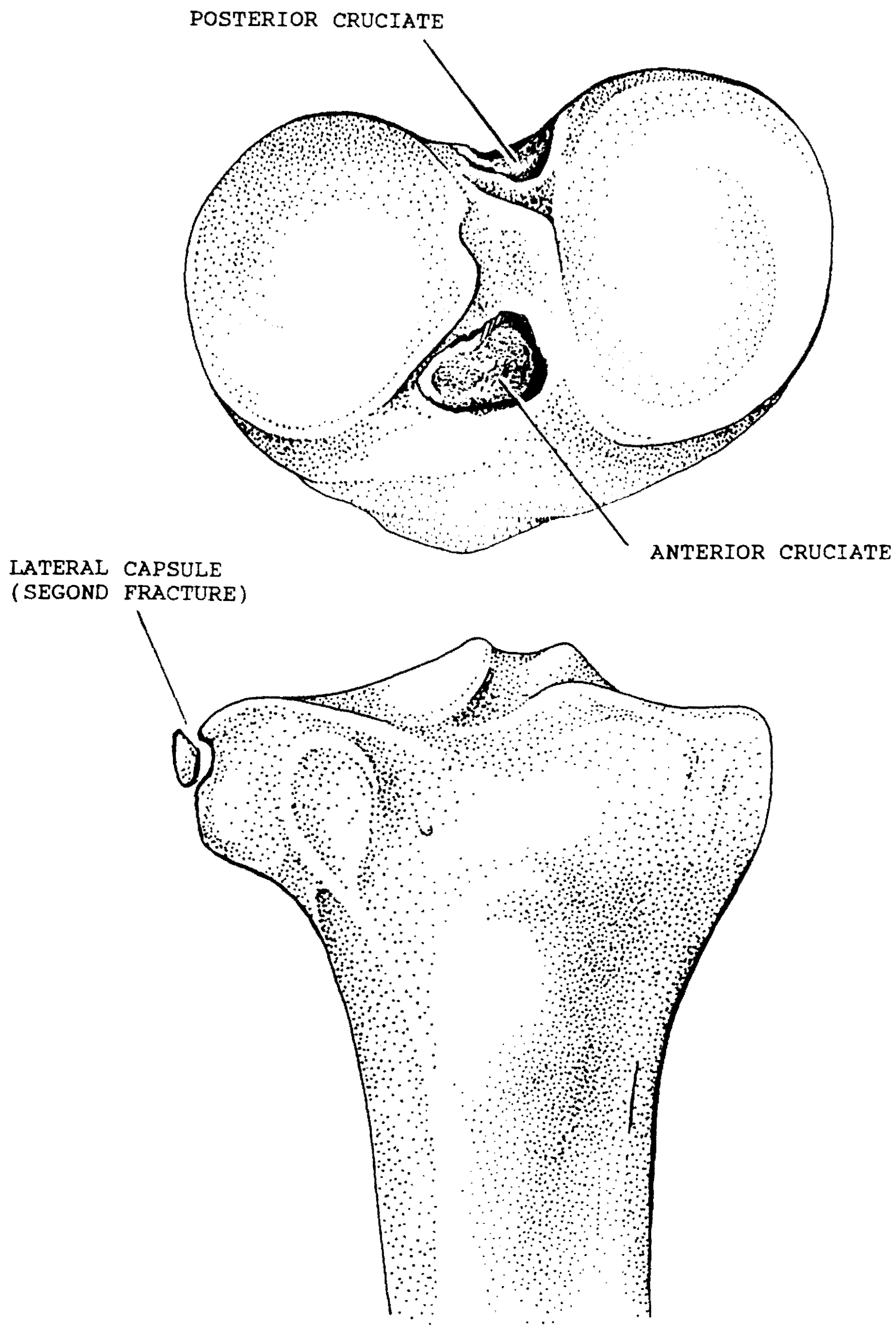

FIGURE 2-13. AVULSION FRACTURES

Just as on the femur, avulsion fractures of the tibia occur at the attachment site of ligaments and tendons. Three of the most comon sites of avulsion fractures are shown in figure 2-13.

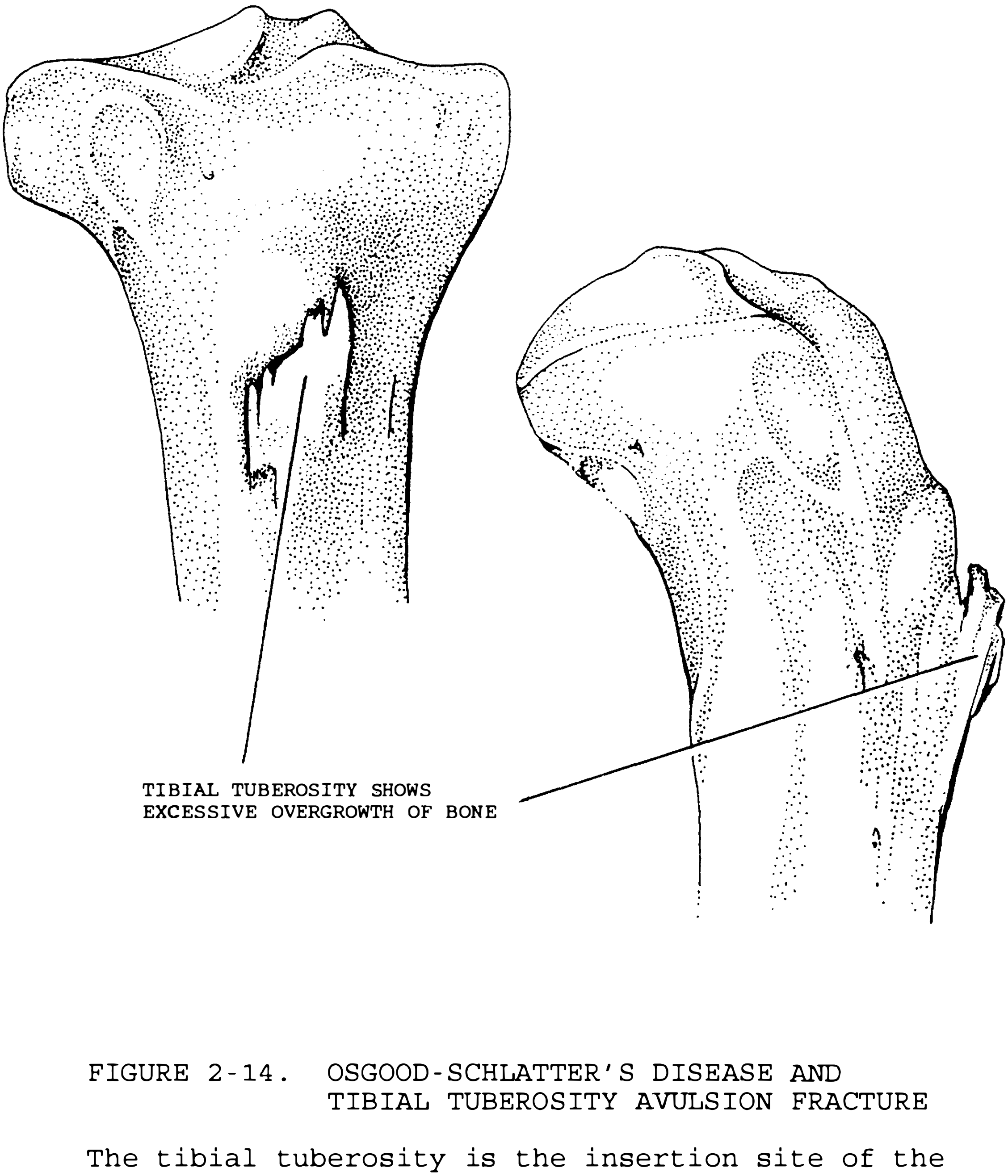

FIGURE 2-14. OSGOOD-SCHLATTER'S DISEASE AND TIBIAL TUBEROSITY AVULSION FRACTURE

The tibial tuberosity is the insertion site of the patellar ligament, and as such is subjected to stresses from the quadriceps femoris. An abnormal overgrowth of bone here can develop following repeated microtrauma to the growing epiphysis. The tuberosity occasionaly fractures as a result of forceful contraction of the quadriceps (Hand et al., 1971; Rockwood and Green, 1975).

FIBULA:

Since the fibula does not participate in the actual articulation of the knee joint, the only injuries that are exhibited by this bone are fractures. These fractures can be from direct trauma, or from avulsion of any of the ligaments attaching to the proximal end.

PATELLA:

Injuries and stress to the patella are relatively limited in comparison to the femur and tibia. Fractures and chondromalacia leave the only significant evidence of patellar injury and stress that an individual may have experienced during life.

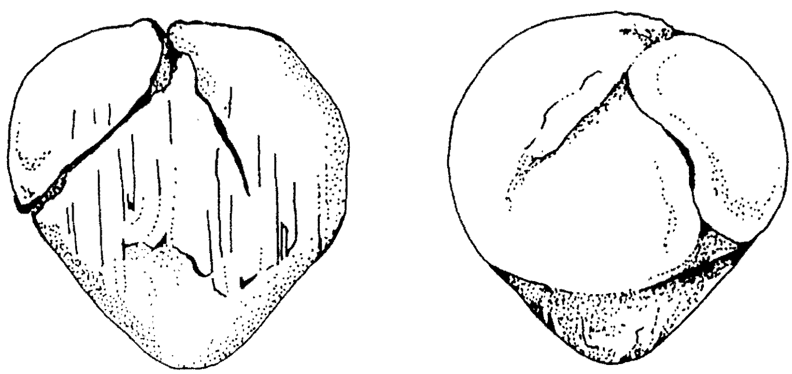

FIGURE 2-15. FRACTURED PATELLA

Patellar fractures sometimes heal without surgical intervention, but the original fracture patterns may remain evident for years (Hughston et al., 1984).

SKELETAL INJURIES IN INFANTS AND CHILDREN

Forensic anthropologists, and society as a whole, must sometimes deal with the deaths of children that are a result of child abuse. For the anthropologist, the recovery and analysis of bones from very young infants and children is a difficult task in itself because the skeletal elements are small, fragile, and often in a precarious state of preservation. The standard procedures for the analyses of age, race, and sex in infants and children have been documented in multiple publications but the examination of the skeletal remains of infants and children for trauma needs special attention.

Antemortem fractures are relatively easy to recognize, even in the tiniest bones. In most cases of documented child abuse, however, only a small (9-11%) percentage of long bone injuries are found (Kleinman, 1987).

Interestingly, in and around the knee joint there are some specific metaphyseal injuries that fit a pattern of skeletal injury unique to child abuse. Indirect torsional, accelerational, and deceleration forces produce the majority of these injuries in infants, and these metaphyseal lesions fit the classic definition of child abuse: There is a radiologic alteration that, regardless of history in an otherwise normal patient, can be viewed as "diagnostic" of nonaccidental injury (Kleinman, 1987: 10)

Radiologists have the advantage of being able to visualize and diagnose these types of injuries in situ. The metaphyses are still connected by non-ossified connective tissues, and all of the other skeletal elements are in relatively normal apposition. The forensic anthropologist, on the other hand, is often faced with tiny fragments of long bones and metaphyses that may or may not be complete. Nevertheless, detailed examination of these metaphyses and their relationships to the ends of the corresponding long bones must be included in the analysis of any infant or small child. If a clinical case of child abuse is documented, it will often be documented radiographically, so there will most likely be a copy of a radiograph in the child's medical record. It would be wise for the anthropologist to obtain radiographs of suspected lesions in any recovered skeletal elements so that these can be compared to any available antemortem records.

The basic anatomical defects or alterations are similar in most cases of child abuse. These may vary somewhat in the degree of involvement and in location, but the bony alterations are strikingly similar in most cases. The metaphyseal "bucket-handle" lesions and "corner" fractures of the distal femur and proximal tibia are shown in figure 2-16.

Details regarding the mechanism of injury that can produce these injuries, and specific histological findings are beyond the scope of this dissertation, but it is not beyond the scope of the forensic anthropologist to be able to recognize and document the presence of these skeletal lesions.

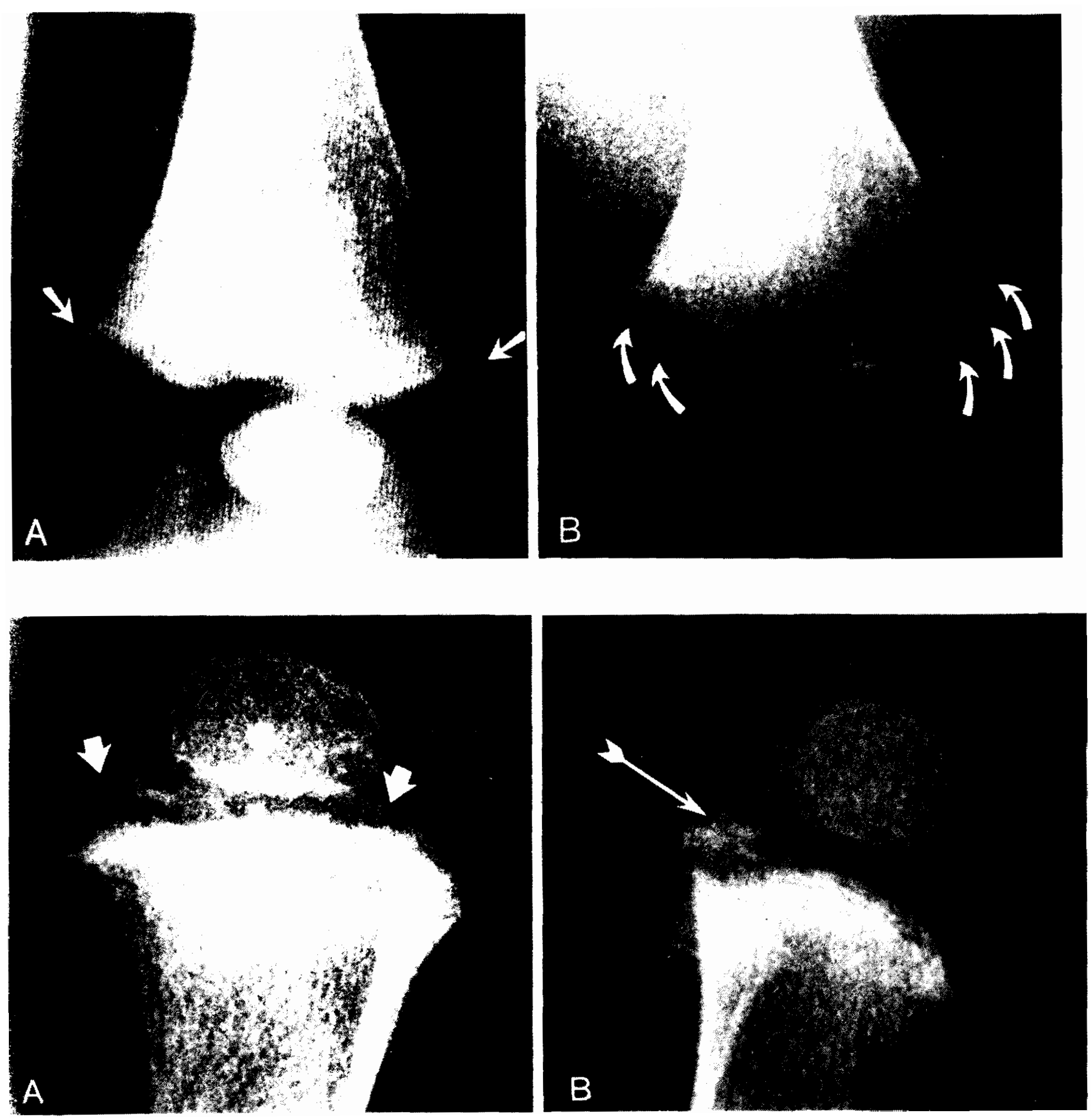

FIGURE 2-16. BUCKET HANDLE DEFECTS AND CORNER FRACTURES

Top photos of a femur show typical corner fractures in A (arrows) and a bucket handle lesion in B (arrows). The bottom photos of a tibia in an abused infant show a bucket handle pattern in A (arrows) and a corner fracture in B (arrow). Reprinted with permission from Kleinman (1987: 19 & 21).

SUMMARY

Evidence of antemortem injury and stress can often be found in skeletal remains. When dealing with the bones of the knee, this evidence can often be linked with information in a patient's medical record, and this in turn can possibly lead to a positive identification.

The biomechanical forces and the changes that they produce in the bony structures are under continual investigation, and research has shown that the amount of healing and remodeling during an individual's lifetime is variable. Nonetheless, the changes are usually sufficient and predictable enough to be a valuable aid in forensic identification.

CHAPTER 3

SURGICAL MODIFICATION OF THE BONES OF THE KNEE

INTRODUCTION

Surgical modifications of the bones around the knee joint are becoming more and more common with the development of new surgical procedures and materials. Evidences of these surgical procedures usually remain as permanent osteological features in the bone. If recognized and correctly classified these evidences can become critical elements in the analysis of skeletal remains of individuals for whom an identification is sought.

The first step is to recognize surgical modifications and to identify individual procedures and pathologies that can be linked to these modifications. The second step is to correlate these findings to the medical histories or medical records of suspected missing persons who match the additional criteria of age, race, sex, and stature of the individual in question.

IDENTIFICATION OF SURGICAL MODIFICATION

Surgical modification can take many forms. Some of these, such as joint replacements and internal fixations are easily recognized because the metal and other synthetic materials are not biodegradable and they usually remain imbedded in the bone. Other modifications are more subtle and often undergo continual remodeling due to the normal physiologic processes described in Chapter 2. In almost all post-operative cases however, some evidence of surgical modification will remain on or in the bone.

DIAGNOSIS AND MEDICAL RECORD INVESTIGATION

The challenge to the forensic anthropologist in regard to the recognition of surgical modifications of the knee is unique. The ultimate goal in forensic analysis is of course identification of the skeletal remains, and more often than not the final identification will be based on the dentition. Sometimes however, evidence from the post-cranial skeleton can provide critical clues for this identification, and in some cases individual features of the knee can provide the investigator with enough evidence to make a positive identification.

In order for the forensic anthropologist to be able to make a determination of surgical modification of the bones of the knee, a thorough knowledge of normal osteology is necessary. The forensic anthropologist should also be able to differentiate surgical modification from the bony modifications that result from knee injury and stress. Both of these subjects were discussed in detail in the first two chapters.

Surgical modification of the bones of the knee can take many forms. Some of these are quite obvious, and others are extremely subtle and can even resemble the patterns of modification associated with knee injury and stress. Orthopaedic surgeons and other medical personnel can be quite helpful when attempting to make a determination of the exact diagnosis in many of these cases. In other cases, the forensic anthropologist must be the one to correlate the skeletal evidence with the medical records of suspected missing persons.

Recognizing and identifying these modifications is just the first step in the identification process, however. The second step is to correlate the surgical modification with the information as it may appear in the medical records of patients. This correlation can become quite complex.

In 1966, the American Medical Association created and published a list of descriptive terms and identifying codes for reporting medical services and procedures performed by physicians. The original purpose of this system of coding and nomenclature was to provide an effective means for reliable communication among physicians, patients, and third parties such as hospital administrative management. This system quickly evolved to incorporate insurance claim forms and today this system has become a universal listing of terms and codes primarily designed to suit the needs of the evaluation and management services of third party payors and government agencies (AMA, 1994).

There are currently two coding systems in common usage in the medical profession. The first is **C.P.T.** (Current Procedural Terminology), and this system is used in physician's offices and hospital outpatient facilities. The other system of coding is **I.C.D.9**, which is the ninth edition of the "International Classification of Diseases". This I.C.D. system is used world wide for the standardization of coding and nomenclature. In the United States, the initials **C.M.** are added, and this then includes the "Clinical Modifications" that are standard in this country's inpatient hospitals. Together this creates the coding system known as "I.C.D.9 - C.M." (I.C.D.9-C.M., 1994).

In order for the forensic anthropologist to correlate skeletal evidence of surgical modification with a possible diagnosis in a medical record, it is important for the anthropologist to be able to communicate with medical records professionals who can access and interpret this system of coding and nomenclature. Once a specific code (or codes) is determined to be appropriate for the case, the evidence can be instantly correlated with the medical record of any suspected missing person. For reference, and easy access, the C.P.T coding and nomenclature for the bones of the knee are listed in APPENDIX I. The I.C.D.9-C.M. codes are listed in APPENDIX II. The listed codes only include those procedures that are likely to create identifiable surgical modifications of the bones of the knee.

FORENSIC APPLICATIONS

The following section will provide basic guidelines and examples to familiarize the reader with some of the most common surgical modifications of the bones of the knee.

As stated earlier in this chapter, some surgical modifications are easily recognized because of dramatic and obvious alterations in the bones. Total joint replacements, permanent metal fixation, and amputations are some examples. Other surgical modifications may not be easily recognized as such. In the forensic setting, drill holes in the articular surfaces, and some ligament repairs can only be identified by looking at radiographs of the recovered skeletal elements. Small bone grafts and abrasion arthroplasty are sometimes difficult if not impossible to differentiate from the changes that occur in response to closed injury and stress at the knee. Hopefully these examples will serve to alert the reader that surgical modifications of the bones of the knee can sometimes provide permanent evidence that can lead to an identification of an unknown individual.

EXAMPLE 1: TOTAL KNEE ARTHROPLASTY.

When an individual undergoes an arthroplasty, one or more of the joint surfaces is/are replaced by an artificial component [FIGURE 3-1]. There are many different types of joint replacement prostheses, and identification of the precise elements used in the procedure can often be made by referring to the catalogs available from manufacturers of these prostheses. Most hospitals keep current catalogs on file in their Central Supply administrative offices. A good reference for the radiologic identification of these devices can be found in the Radiologic Guide to Medical Devices and Foreign Bodies (Hunter and Bragg, 1994)

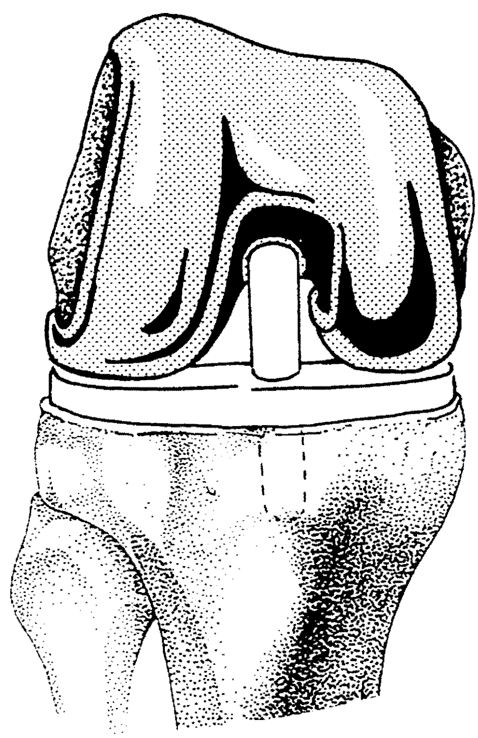

FIGURE 3-1. KNEE ARTHROPLASTY "TOTAL KNEE"

Both condyles of the femur as well as the entire tibial plateau, and often the patella are replaced in a "total knee" procedure. [C.P.T. code: 27447].

EXAMPLE 2: ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION.

Reconstruction of the anterior cruciate ligament has become a relatively common procedure (Hughston, 1993). Ligament repair and augmentation using any combination of techniques can permanently modify the bones of the knee. the modifications of the femur and tibia will be most obvious on radiographs, but the entrance and exit defects of the drill holes should be a clue to the original pathology.

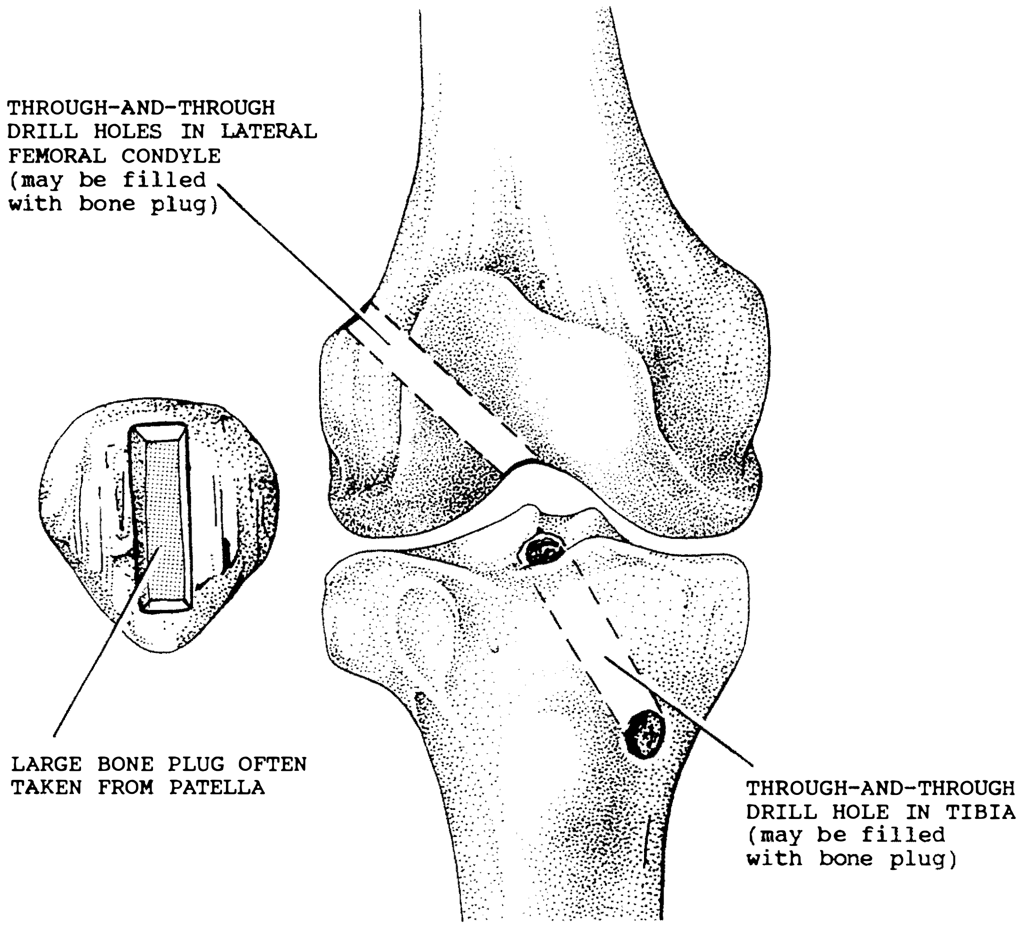

FIGURE 3-2. ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Repair and augmentation of the anterior cruciate will leave tell-tale evidence on the femur, tibia, and/or patella. [CPT codes: 27407, 27409, 27428]

EXAMPLE 3: POSTERIOR CRUCIATE RECONSTRUCTION.

Posterior cruciate reconstruction is not as common as anterior cruciate reconstruction, but it is equally easy to recognize the tell-tale modification of the bone. When posterior cruciate reconstruction involves the femur, the primary drill holes will be in the medial femoral condyle.

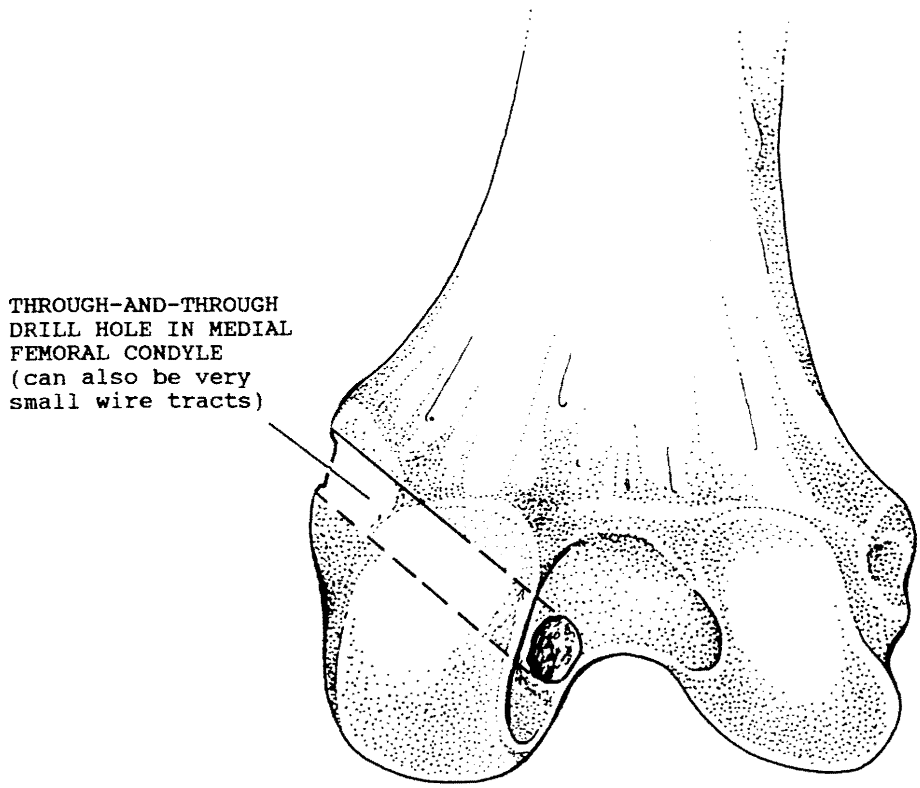

FIGURE 3-3. POSTERIOR CRUCIATE RECONSTRUCTION

Drill holes in the medial femoral condyle can be large, as shown here, or they can be only large enough for one or two tiny Kirschner wires. [C.P.T. codes: 27407, 27409, 27428].

EXAMPLE 4: TIBIAL OSTEOTOMY.

Tibial osteotomies are performed to correct either varus or valgus deformities of the knee. A large wedge of bone is removed just distal to the tibial condyles, and the tibia is usually secured with a metal plate. the upper half of the fibular head is often removed as well.

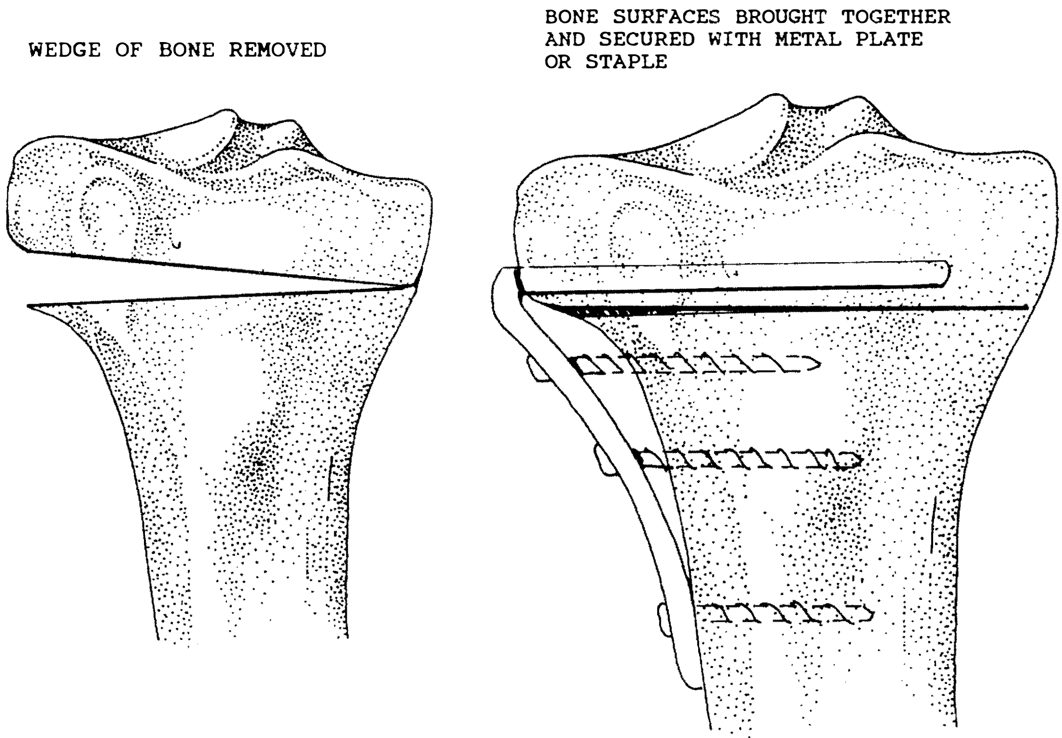

FIGURE 3-4. TIBIAL OSTEOTOMY

The tibia is secured with a metal plate after a wedge of bone is removed. [C.P.T. code: 27455; I.C.D.-9 CM codes: 77.27].

EXAMPLE 5: SUBLUXING PATELLA (HAUSER TYPE)

There are many surgical procedures that are designed to prevent the patella from subluxing (mild dislocation). Most of these procedures involve repositioning the patella ligament more medially on the tibial tuberosity. The procedures that utilize metal staples are obvious, but the procedures that involve simple modification of the tibial tuberosity are sometimes more difficult to recognize. These surgical modifications are much more dramatic than those that result from Osgood-Schlatter's disease or tibial tuberosity microfractures.

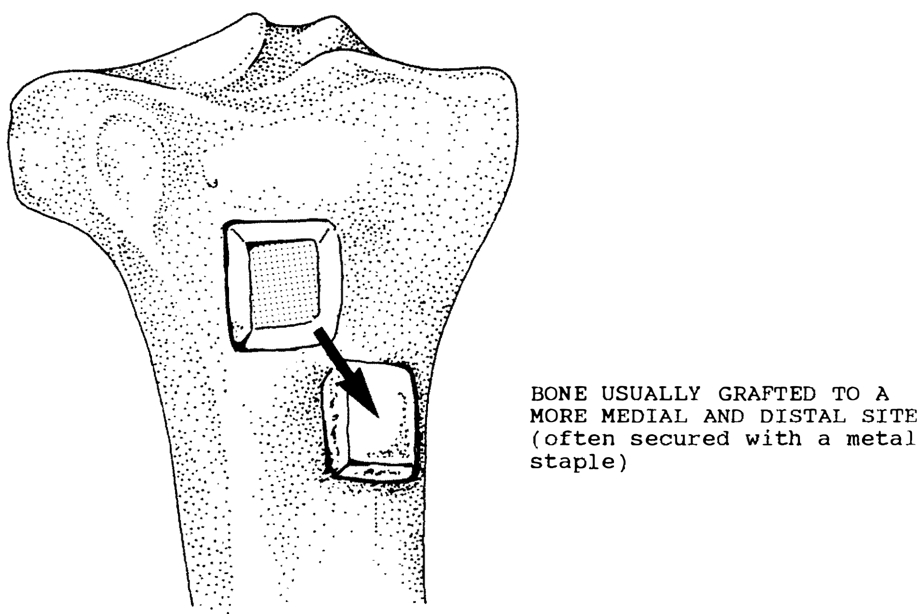

FIGURE 3-5. SUBLUXING PATELLA (HAUSER TYPE)

The Hauser procedure shown here is just one of many different methods used to correct a subluxing patella. [C.P.T. codes 27420, 27418].

SUMMARY

Surgical procedures in and around the knee joint are a frequent occurrence in the United States today. Bony evidence of these procedures, though often quite subtle, will remain for years - sometimes throughout a lifetime. The forensic anthropologist should be familiar with the general bony changes and appearance produced by some of these procedures and should be able to correlate the evidence with information in a medical record. This is one way the recognition of surgical modification of the knee can help lead to a positive identification.

CHAPTER 4

INTERCONDYLAR SHELF ANGLE: A NEW METHOD TO DETERMINE RACE FROM THE DISTAL FEMUR

INTRODUCTION

Modern physical anthropologists have countless methods at their disposal with which to analyze and describe human variation. However, only a few of these methods use analysis of the femur to distinguish aspects of race (Farrally and Moore, 1975; Gilbert, 1976; Lavelle, 1973; Stewart, 1962), and even fewer use metric analysis of the intercondylar notch (Baker et. al., 1990). Baker et al. attempted to find a pattern of racial variation in the height of the anterior outlet of the inter-condylar notch, and their study revealed a slight difference in the average height of the notch between Whites and Blacks in a skeletal sample. To my knowledge, racial variation in the intercondylar shelf angle has not been previously described in the literature, but it stands to reason that differences in the intercondylar shelf angle would correspond to the differences in height of the anterior edge of the intercondylar notch. A more acute angle would result in a higher notch, and a more obtuse angle would result in a lower notch. Therefore, the average intercondylar shelf angle in Blacks should theoretically be more acute than that of Whites, to account for the average differences in notch height between the races [FIGURE 4-1].

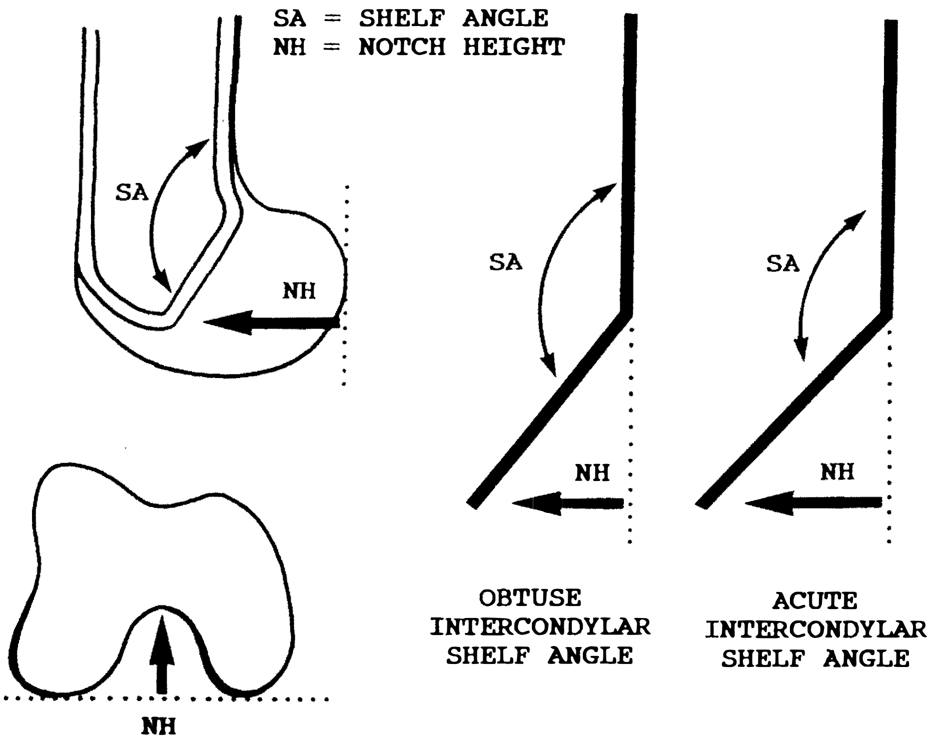

FIGURE 4-1. GRAPHIC REPRESENTATION OF INTERCONDYLAR NOTCH HEIGHT AND INTERCONDYLAR SHELF ANGLE

Variation in the height of the intercondylar notch reflects variation in the angle of the intercondylar shelf. A more acute intercondylar shelf angle will result in a higher notch and vise-versa. The height of the intercondylar notch is dependent on the size of the femur as well as variations in the curvature of the anterior edge of the notch. The intercondylar shelf angle, on the other hand, is independent of these factors.

To test this hypothesis, I measured the angle between the intercondylar shelf and the posterior shaft of the femur in a sample, and I found a relatively consistent and statistically significant difference in this angle between American Whites and Blacks. The difference between the means of the angles is only about ten degrees, and the angles do not always vary consistently between the races, but the difference in the average angle in a large percentage of the population is consistent enough to be used as a valuable tool to help differentiate American Whites from Blacks. This is especially useful in the field of forensic identification where there are so few post-cranial criteria for the reliable determination of race.

ANATOMY

The intercondylar notch is the central fovea in the distal metaphysis of the femur. It is bounded on the lateral side by the lateral femoral condyle and on the medial side by the medial femoral condyle. Anteriorly it extends to the border of the articular cartilage, and posteriorly it extends to the intercondylar line, which separates it from the popliteal surface (Gray, 1973, Hughston, 1993).

In a sagittal section of the femur, the intercondylar shelf can be seen as a line of dense cortical bone that actually forms the "roof" of the intercondylar notch. This area of dense bone can also be seen in a lateral radiograph of the knee, and it appears as a relatively radiopaque line. This line was first described by Blumensaat in 1938 and in clinical studies, this line has often been used as a reference point for the normal position of the patella (Blumensaat, 1938 ; Hughston et al., 1984) [FIGURE 4-2].

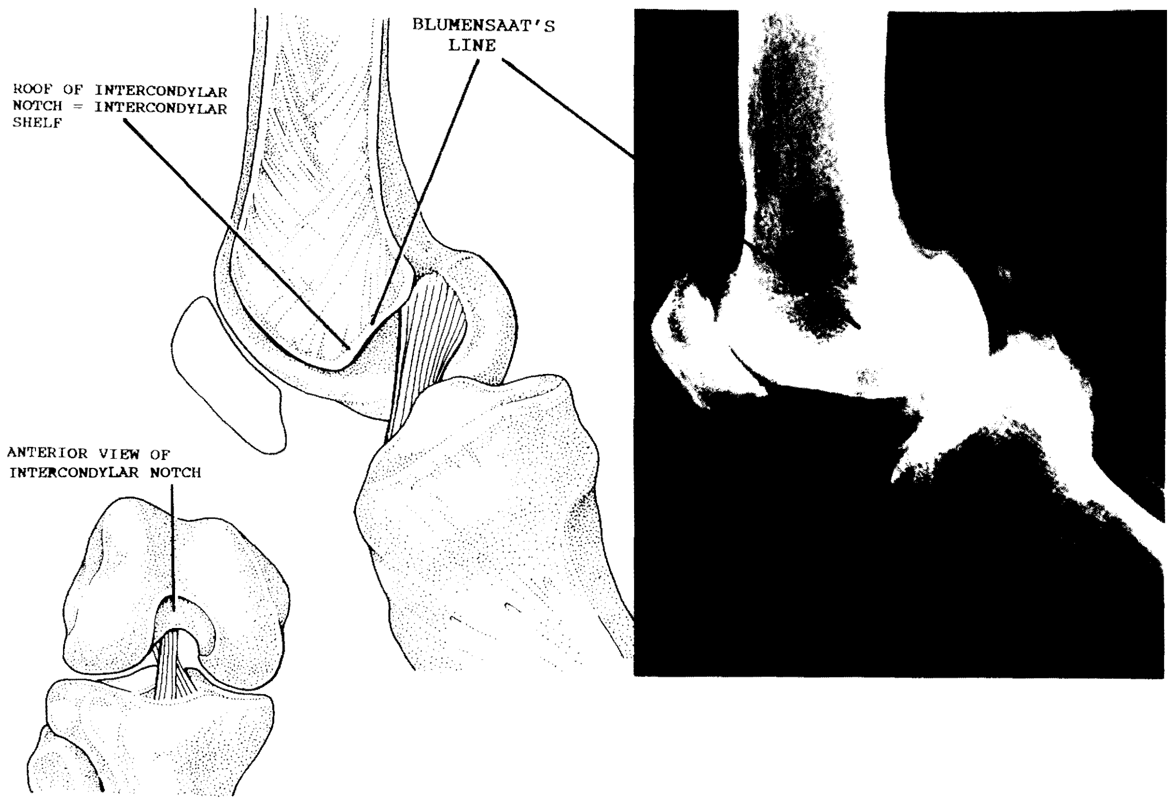

FIGURE 4-2. SAGITTAL SECTION OF A RIGHT FEMUR AND A LATERAL RADIOGRAPH OF A RIGHT KNEE

This shows the intercondylar shelf in relation to the intercondylar notch and Blumensaat's line. The lateral radiograph of a knee shows how comparative changes in opacity correspond to anatomical structures.

MATERIALS AND METHODS

PATIENT SAMPLE:

A list of 87,000 knee patients was obtained from the Hughston Orthopaedic Clinic in Columbus, Georgia (85,000) and from the University of Tennessee Medical Center in Knoxville, Tennessee (2,000). From the list in Georgia, a restricted random sample of 200 White and 200 Black patients was generated, and from the list in Tennessee, a restricted random sample of 100 of each race was obtained. Lateral radiographs were retrieved for all 600 patients.

Radiographs from 177 individuals were excluded because of various factors such as the presence of a total joint replacement, malalignment of the distal femur due to trauma, and/or poor visualization of Blumensaat's line due to exposure error. The final sample consisted of 423 individuals. All of these individuals had requested medical evaluation for a variety of complaints relative to the knee. In the sample from Tennessee, 73% of the patients were victims of trauma, primarily motor vehicle accidents. In the sample from Georgia, almost all of the patients had x-rays of the asymptomatic knee included with their initial knee exam. For the test of the intercondylar shelf angle, only one knee from each individual was analyzed. In cases where the asymptomatic knee was documented in the patient's chart, that knee was selected for analysis of the intercondylar notch angle. In the remaining cases the right knee was used if it was present, otherwise the left knee was used. The sample included 240 Whites and 183 Blacks, 235 males and 188 females. Because of the size and the nature of the sample, it can be considered a sample of the normal population.

Each radiograph was placed on a light box, and positioned as if the anterior of the knee was facing to the left. This was to avoid any possible measuring bias from the positioning of the instruments. A metal ruler was aligned with one edge against the distal one-third of the femur parallel to the posterior cortex of the bone, and a line was drawn with a grease pencil along the opposite edge of the ruler. The ruler was then placed so that one edge went through Blumensaat's line in a "best-fit" alignment. A second line was then drawn along the edge of the ruler through Blumensaat's line. A goniometer was placed over the intersection of these two lines, and the interior angle was measured [FIGURE 4-3]. The intercondylar shelf angle was recorded and was written along with the patient's I.D. number and date of birth on a master log. The presence or absence of a fabella and anterior cruciate tear was also noted and recorded. At the completion of each measurement session, the patient's race and sex were added to the master log [APPENDIX III]. The race and sex of the individual was intentionally ommitted from the record until after the angle was recorded, in order to avoid any unintentional bias in marking the radiographs or in measuring the angle.

FIGURE 4-3. LATERAL RADIOGRAPH OF THE KNEE

One mark should parallel the posterior shaft of the femur. The distance of the mark from the shaft of the femur is not important: The objective is to simply avoid having the mark intersect directly through Blumensaat's line on the radiograph The second mark should be drawn in a "best fit" directly through Blumensaat's line. Determine the intercondylar shelf angle by simply measuring the angle created by these two lines.

All of the information from these patients was then analyzed to find the amount of variation in a sample population. A repeatability study was also conducted.

SKELETAL SAMPLE:

In order to test the hypothetical method of determining race from the intercondylar shelf angle, the same method of measurement was applied to a skeletal sample. A total of 67 individuals were randomly selected from the William Bass donated skeletal collection. The bones of these individuals are kept in boxes in the osteology laboratory at the University of Tennessee. One box contains one individual, and from each box that contained a right femur, that femur was removed. These were then placed collectively into another box for transport. These bones had all been marked with an identification number when they were accessioned into the collection, so there was no danger of misidentification. Only this identification number was entered on the master log, and all 67 of these femora were taken en masse to the Student Health Center where they were x-rayed.

Positioning of each femur was critical because it was necessary to get a lateral view that closely approximated the true lateral seen in the patient radiographs. Patients are routinely radiographed after their knee has been precisely positioned in reference to anatomical landmarks on the ankle, hip and knee. In order to obtain a similar alignment, I used a 14X17 inch sheet of foam rubber "egg crate" material that was approximately 6 inches thick. A femur could be placed across the sheet and it would fit in between the ridges and the bone could then be rotated to a true lateral position. After some experimentation, it was apparent that the best placement of the femur was to have the medial femoral condyle up, away from the table. In this position, the femur could be rotated so that none of the lateral femoral condyle could be seen from a position directly above the table. This gave the best overall lateral image [FIGURE 4-4].

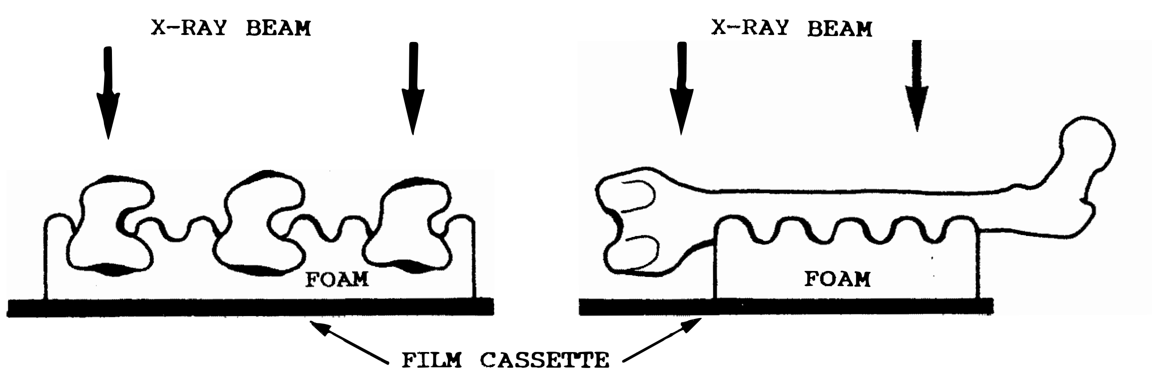

FIGURE 4-4. POSITIONING SEVERAL FEMORA FOR X-RAY

Several femora can be x-rayed at one time by arranging them on "egg crate" foam over a large cassette. A true lateral can be achieved if the femoral condyles are parallel and directly in line with the x-ray beam.

For this test, four femora were x-rayed at a time, over a cassette containing a sheet of 14x17 radiographic film. The identification number of each femur was marked with radiopaque letters at the time of exposure, and all four femora were exposed at 100 m.A. for 1/30 sec. at 54 k.V.. The radiographs from this test sample were measured using the same method described for the patient sample.

The best radiographic technique for individual forensic cases is a simple laterally-directed x-ray beam. Lay the femur flat on top of a cardboard box or similar radio-lucent platform, and expose the film as shown in figure 4-5A. If the femur is broken, or if there is significant articular trauma, a small piece of foam or cloth will support it well enough to get a good lateral view [FIGURE 4-5B].

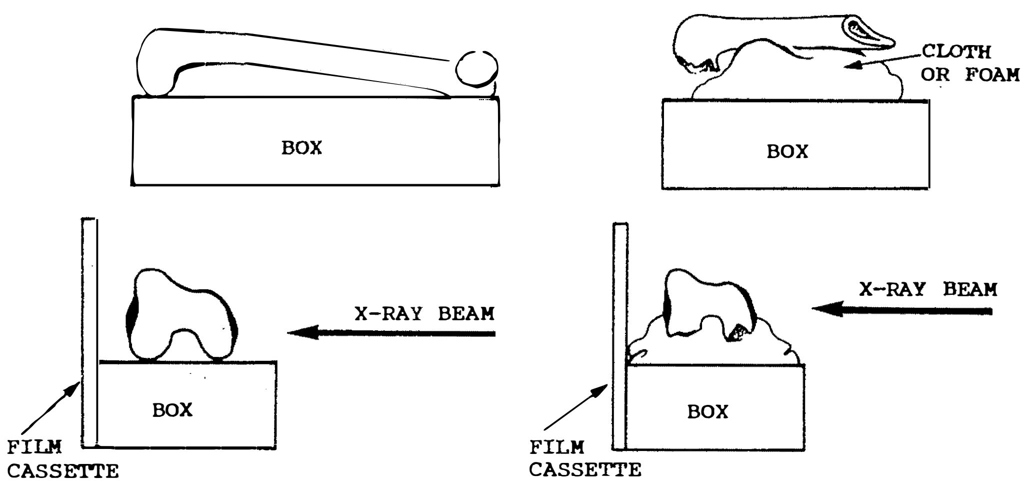

FIGURE 4-5. POSITIONING OF A SINGLE FEMUR FOR X-RAY

A) A single femur can be placed on top of a radiolucent box, as shown.
B) A broken or partial femur can be propped up on foam or cloth.

RESULTS

PATIENT SAMPLE:

The data from the patient sample was entered into the University of Tennessee's VAX computer system. T-TEST procedures were performed to find the mean, standard deviations, and p-values for race and sex [APPENDIX IV]. Sex was included as a variable in order to determine if the angle varied by sex as well as race. The results are shown in Figure 4-6, and summarized below. A discriminant analysis was used (Crow et al., 1960) to determine the ability to classify race, given the angle and those results are included in this summary .

OVERALL BY RACE: The overall White mean was 146 degrees (std. dev. 4.29) and the Black mean was 138 degrees (std. dev. 4.18). This difference is highly significant ($p < .0001$) and yields a correct classification of 83%.

OVERALL BY SEX: The overall mean for females is 142.58 degrees (std. dev. 6.30) and the overall mean for males is 142.54 degrees (std. dev 5.6114). The difference here is almost non-existent. The angle is based on SHAPE not SIZE.

FEMALES: The mean for White females is 147 degrees (std. dev. 4.31) and the mean for Black females is 137 degrees (std. dev. 4.14). This difference is highly significant ($p < .0001$) and yields a correct classification of 88%.

MALES: The mean for White males is 146 degrees (std. dev. 4.25) and the mean for Black males is 138 degrees (std. dev. 4.16). This difference is highly significant ($p < .0001$) and yields a correct classification of 83%.

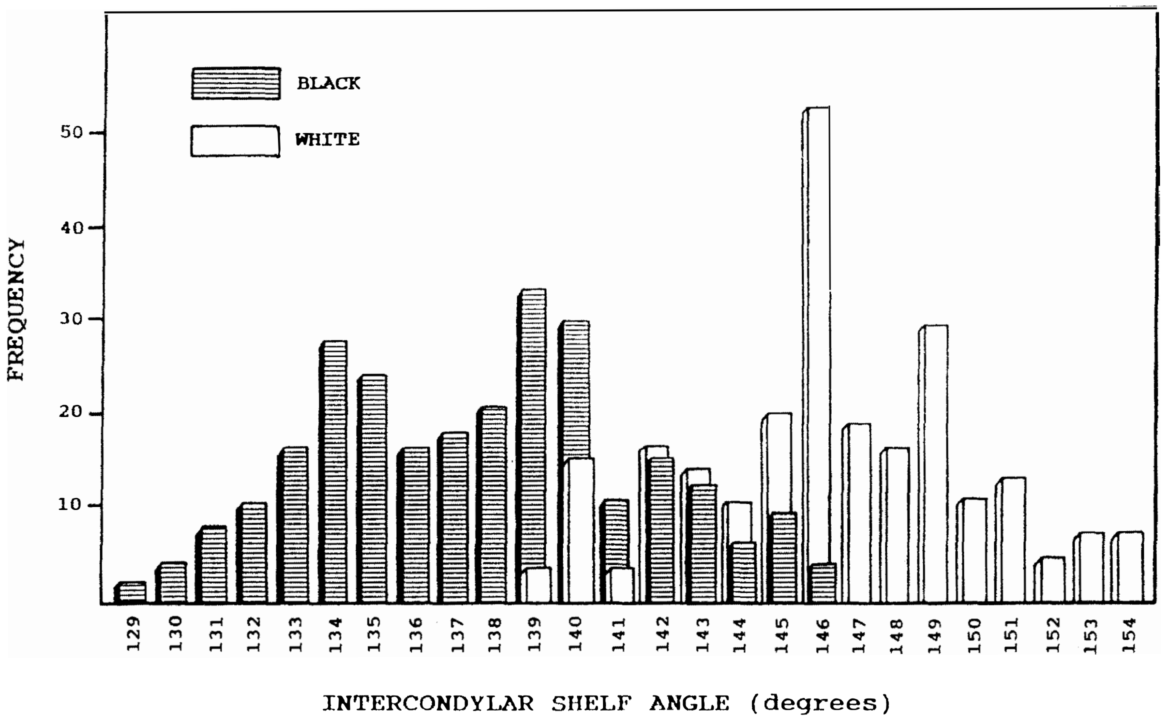

FIGURE 4-6. HISTOGRAM OF THE SHELF ANGLES FROM THE PATIENT SAMPLE OF 423 KNEES

The mean for the intercondylar shelf angle in Whites is 146.2 degrees and the mean for Blacks is 137.8 degrees. The sectioning point is 141 degrees. Eighteen percent of the sample overlapped across the sectioning point. (Data shown in APPENDIX IV)

SKELETAL SAMPLE:

The data from the skeletal sample was not initially entered into the computer system. This was designed to be a blind test of the ability to classify race based only on the intercondylar shelf angle. Since this was a relatively small sample, I divided the method of analysis into 2 different components in an attempt to find the optimal method of analysis [APPENDIX VI].

The first test included 46.3% of the sample and only involved those individuals whose notch angle was equal to or beyond the mean for each race. Those whose notch angle was 146 degrees or greater were classified as White. Those whose notch angle was 138 degrees or less were classified as Black. Twenty-eight individuals, or 90% of the involved individuals were correctly classified.

For the second test, the entire sample was classified. The sectioning point for this test was 141 degrees. Anyone with a notch angle of 142 degrees or greater was classified as White and anyone with a notch angle of 141 degrees or less was classified as Black. Fifty-seven individuals, 85% of the entire sample were correctly classified [TABLE I].

TABLE I

RESULTS OF THE BLIND TEST ON THE SKELETAL SAMPLE

	I	II
	>145=W <139=B	142 & OVER=W
TOTAL CLASSIFIED	31	67
% OF TOTAL SAMPLE	46	100
CORRECT CLASSIFICATION	28	57
INCORRECT CLASSIFICATION	3	10
PERCENT CORRECT	90	85

DISCUSSION

The intercondylar shelf angle shows variation between American Whites and Blacks, and is an effective new method for post-cranial metric analysis.

There are, however, several factors that need to be discussed in regard to the measurement and analysis of the angle as well as the angle itself.

First of all, the measurement of the radiographs in the patient sample was based on lateral radiographs of the knees of living patients. In the clinical situation, the leg and knee are positioned in reference to specific anatomical landmarks and the rotation of the entire limb can be controlled. With this amount of control, the alignment of the leg and femur almost always results in a "true lateral" radiograph, and the position of Blumensaat's line is consistently correct.

The lateral radiographic method shown in figure 4-5 is the only way to consistently achieve a "true lateral" with a single femur specimen. When the femora from the skeletal collection were positioned and x-rayed, the "true lateral" was more difficult to achieve but because of the morphology of the intercondylar shelf in relation to the posterior shaft of the femur, there was very little variation in the ANGLE even when the femur was slightly rotated.

One very encouraging finding with this method is that measuring the intercondylar notch angle is a relatively easy and straight forward procedure. Once the landmarks are located and marked, the angle is simply measured with a goniometer, protractor, or any similar device.

In the test for interobserver error, the variation among the observers averaged less than 1 degree. Three people (a radiology resident, myself, and another anthropology PhD student) independently marked and measured the intercondylar shelf angle on 23 patient radiographs, according to the method described earlier. The lines were removed from the radiographs between each observer's measurements [APPENDIX VII].

The primary problem still lies with the analysis of those individuals whose intercondylar shelf angle approaches or overlaps the sectioning point. This overlap in measurements between the two races is a typical problem in forensic identification, and is a problem in anthropology in general.

In spite of these problems, however, there are some advantages to this new method. One advantage of this method of measuring the intercondylar shelf angle instead of the height of the notch is that fragmentary femora can be measured, and the angle of the intercondylar notch is not affected by periarticular arthritis or articular trauma.

The intercondylar shelf angle is also not affected by the size, length, or overall curvature of the femur. The femora of Blacks are generally longer (Trotter and Gleser, 1952) and have less anterior curvature than those of Whites (Stewart, 1962), so when the anterior outlet is measured with the femur lying on a flat surface (as described by Baker et al., 1990), the degree of curvature would undoubtedly create a corresponding increase or decrease in height (Baker et. al., 1990). The question of curvature of the femur was considered as a possible variable in the measurement of the intercondylar shelf angle, and has been temporarily dismissed. If the curvature is eventually included in the angle analysis, it will only serve to enhance the acute and obtuse angles in the respective races.

SUMMARY

The intercondylar shelf angle is a radiographic feature of the distal femur that can be used to help determine the race of an individual. In a blind test of the method in a skeletal sample, the results were excellent. Any criteria, especially in the post-cranial skeleton that can be used to help determine the race of an individual should be considered valuable.

In addition to the ability to classify Whites and Blacks, a primary advantage of this method is that it is a single measurement that is easy to obtain, and it is not dependent on the size of the femur. This measurement can be taken regardless of periarticular pathology or trauma to the articular surfaces.

The variation in the intercondylar notch angle is functionally significant because the intercondylar shelf has been proven to limit extension of the knee (Norwood and Cross, 1977). Speculation on the reasons for, and the evolution of this variation have only just begun.

CONCLUSION

The bones of the knee have often been overlooked as key elements in the science of forensic identification. It is not because they hold no information, but because other skeletal elements usually contain the most obvious indicators regarding the age, race, and sex of an unknown individual. In some cases however, the bones of the knee can often provide the answer to the puzzle of victim identification. More likely than not, evidence regarding the bones of the knee will simply lead to an entry in a person's medical record which will in turn lead to more and more information regarding someone's identity.

Before any of this can take place, a thorough knowledge of the "clinical" osteology of these bones is necessary. Then and only then can abnormalities be recognized and diagnosed in reference to antemortem modifications. Hopefully the first three chapters give the reader the essential information for this type of analysis.

The fourth chapter is a summary of an original research project that has uncovered and documented a heretofore unrecognized difference between American Whites and Blacks. This is one feature of the post cranial skeleton that hopefully will prove to be invaluable in years to come.

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APPENDIX

APPENDIX I

C.P.T. CODING OF KNEE TREATMENTS (AMA, 1994)

TREATMENT	CODE
Insertion of wire or pin with application of skeletal traction	20650
Application of a uniplane (pins or wires in one plane) unilateral, external fixation system	20690
Application of multiplane (pins or wires in more than one plane) unilateral fixation system	20692
Bone graft, any donor area, minor or small	20900
major or large	20902
Unlisted procedure, musculoskeletal system, general	20999
Patellectomy or hemipatellectomy	27350
Partial excision (craterization, saucerization, or diaphysectomy) of bone, femur, proximal tibia and/or fibula	27360
Radical resection for tumor, femur or knee, bone	27365
Repair, primary, torn ligament and/or capsule, knee; collateral	27405
with cruciate	27407
Collateral and cruciate ligaments	27409
Anterior tibial tubercleplasty for chondromalacia patella	27418
Reconstruction for recurrent dislocating patella (Hauser type procedure)	27420
with patellectomy	27424
Ligamentous reconstruction (augmentation), knee extra-articular	27428
intra-articular	27428
intra-articular and extra-articular	27429

Arthroplasty, patella; with prosthesis	27438
Arthroplasty, knee, tibial plateau	27440
Arthroplasty, knee, femoral condyles or tibial plateaus	27442
Arthroplasty, knee, constrained prosthesis	27445
Arthroplasty, knee, condyle and plateau; medial or lateral compartment	27446
medial AND lateral compartments with or without patella resurfacing ("total knee replacement")	27447
Osteotomy, femur, shaft or supracondylar; without fixation	27448
with fixation	27450
Osteotomy, proximal tibia, including fibular excision or osteotomy before epiphyseal closure	27455
after epiphyseal closure	27457
Epiphyseal arrest by epiphysiodesis or stapling; distal femur	27457
tibia and fibula	27477
combined distal femur, proximal tibia and fibula	27485
Arrest, hemiepiphyseal, distal femur or proximal leg	27485
Revision of total knee arthroplasty, with or without allograft	27486
all components	27487
Removal of knee prosthesis, including "total knee"	27488
Prophylactic treatment (nailing, pinning, plating, or wiring) with or without methylmethacrylate, femur	27495
Closed treatment of supracondylar or transcondylar femoral fracture with or without intercondylar extension	27501

Percutaneous skeletal fixation of femoral fracture, distal end, medial or lateral condyle, or supra-condylar or transcondylar, with or without inter-condylar extension, or distal epiphyseal separation	27509
Closed treatment of femoral fracture, distal end, medial or lateral condyle, without manipulation	27508
with manipulation	27510
Open treatment of femoral fracture, distal end, with or without internal or external fixation	27514
Closed treatment of distal femoral femoral epiphyseal separation, without manipulation	27516
with manipulation, with or without skeletal traction	27517
Open treatment of distal femoral epiphyseal separ-ation, with or without internal or external fixation	27519
Closed treatment of patellar fracture	27520
Open treatment of patellar fracture, with internal fixation and/or partial or complete patellectomy	27524
Closed treatment of tibial fracture, proximal (plateau)	27530
with skeletal traction	27532
Open treatment of tibial fracture, proximal (plateau) with or without internal or external fixation	27535
bicondylar, with or without internal fixation	27536
Closed treatment of intercondylar spine(s) and/or tuberosity fracture(s) of knee	27538
Open treatment of intercondylar spine(s) and/or tuberosity fracture(s) of the knee, with or without internal or external fixation	27540
Open treatment of knee dislocation, with or without internal fixation	27556
Fusion of knee, any technique	27580
Amputation, thigh, through femur, any level	27590

Disarticulation at knee	27598
Unlisted procedure, femur or knee	27599
Osteotomy, tibia (proximal)	27705
Osteotomy, fibula	27707
tibia and fibula	27709
multiple, with realignment on intramedullary rod	27712
Closed treatment of proximal fibula or shaft fracture	27780
Open treatment of proximal fibula or shaft fracture with or without internal or external fixation	27784
Open treatment of proximal tibiofibular joint dislocation, with or without internal fixation, or with excision of proximal fibula	27832
Arthodesis, tibiofibular joint, proximal or distal	27871
Amputation of leg, through tibia and fibula	27880
Arthroscopic abrasion arthroplasty or multiple drilling	29879
drilling for osteochondritis dissecans with bone grafting with or without internal fixation	29885
drilling for intact osteochondritis dissecans lesion	29886
drilling for intact osteochondritis dissecans lesion with internal fixation	29887

APPENDIX II

I.C.D.-9 CM CODING OF KNEE TREATMENTS

TREATMENT	CODE
Sequestrectomy	77.00
Femur	77.05
Patella	77.06
Tibia/Fibula	77.07
Other incision of bone without division	77.10
Femur	77.15
Patella	77.16
Tibia/Fibula	77.17
Wedge osteotomy	77.20
Femur	77.25
Patella	77.26
Tibia/Fibula	77.27
Other division of bone	77.30
Femur	77.35
Patella	77.36
Tibia/Fibula	77.37
Biopsy of Bone	77.40
Femur	77.45
Patella	77.46
Tibia/Fibula	77.47
Local excision of lesion or tissue or bone	77.60
Femur	77.65
Patella	77.66
Tibia/Fibula	77.67
Excision of bone for graft	77.70
Femur	77.75
Patella	77.76
Tibia/Fibula	77.77
Other partial ostectomy	77.80
Femur	77.85
Patella	77.86
Tibia/Fibula	77.87
Total ostectomy	77.90
Femur	77.95
Patella	77.96
Tibia/Fibula	77.97

Bone graft	78.00
Femur	78.05
Patella	78.06
Tibia/Fibula	78.07
Application of external fixation device	78.10
Femur	78.15
Patella	78.16
Tibia/Fibula	78.17
Limb shortening procedures	78.20
Femur	78.25
Patella	78.26
Tibia/Fibula	78.27
Limb lengthening procedures	78.30
Femur	78.35
Patella	78.36
Tibia/Fibula	78.37
Other repair or plastic operations on bone	78.40
Femur	78.45
Patella	78.46
Tibia/Fibula	78.47
Internal fixation of bone without fracture reduction	78.50
Femur	78.55
Patella	78.56
Tibia/Fibula	78.57
Removal of implanted devices from bone	78.60
Femur	78.65
Patella	78.66
Tibia/Fibula	78.67
Osteoclasis	78.70
Femur	78.75
Patella	78.76
Tibia/Fibula	78.77
Closed reduction of fracture without internal fixation	79.00
Femur	79.05
Tibia/Fibula	79.07
Closed reduction of fracture with internal fixation	79.10
Femur	79.15
Tibia/Fibula	79.17

Open reduction of fracture without internal fixation..	79.20
Femur	79.25
Tibia/Fibula	79.27
Open reduction of fracture with internal fixation.....	79.30
Femur	79.35
Patella	79.36
Tibia/Fibula	79.37
Closed reduction of separated epiphyses	79.40
Femur	79.45
Tibia/Fibula	79.47
Open reduction of separated epiphyses	79.50
Femur	79.55
Tibia/Fibula	79.57
Debridement of open fracture site	79.60
Femur	79.65
Tibia/Fibula	79.67
Closed reduction of dislocation	79.70
knee	79.76
Open reduction of dislocation	79.80
knee	79.86
Unspecified operation on bone injury	79.90
Femur	79.95
Patella	79.96
Tibia/Fibula	79.97

APPENDIX III

DATA FROM 423 INDIVIDUAL KNEES

(Clinic, ID #, Race, Sex, D.O.B., Shelf Angle, R/L, Fabella, Anterior cruciate tears)

H	075768	w	m	1969	140	r	n	.
H	075634	w	m	1967	145	r	n	.
H	075619	w	m	1966	145	r	n	.
H	000200	w	m	1947	148	r	n	.
H	000264	w	m	1980	155	l	n	.
H	000340	w	m	1931	142	r	n	.
H	004026	w	m	1918	150	r	y	.
H	000453	w	m	1942	146	r	n	.
H	004091	w	m	1951	150	l	n	.
H	004117	w	m	1950	152	r	y	.
H	004127	w	m	1949	140	l	n	y
H	004131	w	m	1944	146	r	n	.
H	022580	w	m	1921	146	r	n	.
H	022601	w	m	1946	144	l	n	.
H	002581	w	m	1917	147	r	n	.
H	022570	w	m	1918	146	r	n	.
H	000018	w	f	1948	145	l	n	.
H	000136	w	f	1926	145	l	n	.
H	000270	w	f	1948	143	l	n	.
H	000331	w	f	1980	151	r	n	.
H	000334	w	f	1920	150	r	n	.
H	022644	w	f	1925	150	r	n	.
H	022646	w	f	1955	145	r	n	.
H	022574	w	f	1932	150	r	n	.
H	204079	b	m	1971	133	l	n	.
H	202548	b	m	198[illegible]	136	r	n	.
H	005390	b	m	1927	136	r	n	.
H	008563	b	m	1947	141	l	n	.
H	014616	b	m	1947	132	r	n	.
H	017820	b	m	1933	135	l	n	.
H	00	b	m	1945	130	r	n	.
H	000	b	m	1925	140	r	n	.
H	0000	b	m	1925	143	l	n	.
H	001905	b	f	1927	131	l	n	.
H	009637	b	f	1917	145	r	n	.
H	014115	b	f	1924	140	r	n	.
H	014308	b	f	1920	138	r	n	.
H	015282	b	f	1931	136	r	n	.
H	018866	b	f	1949	138	r	n	.
H	018987	b	f	1927	136	r	n	.
H	019311	b	f	1918	145	r	n	.
H	027832	b	f	1931	145	r	n	.
H	026678	b	f	1921	140	l	y	.
H	025848	b	f	1934	129	l	n	.
H	025217	b	f	1934	143	l	n	.
H	064003	w	m	1998	149	l	n	y
H	064243	w	m	1998	147	l	n	y
H	067437	w	m	1998	148	r	n	y
H	068910	w	m	1998	152	l	n	y
T	676790	b	m	1973	137	l	n	y
T	686797	w	f	1932	150	r	n	.
T	698942	w	f	1942	147	r	n	.
T	686676	w	f	1973	147	r	n	.
T	717180	b	m	1951	136	l	n	.
T	754470	w	f	1966	147	l	n	.
T	675825	w	m	1998	145	r	y	.
T	346551	w	m	1998	150	l	n	.
T	628145	w	f	1998	146	r	n	.
T	676108	w	f	1968	140	r	n	.
T	696990	w	m	1957	145	r	n	.
T	679974	w	m	1950	149	l	n	.
T	692724	w	m	1970	137	l	n	.
T	695539	b	f	1966	140	r	n	.
T	698469	w	m	1963	146	l	n	.
T	648905	w	f	1936	147	r	y	.
T	377725	w	f	1968	150	r	n	.
T	654856	w	m	1922	142	l	y	.
T	727501	w	m	1961	155	r	n	.
T	663562	w	m	1971	145	r	n	.
T	666944	w	f	1998	144	r	y	.
T	696852	w	m	1951	150	r	n	.
T	672094	w	m	1938	155	l	n	.
T	679251	w	m	1926	146	r	n	.
T	718527	w	f	1932	144	l	n	.
T	358281	w	f	1944	150	r	n	.
T	720155	w	f	1922	151	r	n	.
T	720501	w	m	1968	145	r	n	.
T	630544	w	f	1920	134	l	n	.
T	506088	w	f	1954	135	l	n	.
T	707890	b	f	1958	133	l	n	.
T	721644	w	m	1972	144	l	n	.
T	721767	w	m	1961	134	l	n	.
T	504724	w	m	1957	141	l	n	.
T	722075	w	m	1977	145	l	n	.
T	725494	w	m	1955	146	l	n	.
T	726933	w	f	1976	150	r	n	.
T	661333	w	f	1964	145	l	n	.
T	691873	w	m	1946	141	l	n	.
T	359776	w	m	1940	143	l	n	.
T	525570	w	f	1980	135	r	n	.
T	365235	w	f	1956	141	l	n	.
T	691463	b	f	1979	141	l	n	.
T	376017	b	m	1957	138	r	n	.
T	731877	w	m	1998	143	r	n	.
T	717152	w	f	1914	151	r	n	.
T	717073	b	m	1967	133	l	n	.
T	714299	w	f	1971	140	r	n	.
T	648279	w	f	1974	144	r	n	.
T	715191	b	m	1971	140	r	n	.
T	670516	w	m	1925	151	r	n	.
T	712589	w	f	1912	145	l	n	.
T	392482	b	f	1964	141	r	n	.
T	713444	w	m	1960	140	l	n	.
T	714090	w	m	1968	147	r	n	.
T	688919	w	m	1960	145	l	n	.
T	336166	b	m	1998	135	l	n	.
T	397947	b	m	1950	138	l	n	.
T	717546	w	m	1976	147	l	n	.
T	682839	w	f	1973	150	r	n	.
T	718097	w	f	1977	150	r	n	.
T	405044	w	f	1929	152	l	n	.
T	378119	b	f	1961	141	r	y	.
T	694415	w	f	1949	147	l	n	.
T	699494	w	f	1962	153	r	n	.
T	680496	w	m	1971	140	r	n	.
T	703336	w	m	1947	145	r	n	.
T	712136	w	f	1943	145	r	y	.
T	705841	w	f	1953	145	l	n	.
T	708940	w	m	1972	145	r	n	.
T	355953	w	m	1914	145	r	y	.
T	704649	w	f	1963	138	l	n	.
T	624101	w	f	1961	152	r	y	.
T	731515	w	m	1967	141	r	n	.
T	686153	w	f	1931	150	r	y	.
T	685425	b	m	1969	135	l	n	.
T	353343	b	m	1955	139	l	n	.
T	000000	w	f	1955	150	r	n	.
T	574846	w	m	1998	150	l	n	.
T	581104	w	f	1968	150	r	n	.
T	688607	w	m	1958	148	r	n	.
T	589572	w	f	1931	152	r	y	.
T	554824	w	m	1965	150	r	n	.
T	688111	w	f	1977	149	l	n	.
T	559835	w	f	1959	150	l	n	.
T	688271	w	f	1963	140	l	n	.
T	688392	w	m	1957	149	l	n	.
T	688446	w	f	1973	150	l	n	.
T	572021	w	m	1975	140	r	n	.
T	741691	w	f	1980	150	r	n	.
T	688688	w	f	1971	149	l	n	.
T	623740	w	f	1933	145	l	n	.
T	599772	w	f	1998	151	r	n	.
T	724787	b	m	1973	132	l	n	.
T	688890	w	f	1952	143	l	n	.
T	612987	w	m	1943	153	r	n	.
T	469345	w	m	1918	145	l	n	.
T	612987	w	m	1943	153	r	n	.
T	469345	w	m	1968	141	r	n	.
T	610410	w	m	1952	143	r	n	.
T	703398	w	m	1946	136	l	n	.
T	689600	w	m	1969	141	l	n	.
T	689590	w	m	1952	146	r	n	.
T	624793	w	f	1943	150	r	n	.
T	732090	w	m	1968	143	l	n	.
T	621317	w	f	1998	150	l	n	.
T	468212	w	f	1920	146	r	n	.
T	731594	w	m	1974	142	r	n	.
T	468543	w	m	1917	146	l	n	.
T	626037	w	f	1965	144	l	n	.
T	626549	w	f	1964	142	l	n	.
T	105548	w	f	1966	152	r	n	.
T	629350	w	m	1923	156	r	y	.
T	689665	w	m	1936	142	l	n	.
T	689631	w	f	1958	149	r	n	.
T	689377	w	f	1964	152	r	n	.
T	620441	w	f	1961	145	r	n	.
T	469055	w	m	1924	145	r	n	.
T	689130	w	m	1965	150	l	n	.
T	688928	w	m	1967	145	r	n	.
T	688897	w	m	1972	144	r	n	.
T	688826	w	m	1960	135	l	n	.
T	600545	w	f	1953	145	r	n	.
T	688681	w	f	1973	150	l	n	.
T	592780	w	m	1973	146	l	n	.
T	688679	w	m	1974	145	l	n	.
T	688619	w	f	1973	147	l	n	.
H	154884	b	m	1970	141	r	n	.
H	155128	b	m	1969	144	l	n	.
H	155292	b	f	1998	136	r	n	.
H	155381	b	f	1970	137	r	n	.

APPENDIX III, continued:

H 012682	b	m	1905	142	r	n	.
H 020731	b	m	1905	139	l	n	.
H 020832	b	m	1907	144	r	y	.
H 024570	b	m	1913	146	l	y	.
H 041343	b	m	1906	140	r	y	.
H 066932	b	m	1914	140	l	y	.
H 086174	b	m	1914	134	r	n	.
H 087959	b	m	1909	149	l	n	.
H 095171	b	m	1911	140	r	y	.
H 134587	b	m	1915	138	l	y	.
H 131121	b	m	1910	140	r	n	.
H 130900	b	m	1914	140	l	y	.
H 124070	b	m	1915	138	r	n	.
H 123235	b	m	1913	140	r	n	.
H 121678	b	m	1900	140	r	n	.
H 120549	b	m	1907	140	r	y	.
H 102761	b	m	1910	134	r	y	.
H 172324	b	m	1911	145	r	y	.
H 166965	b	m	1914	140	l	n	.
H 166797	b	m	1912	139	l	n	.
H 165883	b	m	1912	141	r	y	.
H 000554	b	m	1936	131	r	n	.
H 007288	b	m	1935	130	r	n	.
H 009903	b	m	1936	132	r	n	.
H 017201	b	m	1939	145	l	y	.
H 165407	b	m	1939	133	l	n	.
H 165300	b	m	1909	141	r	y	.
H 162959	b	m	1914	141	l	y	.
H 160368	b	m	1900	138	r	n	.
H 159640	b	m	1910	142	l	n	.
H 178776	b	m	1936	136	l	y	.
H 180462	b	m	1938	137	r	n	.
H 180216	b	m	1937	137	l	n	.
H 180941	b	m	1938	139	l	n	.
H 057767	b	m	1939	139	l	y	.
H 052649	b	m	1935	144	r	y	.
H 045682	b	m	1936	142	r	n	.
H 092578	b	m	1939	146	r	n	.
H 091007	b	m	1937	137	r	y	.
H 085205	b	m	1939	142	r	n	.
H 084954	b	m	1938	135	l	n	.
H 082225	b	m	1936	138	l	n	.
H 082021	b	m	1936	141	l	n	.
H 073301	b	m	1936	134	r	y	.
H 068637	b	m	1939	138	r	n	.
H 067049	b	m	1939	140	r	n	.
H 064974	b	m	1938	142	l	n	.
H 064093	w	m	1938	155	r	n	y
H 063019	b	m	1939	140	r	n	.
H 008369	b	f	1910	135	l	n	.
H 011197	b	f	1907	137	r	n	.
H 012498	b	f	1913	127	r	n	.
H 204039	b	f	1912	139	r	n	.
H 000994	b	f	1912	131	r	n	.
H 062424	b	f	1902	137	r	n	.
H 053305	b	f	1909	135	r	y	.
H 035153	b	f	1904	137	r	n	.
H 033707	b	f	1908	136	r	n	.
H 046330	b	f	1911	134	r	y	.
H 043366	b	f	1914	130	l	n	.
H 035688	b	f	1915	135	r	n	.
H 084877	b	f	1903	142	l	n	.
H 083335	b	f	1913	132	r	n	.
H 079113	b	f	1900	144	r	y	.
H 076229	b	f	1904	133	r	y	.
H 073170	b	f	1914	134	l	y	.
H 066524	b	f	1911	132	r	n	.
H 092745	b	f	1905	133	r	n	.
H 096698	b	f	1914	138	r	n	.
H 098647	b	f	1900	140	r	n	.
H 088852	b	f	1910	136	r	y	.
H 088561	b	f	1914	140	r	n	.
H 086838	b	f	1914	132	r	y	.
H 086206	b	f	1909	135	l	n	.
H 027897	b	f	1936	133	r	n	.
H 170303	b	f	1939	136	r	n	.
H 169858	b	f	1936	135	l	n	.
H 169855	b	f	1938	139	r	n	.
H 169527	b	f	1938	135	r	n	.
H 169264	b	f	1937	143	r	n	.
H 168131	b	f	1936	137	r	n	.
H 166407	b	f	1937	139	r	n	.
H 164666	b	f	1939	134	r	n	.
H 164277	b	f	1935	143	l	n	.
H 162863	b	f	1939	138	r	n	.
H 162809	b	f	1936	140	l	n	.
H 161422	b	f	1936	135	r	n	.
H 160625	b	f	1939	135	l	y	.
H 160441	b	f	1937	140	r	n	.
H 160360	b	f	1937	126	l	n	.
H 179538	b	f	1935	134	r	n	.
H 179898	b	f	1937	140	l	n	.
H 181405	b	f	1935	139	l	n	.
H 180675	b	f	1939	143	r	n	.
H 182658	b	f	1936	135	r	n	.
H 054933	b	f	1935	136	r	n	.
H 053587	b	f	1934	142	r	n	.
H 089384	b	f	1936	135	r	n	.
H 089089	b	f	1935	140	r	n	.
H 087588	b	f	1939	134	r	n	.
H 000001	w	m	1926	152	r	y	.
H 000069	w	m	1909	150	r	y	.
H 000072	w	m	1884	145	l	n	.
H 000259	w	m	1913	149	r	n	.
H 022619	w	m	1904	140	r	y	.
H 022599	w	m	1913	154	r	n	.
H 075705	w	m	1912	150	r	y	.
H 076759	w	m	1907	146	r	n	.
H 081282	w	m	1911	145	r	n	.
H 081255	w	m	1914	144	r	n	.
H 080779	w	m	1910	150	r	y	.
H 080414	w	m	1912	146	r	n	.
H 079561	w	m	1915	148	r	n	.
H 079441	w	m	1911	145	r	y	.
H 079049	w	m	1910	149	r	y	.
H 078996	w	m	1909	147	r	n	.
H 078691	w	m	1904	145	r	n	.
H 078131	w	m	1914	150	r	n	.
H 078131	w	m	1914	143	l	n	.
H 077867	w	m	1912	146	r	y	.
H 077679	w	m	1915	153	r	n	.
H 082588	w	m	1913	146	r	n	.
H 082278	w	m	1908	140	l	y	.
H 082006	w	m	1908	142	r	n	.
H 081915	w	m	1915	142	r	n	.
H 081556	w	m	1908	142	l	n	.
H 081531	w	m	1913	141	r	y	.
H 000140	w	f	1887	140	r	n	.
H 000156	w	f	1910	148	r	y	.
H 000242	w	f	1906	142	l	n	.
H 004198	w	f	1897	140	r	n	.
H 003967	w	f	1915	150	r	n	.
H 022636	w	f	1915	140	r	n	.
H 022621	w	f	1904	139	l	n	.
H 075691	w	f	1904	143	r	n	.
H 075483	w	f	1906	148	r	n	.
H 075431	w	f	1912	148	r	n	.
H 077270	w	f	1912	145	r	n	.
H 077046	w	f	1902	150	r	n	.
H 076978	w	f	1912	147	r	n	.
H 076975	w	f	1914	145	r	n	.
H 076599	w	f	1903	144	r	n	.
H 076553	w	f	1910	152	l	n	.
H 076489	w	f	1915	144	l	n	.
H 076448	w	f	1906	145	r	n	.
H 076248	w	f	1912	150	r	n	.
H 076004	w	f	1915	148	l	y	.
H 077942	w	f	1914	145	r	n	.
H 077829	w	f	1912	145	r	y	.
H 077730	w	f	1913	150	l	n	.
H 077559	w	f	1914	145	r	n	.
H 000081	w	m	1935	142	r	n	.
H 075220	w	m	1937	145	l	n	.
H 077287	w	m	1935	147	r	n	.
H 077144	w	m	1935	146	l	n	.
H 076572	w	m	1939	146	l	n	.
H 076076	w	m	1936	145	r	y	.
H 075954	w	m	1937	147	r	y	.
H 083247	w	m	1939	145	l	y	.
H 083010	w	m	1935	145	r	n	.
H 082935	w	m	1937	142	r	n	.
H 082612	w	m	1937	149	r	n	.
H 080617	w	m	1935	154	r	n	.
H 079400	w	m	1935	154	r	n	.
H 079209	w	m	1937	147	r	n	.
H 078925	w	m	1936	144	r	n	.
H 078971	w	m	1939	142	r	n	.
H 078713	w	m	1936	145	l	y	.
H 078361	w	m	1939	143	r	n	.
H 078227	w	m	1936	149	r	n	.
H 078121	w	m	1936	145	r	n	.
H 000349	w	f	1938	155	r	n	.
H 004140	w	f	1935	143	r	n	.
H 022547	w	f	1935	146	l	n	.
H 075550	w	f	1939	155	r	n	.
H 076830	w	f	1937	144	l	n	.
H 076264	w	f	1938	142	r	n	.
H 075970	w	f	1938	146	r	n	.
H 075939	w	f	1938	145	r	n	.
H 075647	w	m	1967	143	r	n	.

APPENDIX III, continued:

H	155499	b	m	1969	145	r	n	.
H	155739	b	m	1971	135	r	n	.
H	155825	b	f	1970	136	l	n	.
H	156817	b	f	1970	138	l	n	.
H	156497	b	m	1970	126	r	n	.
H	156379	b	f	1967	136	r	n	.
H	156155	b	m	1965	136	l	n	.
H	157625	b	f	1973	136	l	n	.
H	158028	b	m	1968	143	r	n	.
H	158377	b	m	1967	142	l	n	.
H	158909	b	m	1975	138	l	y	.
H	159474	b	m	1998	141	r	n	.
H	159118	b	m	1998	143	r	n	.
H	159766	b	m	1967	135	l	n	.
H	160503	b	m	1970	131	l	n	.
H	160951	b	f	1962	144	r	n	.
H	160984	b	m	1969	139	l	n	.
H	161447	b	f	1959	137	l	y	.
H	161057	b	m	1970	135	l	n	.
H	161540	b	m	1998	139	l	n	.
H	161985	b	m	1976	135	l	n	.
H	154067	b	m	1998	140	l	n	.
H	154025	b	m	1973	135	r	n	.
H	153284	b	m	1970	144	r	n	.
H	153125	b	m	1968	140	l	n	.
H	153004	b	m	1967	135	r	n	.
H	152908	b	m	1969	142	r	n	.
H	152753	b	m	1968	141	r	n	.
H	152520	b	m	1969	135	l	n	.
H	151771	b	m	1966	136	r	n	.
H	150473	b	m	1956	137	l	n	.
H	154884	b	m	1970	136	l	n	.
H	154565	b	m	1971	130	r	n	.
H	154457	b	m	1969	141	l	n	.
H	154393	b	m	1966	138	r	n	.
H	154375	b	m	1971	136	l	n	.
H	154304	b	m	1972	137	r	n	.
H	154201	b	m	1961	134	r	n	.
H	148975	b	f	1960	140	l	n	.
H	148502	b	f	1998	145	l	n	.
T	676790	b	m	1973	140	l	n	.
T	686797	w	f	1932	150	r	n	.
T	698942	w	f	1942	147	r	n	.
T	686676	w	f	1973	147	r	n	.
T	600000	b	f	1951	136	l	n	.
T	686721	w	m	1970	146	r	y	.
T	498529	w	f	1926	139	l	n	.
T	500038	w	f	1933	147	l	n	.
T	686697	w	m	1970	140	l	y	.
T	686687	w	m	1928	142	l	n	.
T	691808	w	f	1931	153	l	n	.
T	682871	w	f	1977	146	r	n	.
T	697574	b	m	1976	147	r	n	.
T	687891	w	m	1966	145	r	n	.
T	538517	w	f	1970	141	r	n	.
T	687913	w	m	1977	152	r	n	.
T	687696	w	m	1972	143	l	n	.
T	480317	w	f	1912	153	r	n	.
T	544135	w	f	1970	147	l	n	.
T	547429	w	m	1949	146	l	y	.
T	545033	b	f	1971	140	l	n	.
T	389739	w	f	1941	152	l	n	.
T	551401	w	f	1973	147	r	n	.

APPENDIX IV

T-TEST PROCEDURE FOR INTERCONDYLAR SHELF ANGLE

```
options ls=72 ps=54;
data knee;
infile 'singlekn.dat';
input area$ ID race$ sex$ dob angle knee$ fabella$ acl$;
cards;

NOTE: The infile 'singlekn.dat' is:
      File=DSA11:[JBINKLEY]SINGLEKN.DAT
NOTE: 423 records were read from the infile 'singlekn.dat'.
      The minimum record length was 27.
      The maximum record length was 27.
NOTE: The data set WORK.KNEE has 423 observations and 9 variables.

proc ttest;
class race;
var angle;
run;


proc ttest;
class sex;
var angle;
run;


proc ttest;
where sex = 'f';
class race;
var angle;
run;


proc ttest;
where sex = 'm';
class race;
var angle;
run;
```

APPENDIX IV, continued:

TTEST PROCEDURE

Variable: ANGLE

RACE	N	Mean	Std Dev	Std Error
b	183	137.83060109	4.18247826	0.30917769
w	240	146.17500000	4.28710727	0.27673158

Variances	T	DF	Prob>|T|
Unequal	-20.1101	396.6	0.0001
Equal	-20.0431	421.0	0.0000

For H0: Variances are equal, F' = 1.05 DF = (239,182)
Prob>F' = 0.7278

SEX	N	Mean	Std Dev	Std Error
f	188	142.58510638	6.30662087	0.45995760
m	235	142.54893617	5.61141512	0.36604836

Variances	T	DF	Prob>|T|
Unequal	0.0615	377.8	0.9510
Equal	0.0623	421.0	0.9503

For H0: Variances are equal, F' = 1.26 DF = (187,234)
Prob>F' = 0.0905

RACE	N	Mean	Std Dev	Std Error
b	80	137.16250000	4.14131316	0.46301289
w	108	146.60185185	4.31025687	0.41475466

Variances	T	DF	Prob>|T|
Unequal	-15.1853	174.0	0.0001
Equal	-15.0947	186.0	0.0000

For H0: Variances are equal, F' = 1.08 DF = (107,79)
Prob>F' = 0.7123

RACE	N	Mean	Std Dev	Std Error
b	103	138.34951456	4.16029019	0.40992557
w	132	145.82575758	4.25251827	0.37013421

Variances	T	DF	Prob>|T|
Unequal	-13.5365	221.5	0.0001
Equal	-13.4998	233.0	0.0000

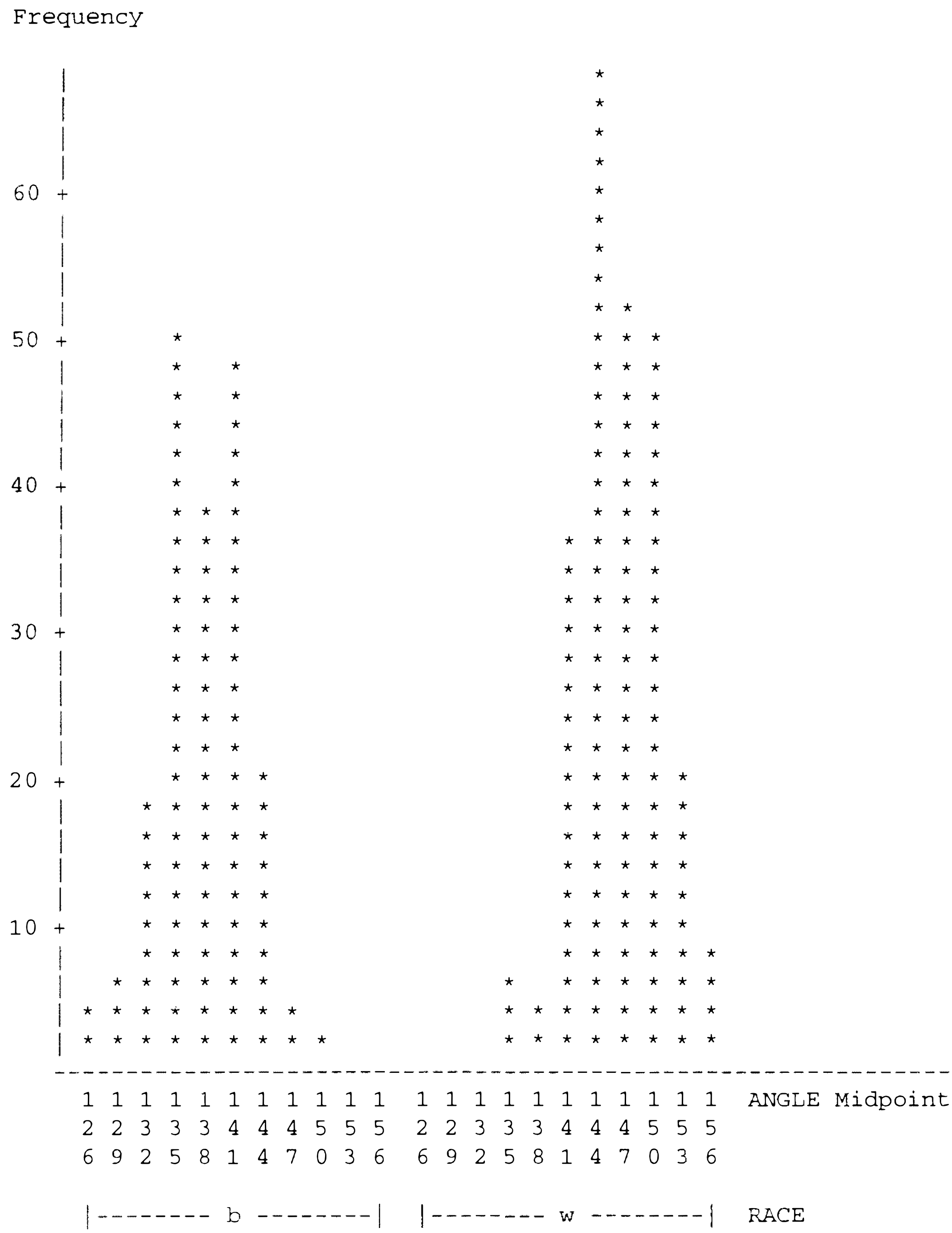
For H0: Variances are equal, F' = 1.04 DF = (131,102)
Prob>F' = 0.8209

APPENDIX V

CHARTS FROM PATIENT SAMPLE DATA

```
 options ls=72 ps=54;
data knees;
infile 'singlekn.dat';
input area$ id race$ sex$ dob angle knee$ fabell$ acl$;
cards;

NOTE: The infile 'singlekn.dat' is:
      File=DSA11:[JBINKLEY]SINGLEKN.DAT
NOTE: 423 records were read from the infile 'singlekn.dat'.
      The minimum record length was 27.
      The maximum record length was 27.
NOTE: The data set WORK.KNEES has 423 observations and 9 variables.

run;
proc chart;
vbar angle / group=race;
run;



proc plot data=knees;
plot angle*race = '*';
run;


proc univariate plot;
where race = 'w';
var angle;
run;


proc univariate plot;
 where race = 'b';
var angle;
run;
```

APPENDIX V, continued:



APPENDIX V, continued:

```
                Plot of ANGLE*RACE.  Symbol used is '*'.

ANGLE |
      |
  156 +                                              *
  155 +                                              *
  154 +                                              *
  153 +                                              *
  152 +                                              *
  151 +                                              *
  150 +                                              *
  149 +  *                                           *
  148 +                                              *
  147 +  *                                           *
  146 +  *                                           *
  145 +  *                                           *
  144 +  *                                           *
  143 +  *                                           *
  142 +  *                                           *
  141 +  *                                           *
  140 +  *                                           *
  139 +  *                                           *
  138 +  *                                           *
  137 +  *                                           *
  136 +  *                                           *
  135 +  *                                           *
  134 +  *                                           *
  133 +  *
  132 +  *
  131 +  *
  130 +  *
  129 +  *
  128 +
  127 +  *
  126 +  *
      |
      ---+-------------------------------------------+--
         b                                           w

                             RACE
```

NOTE: 378 obs hidden.

APPENDIX V, continued:

Univariate Procedure

Variable=ANGLE

Moments

N	240	Sum Wgts	240
Mean	146.175	Sum	35082
Std Dev	4.287107	Variance	18.37929
Skewness	-0.19103	Kurtosis	0.055774
USS	5132504	CSS	4392.65
CV	2.932859	Std Mean	0.276732
T:Mean=0	528.2194	Pr>|T|	0.0001
Num ^= 0	240	Num > 0	240
M(Sign)	120	Pr>=|M|	0.0001
Sgn Rank	14460	Pr>=|S|	0.0001

Quantiles(Def=5)

100% Max	156	99%	155
75% Q3	150	95%	153
50% Med	146	90%	152
25% Q1	144	10%	140.5
0% Min	134	5%	140
		1%	135
Range	22		
Q3-Q1	6		
Mode	145		

Extremes

Lowest	Obs	Highest	Obs
134(	138)	155(	76)
134(	135)	155(	86)
135(	216)	155(	125)
135(	146)	155(	129)
135(	136)	156(	207)

Univariate Procedure

Variable=ANGLE

```
   Stem Leaf                                              #          Boxplot
    156 0                                                 1             |
    155 000000                                            6             |
    154 000                                               3             |
    153 000000                                            6             |
    152 00000000000                                      11             |
    151 00000                                             5             |
    150 0000000000000000000000000000000000               34          +-----+
    149 0000000000                                       10          |     |
    148 00000000                                          8          |     |
    147 00000000000000000000                             20          |     |
    146 00000000000000000000000                          23          *--+--*
    145 0000000000000000000000000000000000000000000      43          |     |
    144 000000000000                                     12          +-----+
    143 000000000000                                     12             |
    142 00000000000000                                   14             |
    141 00000000                                          8             |
    140 00000000000000                                   14             |
    139 00                                                2             |
    138 0                                                 1             |
    137 0                                                 1             |
    136 0                                                 1             |
    135 000                                               3             |
    134 00                                                2             0
        ----+----+----+----+----+----+----+----+---
```

Univariate Procedure

Variable=ANGLE

Normal Probability Plot

```
156.5+                                                ++*
     |                                            ***** *
     |                                          ***+
     |                                        ***+
     |                                     ****
     |                                    **+
     |                               ******
     |                              **++
     |                             **+
     |                           ***
     |                        ****
145.5+                    *****
     |                  **+++
     |                ***+
     |              ***+
     |            ***+
     |        *****
     |       **++
     |      *++
     |    ++*
     |  ++ *
     |++***
134.5+*
      +----+----+----+----+----+----+----+----+----+----+
          -2        -1         0        +1        +2
```

Univariate Procedure

Variable=ANGLE

Moments

N	183	Sum Wgts	183
Mean	137.8306	Sum	25223
Std Dev	4.182478	Variance	17.49312
Skewness	-0.15278	Kurtosis	0.017283
USS	3479685	CSS	3183.749
CV	3.034506	Std Mean	0.309178
T:Mean=0	445.7974	Pr>|T|	0.0001
Num ^= 0	183	Num > 0	183
M(Sign)	91.5	Pr>=|M|	0.0001
Sgn Rank	8418	Pr>=|S|	0.0001

Quantiles(Def=5)

100% Max	149	99%	147
75% Q3	140	95%	145
50% Med	138	90%	143
25% Q1	135	10%	133
0% Min	126	5%	131
		1%	126
Range	23		
Q3-Q1	5		
Mode	140		

Extremes

Lowest	Obs	Highest	Obs
126(	144)	145(	179)
126(	89)	146(	4)
127(	51)	146(	38)
129(	119)	147(	182)
130(	172)	149(	8)

Univariate Procedure

Variable=ANGLE

```
Stem Leaf                            #            Boxplot
 149 0                               1               0
 148
 147 0                               1               |
 146 00                              2               |
 145 0000000                         7               |
 144 000000                          6               |
 143 0000000                         7               |
 142 000000000                       9               |
 141 000000000000                   12               |
 140 000000000000000000000000000    27            +-----+
 139 00000000000                    11            |     |
 138 00000000000000                 14            *-----*
 137 000000000000                   12            |  +  |
 136 0000000000000000000            19            |     |
 135 000000000000000000000          21            +-----+
 134 000000000                       9               |
 133 0000000                         7               |
 132 000000                          6               |
 131 0000                            4               |
 130 0000                            4               |
 129 0                               1               |
 128
 127 0                               1               0
 126 00                              2               0
     ----+----+----+----+----+--
```

APPENDIX V, continued:

Univariate Procedure

Variable=ANGLE

```
                        Normal Probability Plot
149.5+                                                  *
     |                                                  +
     |                                               ++*
     |                                             +**
     |                                         *****
     |                                      ***++
     |                                    ***+
     |                                  ***+
     |                                ***
     |                            *****
     |                          ***++
     |                        ***+
     |                       **+
     |                    ****
     |                *****
     |              ***++
     |            ***+
     |          ***+
     |        ***+
     |     ****
     |    *++
     |  ++
     |++ *
126.5+**
      +----+----+----+----+----+----+----+----+----+----+
          -2        -1         0        +1        +2
```

APPENDIX VI

DATA FROM THE SKELETAL SAMPLE

#	SEX	ANGLE	TEST1	TEST2	ACTUAL RACE
01-81	M	140	0	B	W
03-81	M	144	0	W	W
04-81	F	140	0	B	W
01-82	M	142	0	W	W
01-83	F	147	W	W	W
02-83	M	146	W	W	W
03-83	M	144	0	W	W
05-83	M	144	0	W	W
01-84	M	142	0	W	W
02-84	M	151	W	W	W
01-85	F	148	W	W	W
02-85	M	146	W	W	W
01-86	F	140	0	B	B
07-86	M	145	0	W	W
01-87	M	144	0	W	W
02-87	M	143	0	W	W
03-87	M	142	0	W	W
04-87	M	143	0	W	W
05-87	F	148	W	W	W
06-87	M	140	0	B	B
07-87	M	149	W	W	W
08-87	M	142	0	W	W
10-87	M	140	0	B	W
11-87	M	150	W	W	W

APPENDIX VI, continued:

14-87	M	146	W	W	W
01-88	F	148	W	W	W
02-88	F	136	B	B	B
03-88	M	138	B	B	B
04-88	M	145	0	W	B
05-88	M	142	0	W	W
06-88	F	147	W	W	W
09-88	M	144	0	W	W
10-88	M	144	0	W	W
12-88	M	136	B	B	W
13-88	M	142	0	W	W
14-88	M	147	W	W	W
17-88	M	144	0	W	B
18-88	M	140	0	B	B
19-88	M	147	W	W	W
20-88	M	143	0	W	W
23-88	F	146	W	W	W
24-88	M	150	W	W	W
02-89	M	142	0	W	W
03-89	M	147	W	W	B
04-89	F	151	W	W	W
06-89	M	146	W	W	B
07-89	M	151	W	W	W
08-89	M	143	0	W	W
09-89	M	145	0	W	B
10-89	M	147	W	W	W
11-89	M	143	0	W	W

APPENDIX VI, continued:

12-89	M	143	0	W	W
15-89	M	136	B	B	B
16-89	M	149	W	W	W
03-90	M	145	0	W	W
04-90	M	143	0	W	W
11-90	F	143	0	W	W
12-90	M	150	W	W	W
14-90	M	143	0	W	W
15-90	M	145	0	W	B
16-90	M	148	W	W	W
17-90	F	145	0	W	B
18-90	M	138	B	B	B
21-90	M	147	W	W	W
22-90	M	147	W	W	W
05-91	M	136	B	B	B
08-91	M	144	0	W	B

APPENDIX VII

TEST FOR INTEROBSERVER ERROR

```
options ls=72 ps=54;
data test;
  input code ID$ sex$ observer angle;
cards;

T 676790 M 1 138
T 676790 M 2 140
T 676790 M 3 140
T 551407 F 1 147
T 551407 F 2 141
T 551407 F 3 142
T 389739 F 1 152
T 389739 F 2 148
T 389739 F 3 150
T 547429 M 1 146
T 547429 M 2 149
T 547429 M 3 148
T 697574 M 1 147
T 697574 M 2 144
T 697574 M 3 149
T 686797 F 1 150
T 686797 F 2 150
T 686797 F 3 150
T 686676 F 1 147
T 686676 F 2 153
T 686676 F 3 147
T 717180 M 1 135
T 717180 M 2 136
T 717180 M 3 136
T 732889 M 1 134
T 732889 M 2 131
T 732889 M 3 136
T 686721 M 1 148
T 686721 M 2 149
T 686721 M 3 146
T 732739 M 1 130
T 732739 M 2 132
T 732739 M 3 128
T 458539 F 1 139
T 458539 F 2 135
T 458539 F 3 137
T 500038 F 1 147
T 500038 F 2 150
T 500038 F 3 147
T 686697 M 1 142
T 686697 M 2 136
T 686697 M 3 140
T 686687 M 1 143
T 686687 M 2 144
T 686687 M 3 142
T 691808 F 1 154
T 691808 F 2 150
T 691808 F 3 153
T 687891 M 1 145
T 687891 M 2 145
T 687891 M 3 144
T 538517 F 1 141
T 538517 F 2 145
T 538517 F 3 145
T 687696 M 1 143
T 687696 M 2 140
T 687696 M 3 145
T 480317 F 1 153
T 480317 F 2 151
T 480317 F 3 151
T 687913 M 1 152
T 687913 M 2 149
T 687913 M 3 152
;
proc anova;
CLASS OBSERVER;
model ANGLE = OBSERVER;
MEANS OBSERVER/LSD;
RUN;
```

APPENDIX VII, continued:

Analysis of Variance Procedure

T tests (LSD) for variable: ANGLE

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 60 MSE= 42.44444
Critical Value of T= 2.00
Least Significant Difference= 4.0217

Means with the same letter are not significantly different.

T Grouping	Mean	N	OBSERVER
A	144.429	21	1
A			
A	144.190	21	3
A			
A	143.714	21	2

Analysis of Variance Procedure

Dependent Variable: ANGLE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5.5555556	2.7777778	0.07	0.9367
Error	60	2546.666667	42.4444444		
Corrected Total	62	2552.222222			

R-Square	C.V.	Root MSE	ANGLE Mean
0.002177	4.520776	6.5149	144.11

Source	DF	Anova SS	Mean Square	F Value	Pr > F
OBSERVER	2	5.5555556	2.7777778	0.07	0.9367

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
OBSERVER	3	1 2 3

Number of observations in data set = 63

VITA

Emily Anne Craig was born in Kokomo, Indiana on June 2, 1947 and graduated from Northwestern High School in 1965. She studied art at DePauw University in Greencastle, Indiana from 1965 to 1967, and enrolled in Indiana University at Bloomington in 1971. She received a Bachelor of Arts degree in 1973 with a major from within the Independent Learning Program. This interdisciplinary program allowed a combination of intensive studies in art, medical sciences, and instructional systems technology. Dr. Craig entered graduate school at the Medical College of Georgia in 1973 where, in 1976 she earned a Master of Science degree in Medical illustration.

In 1976, Dr. Craig was employed as a medical illustrator and anatomist by the Hughston Sports Medicine Foundation in Columbus, Georgia. While working directly with Dr. Jack C. Hughston as well as other physicians and staff at the Hughston Sports Medicine Center, Dr. Craig did extensive research with the musculoskeletal anatomy of the knee and shoulder. This culminated in the publication of hundreds of scientific articles, several textbooks, and the creation of an original series of life-size, three-dimensional wax models of the knee and shoulder. This museum collection of teaching models received world-wide acclaim and led to even more sculpture consignments that included requests for facial reconstructions on human skeletal remains.

These combined interests led her to the University of Tennessee in Knoxville where she enrolled in the doctoral program in August of 1991. Under the direction of Dr. William M. Bass, Dr. Craig perfected a method of video enhanced facial reconstruction, and she also did further research with the bones of the knee and their role in the science of human identification.